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DELAYS IN NUCLEAR POWER
PLANT CONSTRUCTION

Progress Report
for Period September 15, 1976-September 14, 1977

G. E. Mason and R. E. Larew

The Ohio State University
Columbus, Ohio 43210

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August 10, 1977

Prepared For

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT NO. E(11-1)-4121

PROGRESS REPORT

DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION Contract No. E(11-1)-4121

Dr. George E. Mason
August 10, 1977

1.0 SCOPE OF INVESTIGATIONS UNDERTAKEN AND SIGNIFICANT RESULTS OBTAINED

1.1 Identification of Existing Barriers to Shortening Construction Schedules

Through a review of the literature, attendance at government and industry seminars, and interviews with utility, contractors, and supplier personnel, existing barriers to shortening construction schedules have been identified. The results of this phase of the investigation by the prime contractor and its subcontractors are given in Volume I, Section 3, of the attached draft report. The individual subcontractor reports are given in Volume II, Section 1, of the attached draft report.

1.2 Identification of Research Needs to Mitigate or Eliminate Existing Barriers

Based on the identified barriers, the prime contractor and each of the subcontractors have worked individually and in conjunction with industry personnel to develop research topics to address the identified barriers. The research topics have been grouped into five generic areas: 1) Design/Construction Interface, 2) Construction Methods, Equipment, and Materials, 3) Construction Coordination and Communication, 4) Manpower and Productivity, and 5) Other Research Areas. The results of this phase are given in Volume I, Sections 4 through 8, of the attached draft report.

2.0 COMPLIANCE WITH ALL CONTRACT REQUIREMENTS

All requirements of the contract as originally signed or as modified by mutual agreement have been adhered to. Significant modifications are as follows:

- 1) Replacement of Dr. Russel C. Jones by Dr. George E. Mason as project director;
- 2) Replacement of Dr. George E. Mason by Dr. Richard E. Larew as co-investigator;
- 3) Issuance of three subcontracts instead of four;
- 4) Budget revisions to account for the above stated modifications.

3.0 INVESTIGATORS TIME ALLOCATION

The time, as an approximate percentage, which each investigator has devoted to the project to date and an estimate of time to be allocated in the remaining contract period is given in Table 1.

4.0 TECHNICAL REPORTS, PREPRINTS, AND ARTICLES PREPARED FOR PUBLICATION

No technical reports, preprints, or articles have been prepared for publication as of this date.

5.0 SCHEDULE FOR REMAINDER OF CURRENT CONTRACT TERM

The following schedule was adopted by the prime contractor and all subcontractors at the 4 June 1977 Project Coordination Meeting.

Date

August 10, 1977	Draft report to ERDA
October 15, 1977	Final report to Ohio State, V.II, Sec. 1 - 3
November 15, 1977	Final report to Ohio State, V.I, Sec. 1 - 9
December 14, 1977	Final report to ERDA

Investigator		Percent Time	
Name	Organization	To Date	Remaining Period
Dr. G. E. Mason	Ohio State Univ.	10% 5% univ. contrib. 100% 2 mo. off qtr.	10% 5% univ. contrib. ---
Dr. R. E. Larew	Ohio State Univ.	9% 100% 1.5 mo. off qtr.	9% ---
Dr. J. D. Borcharding	Univ. of Texas	10%	10%
Mr. M. Wilkinson	Kellogg Corporation	1%	1%
Mr. S. Okes	Kellogg Corporation	6%	6%
Mr. J. Kellogg	Kellogg Corporation	1.25%	1.25%
Dr. P. F. Rad	Clemson University	35%	25%

Table 1 Investigators Time Allocation

ABSTRACT

This report, in draft form, identifies barriers to shortening nuclear power plant construction schedules and recommends research efforts which should minimize or eliminate the identified barriers. The identified barriers include: 1) Design and Construction Interfacing Problems; 2) Problems Relating to the Selection and Use of Permanent Materials and Construction Methods; 3) Construction Coordination and Communication Problems; and 4) Problems Associated with Manpower Availability and Productivity.

PREFACE

This draft report is issued solely for the purpose of soliciting the comments and suggestions of the research sponsor, the Project Advisory Committee and the individual research participants. The draft report should be returned directly to Ohio State University along with comments and suggestions. In order for the comments and suggestions to be addressed in the Final Report, they should be communicated as soon as possible, but not later than 15 September 1977.

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VOLUME I SECTION 1

INTRODUCTION

By

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1.0 INTRODUCTION

1.1 Impetus

Time delays in the construction of large projects, and related cost escalations, have become a major concern of the construction industry and its clients. This problem has become particularly bad in the construction of large technically complex projects such as the construction of a nuclear power plant. In such projects, construction time delays and cost escalations not only have major impact on the initial cost of the facility but are additionally very costly in terms of lost production capability.

The Construction Research Council of the American Society of Civil Engineers, consisting of persons with background and expertise in the construction process and an interest in the improvement of that process through research and development, developed an interest in studying construction delays on nuclear power projects during meetings in 1975 and early 1976. A pre-proposal indicating an interest in undertaking a substantial research effort in this area was prepared and circulated to potentially interested agencies. During 1976 the Energy Research and Development Administration indicated an interest in having the Construction Research Council initiate such research with ERDA funding.

Interest by ERDA in construction delays on nuclear power projects stems from concerns in both the electric power industry and the major part of the construction industry involved in constructing nuclear power projects. Since industry sources were not organized to define and sponsor research on con-

struction delays in this area, ERDA agreed to play that role. The Light Water Reactor Program, Nuclear Research and Applications Branch, of ERDA provided funds for this research on construction delays on nuclear power projects, beginning in late 1976.

1.2 Purpose

The primary research objective of this study is the identification of the major types of delays occurring on nuclear power plant construction projects, their direct causes, and contributing factors. This study has been organized to document delays occurring on actual nuclear power plant projects and to classify delay sources into categories containing similar causes. In order to give a measure of the importance of types of delays identified, frequency of occurrence and severity of delay will be estimated.

The output of the first phase of this research effort is to be the identification of areas for future research needed to eliminate the delay causes or minimize the delay impact. It is intended that several researchable areas be identified and defined so that necessary research will be undertaken by appropriate individuals and agencies. The results of such research could be disseminated most effectively through demonstration projects involving industry in direct cooperation.

Thus, the overall objective of this research project is to substantially reduce the cost associated with nuclear power plant construction by identifying and making recommendations on how to reduce the time delays associated with their construction.

1.3 Methodology

The Construction Research Council of ASCE is not in itself a research contracting agency but instead works through the established research organizations of its members. This study on construction delays on nuclear power projects has been centered at the Ohio State University, in the Department of Civil Engineering and advisory committee of Construction Research Council members not directly involved in the project has been established to provide overall guidance and monitoring.

It was anticipated in structuring the research team to carry out this project that there would be significant differences in construction delays in the several geographic regions where nuclear power plant construction has been undertaken. In order to most effectively conduct this research in several geographic regions of the country, regional subcontractors to Ohio State University were sought and engaged. Proposals from several potential subcontractors were received and evaluated by the Construction Research Council Advisory Group and final selections were made on the basis of background and expertise in this type of construction research, geographic location and ability to complement the other researchers on the team such that a broad area of construction expertise was represented.

The first part of this research effort has emphasized the identification of delays being experienced in the construction of nuclear power plants currently underway. A list of nuclear projects in all phases of construction has been developed. Each project was assigned to one of the subcontractors depending upon geographical location. The participating subcontractors were

then assigned a representative subset of these projects for detailed examination through questionnaires and visits. A common questionnaire was developed to provide similarity of results between regions but each subcontractor had the flexibility to adopt it to his own particular needs.

In addition to questionnaires and site visits to probe delays at the actual construction sites of nuclear power projects, the research team has met with the major factors concerned with this construction process: owner - utilities, designers, constructors, and labor. A substantial literature review has also been accomplished.

Based on the results of questionnaires, interviews and the literature review, a set of problem areas has been defined. Problems have been categorized into the following generic problem areas:

- design/construction
- interface
- construction methods, equipment, and materials
- construction, coordination and communications
- manpower and productivity

Several other research areas which do not fit into these broad categories have also been identified and will be described separately.

The second part of the research effort has emphasized the identification of areas of research necessary to eliminate the delay cause or to minimize the impact of the time delay during this portion of the research project. Participants have concentrated their efforts on identifying research needs in

each of the generic problem areas identified above. High priority has been placed on the definition of researchable areas which are likely to lead to demonstratable improvements on the time scale of less than ten years.

It is anticipated that the research report on this project will be widely distributed in order to stimulate research development and demonstration projects involving individuals, agencies and industry groups, both within and beyond the ASCE Construction Research Council. A conference which would bring together researchers and industry representatives has been proposed as a major mechanism to stimulate such research development and demonstration.

1.4 Scope

The first phase of this research effort culminating in December, 1977, has concentrated on an identification and codification of the existing encountered delays, the sources of those delays and contributing factors. The primary objective of this problem statement phase has been to provide a comprehensive report to ERDA, identifying areas in which research is needed to solve existing problems.

The second phase of the research effort, proposed to take place in the spring of 1978, is to be an information dissemination and discussion conference held at a central location and used as the primary mechanism of distributing and discussing the findings of the first phase of this research. It is intended that the report on phase one findings be used as pre-conference input

to attendees and that the conference proceedings would be widely disseminated in order to stimulate needed research development, demonstration and implementation.

It is anticipated that the next phase of this overall research effort will consist of solution studies based on the needs identified in the first phase of this study and made available with discussion in the second phase conference described above. This solution study phase would be initiated and carried out individually by interested researchers, not necessarily within the Construction Research Council framework. It is anticipated that the fourth and final phase of this research effort will involve the selection of promising solution methodologies and techniques for implementation at ongoing nuclear power construction projects.

VOLUME I SECTION 2

NUCLEAR POWER PLANT CONSTRUCTION
AN OVERVIEW

By

Mr. Miguel A. Gonzalez
Graduate Student
Ohio State University

Note: This section, in draft form, has been written in partial fulfillment of degree requirements at Ohio State University. After review and comment the section will be rewritten to conform to the needs and organization of the final report.

ACKNOWLEDGMENTS

This report was prepared as an account of work sponsored by the United States Government. The author wishes to thank the U.S. Energy Research and Development Administration for their monetary support.

The author also wishes to acknowledge the assistance provided by Professors G. E. Mason, R. E. Larew and L. F. Smith in reviewing and commenting on the report as it was developed.

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Section 1

INTRODUCTION

1.1 IMPETUS FOR THE STUDY

Under a research grant from the United States Energy Research and Development Administration (ERDA), The Ohio State University and its sub-contractors have been asked to investigate the current sources of delay in the construction of nuclear power plants, to recommend the research necessary to minimize or eliminate the identified delays, and to prepare a report based on the findings and recommendations. The objective of the final report is to provide future university and industry research organizations with an understanding of (1) the nuclear power plant construction process, (2) the delays associated with the process, and (3) the potential research needs aimed at overcoming the delays in the process. A necessary first step for future researchers, particularly those unfamiliar with the nuclear power industry, is to obtain a basic and general understanding of the nuclear power plant construction process.

1.2 PURPOSE

The purpose of this report is to provide the potential researcher unfamiliar with the nuclear power plant construction process with a general overview of the process, and to provide literature references where a more detailed treatment of the subject matter may be obtained. The identification of delays in the process and the recommendations necessary for future research are the subjects of reports prepared by

other investigators involved in the project of which this report will become a part.

1.3 PROCEDURE

This report is based primarily upon a review of the literature pertaining to the nuclear power plant construction process. An attempt has been made to collect, from as many sources as possible, information relating to the process of constructing nuclear power plants.

Major sources of information include an unpublished report titled State of the Art of Nuclear Power Plant Construction by Willenbrook and Parsons (22:-)¹ and the seminar proceedings entitled State of the Art of Power Plant Construction.

1.4 SCOPE AND ORGANIZATION

This report is divided into seven sections that can be classified in two general parts. The first part of the report, Sections 2 through 5, describes the different phases and parties involved in the nuclear power plant construction process.

Section 2 deals with the planning process used by the utilities to predict the future power needs.

Section 3 presents the regulation and licensing process required of the utilities in order to bring the nuclear plant into commercial operation. An overview of the development, function, and organization of the Nuclear Regulatory Commission (NRC), is included.

1. Refers to entire reference number 22 in bibliography

Section 4 is devoted to the design phase of the construction process and the different standardization options that can be used in the design of a nuclear power plant.

Section 5 deals with the elements of project control necessary to construct a nuclear unit within the budget, schedule, and quality requirements.

In the second part of the report, two general issues of the nuclear power plant construction process are treated.

Section 6 includes the alternate approaches to the design and construction of nuclear plants, and the different contractual agreements that exist between the parties involved in the nuclear power plant construction process.

Section 7 deals with the time required to plan, design, and construct a nuclear plant, the time trends, and the financial impact that time has in the nuclear construction industry.

Section 8 presents the summary and conclusions of the study.

Section 2

THE PLANNING PROCESS

The planning process is the method by which utilities establish a program in order to meet the future demands for electric power at a minimum cost.

In order to have a reliable planning policy three questions must be answered: (1) When and What amount of new generating capacity is needed (demand forecasting); (2) What type and size of generating facility will provide the necessary supply at the least total cost (plant type and size selection); (3) Where the generating facility will be located to best suit the customer's needs (site selection).

In this section the three aspects of the planning process are examined.

2.1 NEED FOR POWER-ELECTRICITY DEMAND FORECASTING

Electricity Demand Forecasting is the first step in the planning process. Utility planning must anticipate future demand for electric power for the next 20 to 30 years. There has been a trend in the historical electrical load growth for the United States of approximately 7 percent per year which means that generation requirements double approximately every ten years. (22:5)¹

It is the utility's obligation to provide electricity for its

1. Refers to bibliography reference 22, page 5

operating area for the present and future demands. Accurate long-term estimates are essential to avoid shortages in electricity supply and to minimize the excess capital investment that occurs when generation capacity greatly exceeds the demand for electricity. Demand forecasting is a very difficult task due to the many factors involved. Among these factors, the more relevant are weather, and population and land use trends. Figure 2.1 presents a flow chart of the generation selection process.

2.1.1 Load Growth Projections

Generation planning begins with the forecast of future annual peak demands. Annual peak demands are estimated at least once a year for a minimum of fifteen years into the future, and the electricity necessary to reliably supply the estimated peak demands is calculated. (11:4) Once the total demand (peak demand plus reserve) is calculated, it is compared to the installed generation minus scheduled retirements plus committed new capacity. When total demand exceeds the supply, additional generating capacity is needed. Usually, the program of generation expansion is reviewed annually and modified as changes in peak demand forecasts and slippages in service dates of committed units warrant.

Peak Demand Forecasting

Peak demand estimates are generally determined by the weather. For a summer peaking utility, with the advent of air conditioning, it is assumed that the better the weather, the greater will be the electrical yearly peak demand. Variations in weather from one year to the next

Figure 2.1. Generation Selection Flow Chart (11:47)

directly affect the magnitude of the yearly peak demand. (11:6)

Philadelphia Electric Company uses three major steps in the determination of future yearly peak demand estimates (11:7):

1. Estimation of future kilowatt-hour energy sales based on characteristics of customers, trends of population growth, saturation of appliances, new uses, specific customer plans, plus estimates of growth in connected air conditioning equipment.
2. Analysis of the latest actual yearly peak kilowatt demand corrected to standard weather conditions for determination of normal growth patterns.
3. Conversion of estimated future kilowatt-hour energy sales and connected air conditioning equipment to peak kilowatt demand.

Data Required

There is a great variety of data required to make a reliable forecast. This data includes (6:19):

1. Load Data, which consists of historical generation output, hourly demands, sales by classes of service, and daily, weekly, monthly, seasonal and annual peak demands.
2. Number, of existing and future customers in each class. Customers are divided into three basic categories: residential, small commercial and industrial, and large commercial and industrial.
3. Load Surveys, which provide the contribution of each class to the peak demand and energy sales and the effects of appliances.
4. Marketing Data, which provide information about appliance

saturation, potential markets for appliances, and price elasticity.

5. Weather Data, which permit correlation between temperature and load. The probability of exceeding a certain load can be calculated.
6. Economic Data, which include number of marriages, interest rates on mortgage, the business cycle, the market prospects for the products of large industrial customers, and the cost of competing fuels.

Reserve Forecasting

Utilities must provide electricity in excess of the anticipated peak demands as a margin of reserve to insure against the possibility of the demand exceeding available generating capacity. Electric utilities use three different basic methods of determining the size of this generation reserve (11:14):

Standard Percent Reserve. In this method, some fixed percent of the forecasted system peak demand is used as the required reserve. Because the constant percent is usually determined from the past history of a utility's reliability record, the standard percent reserve method will not necessarily provide the same reliability for future system conditions as for those of the past.

Loss of Largest Generator. In this method the reserve will be equal to the size of the largest generator plus, usually, some percent of the estimated peak demand to allow for forecasting error. Loss of largest generator method is also based on an unknown reliability for future conditions.

Probability. This method takes into account a desired level of reliability to be designed into the system. With reliability fixed, the installed generation reserve becomes a variable which changes with the characteristics of the demand, and the size and availability of units. The probability method determines the required reserve as a function of the probability of loss of load due to demand exceeding the generating capacity. There are two probabilistic models generally used by this method, the Generation Model and the Load Model. In the generation (or capacity) model, each generator has a probability of being unavailable for operation due to an uncontrolled or forced outage. The individual generator data are combined to determine a probabilistic expression of the generating capacity of the system. The load model is developed to show the variability of daily peak demands on an annual basis, based on historical records of daily peaks with adjustments made for future changes in characteristics. The two models are combined to calculate the necessary reserve for the desired level of reliability.

2.1.2 Types of Demand Load

Because the amount of electricity demand varies on hourly, daily, and seasonal basis, it is necessary to project the shape of the load curve. For a typical utility, the minimum load for the year might be in the order of 30 to 45 percent of the maximum peak load for the year. For a normal weekday, the nighttime load may be as low as 40 to 60 percent of the peak load during the day. (6:25) A typical weekly load cycle is shown in Figure 2.2.

In order to classify the different amounts of demand, three types of loads are established: base load; intermediate load; and peak load.

Base load is the minimum demand for electricity that exists at any given time.

Intermediate or cyclic load is the demand that usually exists during daytime under no extreme circumstances.

Peak load is the maximum demand for electricity that may exist.

The three different types of loads are shown in Figure 2.2 for the weekly load cycle.

2.2 TYPE OF PLANT AND SIZE SELECTION

Once the type of load generation requirement is determined, the plant type and size selection process can proceed.

Besides the generation requirements, the decision as to what type of power plant to build is influenced by many other factors. Among these factors are the time required to bring the plant into commercial operation of the plant and the cost to build and operate the plant.

Figure 2.2. Typical Weekly Load Cycle (11:50)

2.2.1 Base Load Units vs Peak Load Units

The main factor that determines what type and size of plant is to be built is the generation requirement. In order to fulfill the required type of load generation, base load, intermediate load, peak load, two types of units can be defined, base load units and peak load units.

Base units are those generators which are expected to operate continuously every day of the week. Base units provide the operating requirements for all of the base load and part of the intermediate load. For base load units, it is important that the fuel costs be low as the unit will be producing a tremendous amount of energy for a high percentage of the time during the year. Capital investments that improve the efficiency of the plant can pay off to a large degree in base load plants. A nuclear plant or a large fossil unit are good examples of base load plants.

Peak units are those plants that must be flexible enough to follow the load pattern. If necessary, peak load units may be shut down completely at night, when electric demand is low, and be ready to operate the next day, when demand is again increased. Peak units cover the operating requirements for some of the intermediate load and all the peak load. A combustion turbine unit that burns natural gas or oil as fuel is a good example of a peak load unit.

Figure 2.3 shows what type of units will be in operation during what portions of the year depending on the amount of the demand.

2.13

Figure 2.3. Typical Utility - Annual Load Duration Curve and Generating Capacity (6:24)

2.2.2 Time Required for Commercial Operation

After the decision has been reached as to whether a base unit or peak unit is needed based on the generation requirements, an important factor that often determines the type of plant to be built is the time required for commercial operation.

In the case that a small peak unit is needed, time is not of major importance. However, economic considerations such as the cost of building the plant, fuel and maintenance costs, will be the decisive factors when the decision as to what type of plant is reached.

For base load units, the time required for commercial operation is a very important factor. As shown in Figure 2.4, the lead time for a nuclear power plant, after the decision to build has been reached, is between 11 and 12 years. In comparison, Figure 2.5 shows that the time required to bring into commercial operation a large fossil unit is only 8 years.

Time also influences the economic considerations that impact the decision of the type of plant. If the construction of a fossil generating unit takes three years compared to the five to six year duration for the construction of a nuclear power plant, the time the money is tied up, and the interest and escalation costs of the three years of the fossil unit compared to the six years of the nuclear unit is weighted and taken into consideration.

A more detailed treatment of the time and cost required for the design and construction of nuclear power plants is given in Section 7.

Figure 2.4. Schedule for Installation of Nuclear Unit (11:54)

Figure 2.5. Schedule for Installation of Fossil Unit (11:55)

2.2.3 Financial Impact on the Selection

Under normal circumstances, financial considerations generally determine the type of plant to be built. The electric utilities are in business to provide electric power, but this power should be provided at a minimum cost to the public. Therefore, the type of generating unit that will provide the minimum cost per kilowatt-hour will be preferable when the decision as to what type of plant to build is reached.

The economic factors that influence the cost of electric power are the cost of construction, cost of fuel, cost of transmission, maintenance and other related costs. These economic considerations are important especially to the utility industry because "an electric utility is unique in that it has the highest investment-per-end-product annually and the highest investment-per-manhour of effort than any other industry". (6:26) Since electricity demand grows at a rate that doubles approximately every ten years, the utility has to double its investment in facilities in ten years in order to double the capacity to carry the load.

All these financial constraints are influenced by the cost of money. "In the early 1970's the cost of money was between 8 and 11 percent on bonds alone. When you consider that net earnings on common stock are between 11 and 15 percent, and on top of that, you must earn somewhere in the order of $1\frac{1}{2}$ times that much to be able to pay taxes on profit, the average cost of money for the utility ranges in the order of 13 to 18 percent". (6:27)

Another important economic consideration is the cost of fuel. In Figure 2.6 a comparison of the cost trends of the three types of fuel,

Figure 2.6. Fuel Costs Trends (22:7)

oil, coal, and nuclear, is shown. Note that although it is not shown in the figure, prices of fuel, especially uranium, have risen sharply in the last couple of years.

Although the capital costs of construction of a nuclear power plant are significantly higher than for a fossil plant, the average cost of the plant per kilowatt of electricity over the life of the plant is often less. This is primarily due to lower fuel and maintenance costs in a nuclear plant, increased reliability and availability and the fact that a nuclear power plant has a significantly longer economic life.

(22:6)

An economic comparison for three base generating units is presented in Table 2.1. For this hypothetical example it is assumed that two 1100 MWe generators would be installed two years apart - one in 1984, one in 1986. For each of the three fuel options the plant is assumed to have equal generating capacity and the same set of service dates. As expected, nuclear power is the cheapest of the three fuel options. (11:28)

Air and water quality control also have an impact on the cost of the plant, mainly the stack-emission limits for fossil fuel plants. One of the major stated environmental advantages of nuclear power is that it produces no air or chemical water pollution.

2.3 SITE SELECTION FOR NUCLEAR PLANTS

Site selection is an involved process, especially for a nuclear power plant. Certain fundamental requirements must be met by a parcel of land in order to be considered as a possible site. Among these requirements, size and water availability are crucial. The selection

	Fuel Type		
	Coal	Oil	Nuclear
A. <u>Capital Cost</u>	\$1,750,000,000	\$1,240,000,000	\$2,310,000,000
B. <u>Annual Fixed Cost - \$/Yr.</u>			
Carrying Charge Rate - %	16	16	16
Capital (A x Carrying Charge)	280,000,000	198,000,000	370,000,000
Fixed Operating and Maintenance Insurance	15,200,000	14,700,000	(Included in D) 2,900,000
C. <u>Per Unitized Annual Fixed Costs \$/Kw/Yr.</u> (B/2,200,000 kw)			
Capital	127.27	90.18	168.00
Fixed Operating and Maintenance Insurance	6.91	6.68	- 1.32
D. <u>Equivalent Generation Cost</u> <u>Exclusive of Fuel-Mills/Kwhr</u> (C/6132 hr.) x 1000			
Capital	20.77	14.72	27.40
Fixed Operating and Maintenance Insurance	1.13	1.09	-
Incremental O&M	3.90	1.31	2.3
	5.03	2.40	2.51
E. <u>Fuel Cost</u>			
Cost-Cents/Mbtu	255	364	65
Heat Rate Btu/Kwh	9300	8900	10550
Equiv. Gen. Cost-Mills/Kwh	24.99	32.40	6.86
F. <u>Total Generation Cost</u> <u>Mills/Kwh</u>			
Capital	20.77	14.72	27.40
Fuel	24.99	32.40	6.86
O&M, Insurance	5.03	2.40	2.51
Total	50.79	49.52	36.77
G. <u>Differentials</u>			
Mills/Kwhr	14.02	12.75	-
Dollars/Yr. (70% C.F.)	189,090,000	171,900,000	-

Table 2.1. Economic Comparison of Base Generating Units (11:46)

criteria and the stages necessary for the nuclear power plant siting selection process are treated below.

2.3.1 Selection Criteria

The site selection process for nuclear power plants, in general, is based on the following criteria (20:8):

1. Acreage necessary to build the plant and all auxiliary facilities.
2. Water availability for cooling purposes.
3. Seismic constraints.
4. Distance constraints from power source to user centers.
5. Socioeconomic and geopolitical factors, including zoning and community planning constraints.
6. Property acquisition conditions.
7. Environmental factors such as biological inventories and effects.
8. Archaeological and historical site locations.
9. Population distributions.
10. Transportation and communications limitations.
11. Land use patterns.
12. Meteorological and climatological patterns.

2.3.2 Stages in the Selection Process

In the process of nuclear power plant siting, three major stages are identified (24:22):

Stage I: The regions of interest are examined to identify candidate areas. At this stage, identification and exclusion of major geographic areas from the region of interest is performed. This type

of exclusion analysis would typically eliminate areas lacking a potential coolant source and areas of high population concentration. This initial screening, usually done on topographical maps, results in a reduction of potential site areas to less than 10 percent of the total land area under consideration.

Stage II: Potential sites are identified within the candidate areas and evaluated using generalized siting criteria. This results in the selection of several candidate sites. Aerial photographs can facilitate the identification of potential sites through the analysis of:

- (1) geo-characteristics - The site should be physically suitable in terms of topography and soils, and should show an absence of geological hazards such as fractures, faults, flood-prone, landslide-prone, etc.;
- (2) Transportation network - Suitable access for equipment in plant construction and operation is needed.

Stage III: Candidate sites are compared using weighting and econometric procedures to select the proposed site. At this point, scientific and engineering disciplines are involved. Some of the scientific disciplines include: (1) Biologists; (2) Archaeologists; (3) Geologists; (4) Paleontologists; (5) Meteorologists; (6) Demographers; (7) Radiologists; (8) Safety and Health Planners; (9) Land Planners; (10) Landscape Architects. Engineering disciplines that come into play at this stage are: (1) Civil Engineers; (2) Mechanical Engineers; (3) Plant Layout Specialists; (4) Transmission and Distribution Engineers; (5) Cost Estimators; (6) Chemical Engineers; (7) Noise Engineers; (8) Nuclear Engineers.

Once a full evaluation of the selected sites has been conducted,

the Environmental Assessment Plan is developed in preparation for the later formulation of the Environmental Report and Environmental Impact Statement.

2.4 SUMMARY AND CONCLUSIONS

Due to the long lead times that now exist in the construction of large power plants, especially nuclear units, the planning process has become a more prominent part of the overall construction process. In this section an overview of the three steps that compose the planning process has been presented.

Section 3

REGULATION AND LICENSING

Regulators and licensers play a major role in the design, construction, and operation of a nuclear power plant in the United States in that no such plant may be operated unless the regulations are met and a license is issued.

The details of the nuclear industry regulation and licensing process are constantly undergoing change and are beyond the scope of this work, however, in this section, an overview of the regulatory and licensing process is given.

Both Federal and State agencies are involved in the regulatory process. Federal agencies are involved in all nuclear work in every State in that the Federal regulatory process is common throughout the country. The State regulatory agencies vary among the States. In this report, the State of New Jersey is used as illustrative of the involvement of the State in the regulatory and licensing process.

3.1 THE NUCLEAR REGULATORY COMMISSION

The Nuclear Regulatory Commission (NRC) is a Federal agency created for the protection of the public. The NRC regulates the design, construction and operation of nuclear power plants in the United States. The following subsections summarize the historical development, purpose, and organization of the NRC.

3.1.1 Historical Development of the NRC

During the 1960's and until 1974 the responsibility for the research, development and regulation of all nuclear activities was given to one government agency, the Atomic Energy Commission (AEC). The peaceful use of nuclear energy was constantly increasing and there was a growing concern that the public interest, especially the protection of public health and safety, environmental quality and national security, could not be adequately represented by just one common agency. In order to eliminate possible conflicts of interest among advisory groups within the AEC, it was decided that a totally independent agency would be created whose sole responsibility would be to regulate the civilian nuclear activities in the United States. (22:20)

In order to establish this independent agency, the Energy Reorganization Act of 1974 was signed into law on October 11, 1974, and became effective on January 19, 1975. This Act resulted in the dissolution of the AEC, and the creation of two totally independent agencies, the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA). (4:3)

The NRC was established to regulate all civilian nuclear activities. The initial staff of this new agency was composed primarily of former members of the regulatory staff of the AEC. The second agency, ERDA, was established to further the development of nuclear and other forms of energy.

3.1.2 Purpose of the NRC

The Energy Reorganization Act, under which the Nuclear Regulatory Commission was created, transferred to the NRC the responsibility for

carrying out the regulatory provisions of the Atomic Energy Act of 1954. Under the National Environmental Policy Act (NEPA), the Commission assumed responsibility for evaluating the environmental as well as the social impacts of the construction of nuclear facilities. (4:4)

The purpose of the NRC has been stated very specifically by William A. Anders as chairman of the U.S. Nuclear Regulatory Commission.

The business of the Nuclear Regulatory Commission is regulation. We must maintain a position above the fray, and not allow ourselves to be either apologists for or antagonists of nuclear power. Development or promotion of nuclear technology is the function and responsibility of others. Our job is protecting the health and safety of the public. (22:21)

All Federal regulation of the civilian use of nuclear power is administered by the NRC.

3.1.3 Organization of the NRC

The Nuclear Regulatory Commission is composed of five commissioners that represent composite expertise in the sciences, government and law. They are supported by an extensive staff organization and a line organization for operations. Major support of the Executive Director for Operations is divided in five areas. These areas include standards development, nuclear material safety and safeguards, nuclear reactor regulation, nuclear regulatory research, and inspection and enforcement. An overall organization chart for the NRC is shown in Figure 3.1.

Of the five operational groups the constructor's field construction personnel are most familiar with the activities of the Office of Inspection and Enforcement. Although each of the other groups impacts directly on the construction of a nuclear power project, it is the division of Field Operations that provides the on-site inspections for

2.27

Figure 3.1. U.S. Nuclear Regulatory Commission (4:6)

compliance. The inspectors are organized geographically into five regions with regional offices in Philadelphia, Atlanta, Chicago, Dallas and San Francisco. (22:22)

3.2 THE NRC REGULATION AND LICENSING PROCESS

The following subsections present the major steps involved in the regulation and licensing of a nuclear power plant required by the Nuclear Regulatory Commission.

3.2.1 Preliminary Safety Analysis Report

The Preliminary Safety Analysis Report (PSAR) is developed and submitted by the plant utility or owner. It contains detailed information on the site, design, safety analysis and environmental considerations of the proposed plant.

This document, together with the Environmental Report, are reviewed by the NRC. The NRC is in charge of the technical review which centers on plant safety, environmental considerations and antitrust implications. These documents are later reviewed by the Advisory Committee on Reactor Safeguards (ACRS) which is commissioned by the NRC, but acts independently of them.

The PSAR review process in 1967 required approximately 10.5 months, in 1970 it took 20 months, and in 1972 the duration was over 30 months. It now takes 18 months, and it is predicted by industry and regulatory personnel that no significant increases or decreases in the duration will occur in the near future. (22:26)

The NRC, after preliminary review of the report, may issue a limited work authorization permit, which allows the start of the pre-

liminary site work described in the application for the permit.

Once a construction permit is issued based on the PSAR, the utility is responsible for compliance with the PSAR, and all inspections and citations during construction, as well as review for further licensing will be based mainly on the PSAR.

In the last few years there has been a dramatic increase in the requirements and complexities of the PSAR. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants" (Revision 2, September 1975), provides basic guidance for the development of the PSAR. The broad scope of subjects that are covered is indicated by Table 3.1. (22:30)

3.2.2 Environmental Report

Once a full evaluation of the selected candidate sites has been conducted, which occurs concurrently with the preparation of the PSAR, the utility owner develops the Environmental Assessment Plan in preparation for later formulation of the Environmental Report and Environmental Impact Statement. These reports document the impacts that the construction of the nuclear power unit and other necessary facilities, such as transmission lines, will have on the surrounding environment. These documents are submitted to the Nuclear Regulatory Commission for review and approval.

3.2.3 Public Hearings

Originally, public hearings dealing with the construction of nuclear power plants were a means for informing the public. Today, because of the complexity of the reports on which the hearings are based, this is rarely the case. During the hearing, representatives of each party involved present their data and reports for the application, not

Reg Guide Number	Title
1.70	Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (Revision 2, 9/75)
1.70.1	Additional Information--Hydrological Considerations for Nuclear Power Plants (Revision 1, 1/75)
1.70.2	Additional Information--Air Filtration Systems and Containment Sumps for Nuclear Power Plants (12/73)
1.70.3	Additional Information--Radiation Protection (Revision 1, 11/74)
1.70.4	Additional Information--Fire Protection Considerations for Nuclear Power Plants (2/74)
1.70.5	Additional Information--Water Level (Flood) Design for Nuclear Power Plants (5/74)
1.70.6	Additional Information--Quality Assurance During Design and Construction (7/74)
1.70.7	Additional Information--Geography and Demography Considerations for Nuclear Power Plants (8/74)
1.70.8	Additional Information--Nearby Industrial, Transportation, and Military Facilities (9/74)
1.70.9	Additional Information--Design of Seismic Category I Structures (11/74)
1.70.10	Additional Information--Wind and Tornado Loadings (11/74)
1.70.11	Information for Safety Analysis Reports--Quality Assurance During Operations Phase (12/74)
1.70.12	Information for Safety Analysis Reports--Reactor Materials (12/74)
1.70.13	Information for Safety Analysis Reports--Code Cases Applicable to Reactor Coolant Pressure Boundary Components (12/74)
1.70.14	Information for Safety Analysis Reports--Emergency Planning (12/74)
1.70.15	Information for Safety Analysis Reports--Industrial Security for Nuclear Power Plants (12/74)
1.70.16	Information for Safety Analysis Reports--Missile Barrier Design Procedures (12/74)
1.70.17	Information for Safety Analysis Reports--Hydrologic Engineering (1/75)
1.70.18	Information for Safety Analysis Reports--Mechanical Systems and Components (1/75)
1.70.19	Information for Safety Analysis Reports--Steam Generators (1/75)
1.70.20	Information for Safety Analysis Reports--Reactor Coolant Pressure Boundary Materials and Inservice Inspection (1/75)
1.70.21	Information for Safety Analysis Reports--Reactor Vessels (1/75)

Table 3.1. Regulatory Guides for Safety Analysis Reports (22:30)

Reg Guide Number	Title
1.70	1.70.22 Information for Safety Analysis Reports--Instrumentation and Controls (2/75)
	1.70.23 Information for Safety Analysis Reports--Seismic Qualification of Instrumentation and Electrical Equipment (2/75)
	1.70.24 Information for Safety Analysis Reports--Environmental Design of Mechanical and Electrical Equipment Qualification Tests and Analysis (2/75)
	1.70.25 Information for Safety Analysis Reports--Inservice Inspection of ASME Code Class 2 and 3 Components (2/75)
	1.70.26 Information for Safety Analysis Reports--Metallic Materials for Engineered Safety Features (2/75)
	1.70.27 Information for Safety Analysis Reports--Radioactive Waste Management (4/75)
	1.70.28 Information for Safety Analysis Reports--Steam and Feedwater System Materials (4/75)
	1.70.29 Information for Safety Analysis Reports--Meteorology (4/75)
	1.70.30 Information for Safety Analysis Reports--Pump Flywheel Integrity (4/75)
	1.70.31 Information for Safety Analysis Reports--Plant Procedures (5/75)
	1.70.32 Information for Safety Analysis Reports--Reactor Water Cleanup System (5/75)
	1.70.33 Information for Safety Analysis Reports--Initial Test Programs (5/75)
	1.70.34 Information for Safety Analysis Reports--Fuel System Design (5/75)
	1.70.35 Information for Safety Analysis Reports--Internally Generated Missile (6/75)
	1.70.36 Information for Safety Analysis Reports--Electric Power (6/75)
	1.70.37 Information for Safety Analysis Reports--Pressurizer Relief Discharge System (6/75)
	1.70.38 Information for Safety Analysis Reports--Training (6/75)

Table 3.1. (Continued)

by reading the reports, but rather by indicating the volumes in which they are contained. Therefore, no one, except for the NRC, utility and A/E or consultant, knows the specifics of the project.

The hearing is conducted by a three-member hearing board composed of a chairman and two technical advisors specialized in environmental and nuclear technology. The duration of the hearings can vary a great deal. For example, the hearing for Long Island Lighting's Shoreman plant took two and one-half years, while that for Metropolitan Edison's Three Mile Island Unit 2 was completed on the first morning. (22:26)

Upon completion of the public hearing a successful application results in the issuance of a construction permit. The construction permit authorizes the utility to build the nuclear power plant in accordance with the PSAR.

3.2.4 Other NRC Permits and Licenses Required During Construction

In addition to the approval by the Nuclear Regulatory Commission of the PSAR and Environmental Report, and issuance of a construction permit, there are several other licenses and permits that must be obtained from the NRC after construction has progressed, and prior to operation. These licenses include separate permits for bringing nuclear fuel on site, loading fuel, testing, etc.

3.2.5 Final Safety Analysis Report

The application for commercial licensing of a nuclear power plant depends upon review and approval by the NRC of the Final Safety Analysis Report (FSAR). The review and approval procedure is similar to that required of the PSAR.

The FSAR is a detailed summary of what was actually done in the

design and construction of the plant. It requires a more detailed reporting of information than the PSAR, and it usually exceeds the PSAR in length. The FSAR for the Three Mile Island 2 at the time of its submission was 12 volumes in its entirety. (22:29)

Compilation of the FSAR actually begins with the PSAR and can be completed before the construction is finished.

The last phase before licensing for commercial operation is another public hearing. This is not required by law and is only held on request.

3.3 OTHER REGULATORY AGENCIES

Besides NRC requirements, there are other licenses and permits that must be secured from various local, State and National agencies. Figure 3.2 indicates the different parties that the utility may interact with before and during construction, and during commercial operation. The required licenses and permits required by Federal, State, and local agencies for the commercial operation of a nuclear power plant in the State of New Jersey are presented in Table 3.2. Although the number and description of these permits varies from State to State, and location to location, similar licenses and permits are required in other States.

3.4 SUMMARY AND CONCLUSIONS

Regulation is a long and complicated process that is present from the conception of a nuclear power plant, through construction and operation of the plant. For this reason, regulation and licensing, and specifically the Nuclear Regulatory Commission, exert a predominant influence on the entire nuclear construction industry. In this section, an overview of

Figure 3.2. Interacting Parties for Construction and Operation of a Nuclear Power Plant

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
<u>FEDERAL</u>			
Nuclear Regulatory Commission	Construction Permit	For Construction of the AGS	10 CFR 20, 50, 100
	Manufacturing Permit	For Construction of the Plant	10 CFR 20, 50, 100
	Operating License	To Load Fuel and Operate the AGS	10 CFR 20, 50, 100
	License for Source Material	To Store and Possess Nuclear Materials Not Covered by Plant Operating License	10 CFR 40
	License for Special Nuclear Material	To Store and Possess Nuclear Materials Not Covered by Plant Operating License	10 CFR 70
	License for By- Product Material	To Store and Possess Nuclear Materials Not Covered by Plant Operating License	10 CFR 31
Department of the Interior	Meteorological Towers	To Construct Meteorological Towers on Brigantine Wild- life Refuge	

Table 3.2. Licenses and Permits for a Nuclear Power Plant in New Jersey (22:189)

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
Environmental Protection Agency	Discharge Permit	To Discharge Material Into Waterway	Federal Water Pollution Control Act Amendments of 1972
U. S. Army Corp of Engineers	Land Support Facility Dredging Permit	To Dredge and Repair Dock Facilities for Operational Forces	Section 404, Federal Water Pollution Control Act Amend- ments of 1972
	Construction of Breakwater	For Protection of Plant	33 U.S.C. 403, Section 10 of Rivers and Harbors Act of Mar. 23, 1899
	Dredging and Laying Submarine Cables	Submarine Cable From Plant to Mainland	Section 404, Federal Water Pollution Control Act Amend- ments of 1972
	Site Study Permits	Subsurface Investigations (borings)	
Federal Aviation Agency		To Construct Meteorolo- gical Tower in Ocean	
	Heliport (Mainland)	Operate Heliport at Shore Support Facility	Federal Aviation Regulation 157
	Heliport (Mainland)	Operate Heliport at Switchyard	Federal Aviation Regulation 157
	Tall Structure (Plant)	For Tall Structure of Plant	Federal Aviation Regulation 77

Table 3.2. (Continued)

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
U. S. Coast Guard	Heliport (Plant)	Operate Heliport on Plant	Federal Aviation Regulation 157
	Tall Structure (Mainland)	To Construct Meteorological Tower	
	Construction and Temporary Marking of Breakwater	For Protection During Construction	CFR 67.01 Through 67.30
	Installation and Operation of Permanent Markers on Breakwater	For Protection of Plant	CFR 67.31 Through 67.30
<u>STATE OF NEW JERSEY</u>			
Department of Environmental Protection, Division of Marine Services, Bureau of Marine Lands Management	Construction Areas Facility Permit	For Submarine Cable to Shore	Chapter 185, Public Laws 1973, Coastal Area Review Act
	Land Support Facility	To Dredge and Repair Dock Facilities	New Jersey Statute 12:5-3
	Construction of Breakwater	For Protection of Plant	New Jersey Statute 12:5-3

Table 3.2. (Continued)

2.38

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
	Dredging and Construc- tion of Submarine Cables	For Submarine Cable From Plant to Shoreline	New Jersey Statute 12:3-26
	Construction of Buried Cable	For Buried Cable From Shoreline to Switchyard (Stream Crossings)	New Jersey Statute 12:3-26
	Riparian Grant (Plant) ^b	For Plant and Breakwater	New Jersey Revised Statute 12:3-8
	Wetlands Permit	Construction of Land- side Buried Cables	New Jersey Statute 13:9A
	Transmission Right- Of-Way	For Transmission Line Construction From Switchyard to Grid (Permit for Stream Crossings)	New Jersey Statute 12:3-26
	License for Meteoro- logical Tower (Ocean)	For Meteorological Tower In Ocean	
	License for Meteoro- logical Tower (64 m Land)	For Meteorological Tower on Land	
	License for Buried Cable	For Buried Cable From Shoreline	New Jersey Statute 12:5-3

Table 3.2. (Continued)

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
Department of Environmental Protection, Division of Environmental Quality, Bureau of Radiation Protection	Site Study Permits	Subsurface Investigation Borings	
		To Construct Meteorological Tower in Ocean	
	Registration of Radioactive Material	To Have Radioactive Material on Site	Chapter 116, Public Laws 1958
	Permit	To Dredge and Repair Dock Facilities for Operational Forces	New Jersey Revised Statute 58:1-26
	Certificate of Water Quality	Water for Sanitary and General Usage	New Jersey Statute 58:4A-14
	Construction of Breakwater	For Protection of Plant	New Jersey Revised Statute 58:1-26
	Production Water Well	Sanitary and General Usage at Switchyard	New Jersey Statute 58:4A-14

Table 3.2. (Continued)

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
Department of Environmental Protection, Division of Environmental Quality, Bureau of Air Pollution Control	Dredge and Construct Submarine Cables	For Cable From Plant to Mainland	New Jersey Revised Statute 12:5-3
	Construct Buried Cable to Switch- yard	For Cable From Shoreline to Switchyard	New Jersey Revised Statute 58:1-26
	Fuel Storage Tank	Vent to Atmosphere	Chapter 106, Public Laws 1967 (Title 26:9.2), Supplement to Air Pollution Control Act, Public Laws 1954
	Various Tanks (5-10 Permits)	Approx. 5 to 10 Permits Required to Vent Various Tanks	Chapter 106, Public Laws 1967 (Title 26:9.2), Supplement to Air Pollution Control Act, Public Laws 1954
Department of Labor and Industry	Building Permit	For Construction of Plant	N.J.A.C. 12 (110), Safety Regulations No. 30
	Building Permit	For Construction of Shore Support Facility	N.J.A.C. 12 (110), Safety Regulations No. 30
Department of Health	Sewage Disposal Plant	Approval of Sanitary Waste Treatment on Plant	New Jersey Revised Statute Title 58, Chapter 12

Table 3.2. (Continued)

Agency	Type of License or Permit Required	Purpose of Approval	Statutory and Legal Authority
Department of Transportation	Heliport (Mainland)	Operate Heliport at Shore Support Facility	New Jersey Statute 16:54-5
	Heliport (Mainland)	Operate Heliport at Switchyard	New Jersey Statute 16:54-5
	Heliport (Plant)	Operate Heliport on Plant	New Jersey Statute 16:54-5
Local Municipalities	<u>LOCAL</u>		
Local Municipalities	Building Permits	For Construction of Shore Support Facility	Township Zoning Ordinance and Building Code
	Building Permit	For Construction of Landside Switchyard	Township Zoning Ordinance and Building Code
	Road Opening Permits ^a	For Construction of Buried Cable to Switchyard	
	Road Crossing Permits ^a	For Construction of Buried Cable to Switchyard	
Ocean County	Road Opening Permits ^b	For Construction of Buried Cable to Switchyard	

^a Essential Permits.

^b Amended application to include submarine cable right-of-way May 13, 1974.

Table 3.2. (Continued)

✓ the NRC, NRC's requirements, and other regulatory agencies' requirements has been presented.

Section 4

DESIGN AND STANDARDIZATION

Due to the complexity, physical magnitude, and importance of safety in the nuclear power plant building process, the design of such facilities is a very complicated and expensive part of the total construction process. Depending on the number of reactor units involved, licensing requirements, plant arrangement and other factors, the total design process for a nuclear plant represents from one to four million design manhours, and the trend in engineering manhours per KWe continues to increase. (22:54)

One possible solution to the ever increasing demand in engineering manhours is standardization. Design and standardization are discussed in this section.

4.1 THE DESIGN PROCESS

The design process for a nuclear plant usually begins about six months after the start of the development of the PSAR. Initial steps in the design process include the selection of the supplier of the Nuclear Steam Supply System (NSSS) and of the supplier for the turbine generators. In this report, the design process will be explained by reviewing the development of the documents needed for the successful design of any part or system of the nuclear plant.

4.1.1 Design Criteria Document

The preparation of a design criteria document is the first step

in the design process of a nuclear power plant. (20:15) A generating facility consists of systems, components and structures.

Structures form the housing and foundations for the station systems and components. In most cases components are contained within the physical boundaries of systems. (20:15) The design criteria document is prepared with the purpose of answering the following three basic questions:

1. Why does the system exist in the plant?
2. What must the system do?
3. What codes, regulations and standards apply to the system design?

The answers to these questions plus information from the reactor manufacturer, turbine generator manufacturer, and other system designers, gives what is called "design input". Design input is the design information the engineer needs to incorporate into the system design so that the system will properly perform within the station.

4.1.2 System Diagram

After the designer has gathered all the data necessary to develop the design criteria document, a system diagram must be produced. (20:17)

A system diagram is essentially a symbolic drawing for the presentation of tabular information and the schematic arrangement of system components and interconnections. The diagram is used by designers who produce the mechanical, electrical and instrumentation drawings needed by the manufacturing and construction forces to build the plant systems. The system diagram is not, however, a construction diagram itself. The diagram is also used by the utility to train its operating personnel in the operation of the plant, and by licensing agencies to ensure that

specific licensing requirements are met.

4.1.3 System Description

In conjunction with the system diagram, the system designer develops a system description. (5:17) The system description conveys the intent of the system design, operating modes, instrumentation and equipment characteristics.

The operating utility must review, comment and approve the system diagram and system description. The approval of these two documents constitutes a major milestone in the design process since the information contained permits the responsible parties to proceed to prepare the construction drawings and to proceed with the purchase of major equipment.

4.1.4 Component Specifications

Component specifications are necessary to communicate to the component manufacturer what is required of the system which the Architect-Engineer (A/E) has designed. Two types of component specifications are used. The first type is the prescriptive or detailed specification, which gives the manufacturer the precise instructions as to what is required in the product and how it must be manufactured. The second type of specification, which is the one commonly used by A/E's, is the functional or performance specification. A performance specification outlines what the piece of equipment must accomplish and under what design conditions.

For a piece of equipment there may be as many as three specifications prepared, including (20:19):

1. The purchase specification.
2. The conformed specification.

3. The design specification.

The purchase specification is the document used to solicit bids from manufacturers and it forms the basis of the legal contract with the successful bidder. A conformed specification is generally prepared after an agreement has been reached between the manufacturer, the A/E, and the utility as to the equipment to be purchased. The conformed specification, which is usually a revision of the purchase specification, details exactly what has finally been agreed to by all parties.

For equipment designed to comply with Section III of the ASME Boiler and Pressure Vessel Code, a design specification has to be provided. The design specification can accompany either the purchase specification or the conformed specification, and must contain sufficient details to provide a complete basis for construction and inspection. The design specification must be certified by a Registered Professional Engineer.

There are problems due to the multiplicity and variety of specifications in the nuclear plant construction industry. According to Walt Mikesell of Chicago Bridge and Iron, there is no standard industry specifications. He observes (8:17):

1. No common format.
2. Unclear code references.
3. Lack of concise working that is familiar or common to the industry.
4. Generalized statements.
5. Generic or general references to Federal Regulatory guides such as ANSI and ASME.

In general, if the cost effectiveness of the design and quality

programs is to be improved, the technical specifications on which the designs are based have to be improved accordingly.

The physical drawings are developed based on the preparation and approval of the design criteria, system diagram, system description and component specification. Once the necessary licenses are obtained, fabrication and construction may proceed.

4.1.5 Power Codes

Nuclear power plant systems must be designed and constructed in accordance with many different codes and standards. Technical codes establish standards for safety and operating factors which should be considered during the phases of design, fabrication and inspection of the component or process. Ideally, every possible situation or occurrence must be anticipated, and consistency of the level of detail is very desirable.

There is a need to continuously review and update code requirements, since new information and methods of analysis will often appear after a code has been adopted. On the other hand, there is a need for stabilization of standards so that the design and construction can also be stabilized. These conflicting needs are a source of controversy among persons involved in plant design, construction and regulation.

All nuclear power plants are subject to numerous local and national codes, each applying to specific areas or activities within the power plant. (22:297) For example, pressure vessels and steam generators with their associated piping system for a nuclear steam supply system must comply with the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components. The National Board Inspection Code also covers

inspection and repair welding.

4.2 STANDARDIZATION IN DESIGN

The purpose of standardization is to reduce costs, shorten schedules, and improve availability by the reuse of similar or identical designs.

The primary objectives of standardization have been identified by W.J.L. Kennedy and A. Morse as follows (9:61):

1. Establish an effective arrangement.
2. Standardize and optimize systems.
3. Minimize limitation on choice of equipment vendors.
4. Choose a design compatible with a reasonable maximum number of sites.
5. Achieve maximum man-hour cost and schedule savings.
6. Establish reliability goals to achieve a plant reliability of 86 percent or better.
7. Implement procedures and meet these availability goals.

If these goals are achieved, savings can be made not only in the engineering design, but also in licensing, equipment, construction, and operation.

A group of five electric utility companies is building five standardized nuclear plants on four sites in the Eastern and Mid-Western regions of the United States. The Standardized Nuclear Unit Power Plant System (SNUPPS) project is unique in that it involves identical plants on multiple sites for multiple utilities. The concept provides for a simultaneous review of the licensing applications by the NRC staff.

The NRC review and hearing processes are also consolidated in the consideration of issues common to all of the plants.

4.2.1 Standardization Options

Standardization of nuclear power plants can be achieved by means of the following four options:

Duplicate Design is a concept which provides for a single review of the license application for two or more plants. The plants will have a duplicate design and will be constructed in a limited time frame at different sites. The only differences allowed in the design are those forced by the differences in the site. A single set of detail drawings is prepared and all equipment is procured at one time so that each unit built has the same make and model of all items. (1:-) The duplicate design concept is being used in the SNUPPS project.

Replicate Design is a nearly exact replication of a previously established design constructed in a later time frame at the same or different site under separate license applications. Equipment is procured to the same performance specifications used in the earlier plant, but because the equipment is not ordered at the same time, some items may be of different model or manufacturer. Detail drawings are modified to suit variations in equipment. Davis-Besse Units 2 and 3 are an example of a replicate design. (1:-)

Reference Design allows the design of an entire plant, or of major systems in a plant, to be reviewed with the intent of being standardized for use in subsequent plant applications. The second and subsequent applications would merely reference the first. The reference system concept is expected to primarily benefit manufacturers of the Nuclear

Steam Supply System (NSSS). (22:66)

License to Manufacture concept provides for a licensing review of several facilities that are to be built at a location different from the site where the plants will operate. A follow-up licensing review would be limited to site-related questions. This concept applies primarily to proposals for off-shore, barge-mounted power plants. (22:66) The respective advantages of the license to manufacture concept include savings in engineering and construction effort.

4.2.2 Advantages and Disadvantages of Standardization

From the point of view of the regulatory agency, the expected benefits of standardization deal primarily with safety. The increased safety would result from the additional efforts of regulatory bodies in safety reviews of a design which will be repeated many times. Also the experience that the construction and operating personnel gain by continually working with identical systems should enhance safety.

In addition to safety, standardization offers the potential of reduced lead times which would result from the reduction of time necessary for the preparation of applications, licensing review and for the manufacturing of components. Cost reductions due to standardization would be evidenced in a reduced design effort, savings on funds borrowed for reduced periods of time, and savings in component costs due to multiple orders. (22:63)

Potential disadvantages of standardization involve areas of innovation, competition, and utility involvement in the project. Some industry people fear that an attempt to rapidly standardize the nuclear industry would stifle innovation and improvement in design. (22:64) In

the area of competition there is concern that rapid standardization will limit the ability of new companies to enter the market, either as suppliers, designers, or constructors. Also, it is felt that utility involvement would be reduced because the design would have to follow predetermined standards, therefore not allowing the utility to design the plant according to their specific needs and the resources available for the project.

4.3 SUMMARY AND CONCLUSIONS

The design process of a nuclear power plant is an extremely complicated task requiring an enormous amount of manpower. In this section, an overview of the design process and standardization options has been presented. It was noted that standardization may be a partial solution to alleviate the number of engineering manhours and lead times required. Also noted were major disadvantages related to standardization.

Section 5

PROJECT CONTROL

Due to the magnitude, duration, and number of interacting organizations that are involved in the construction process of a nuclear power plant, an effective form of project control must exist if the construction of the plant is to be on schedule, within budget and in accordance with the established specifications. Four types of project control are commonly recognized: (1) cost control; (2) schedule control; (3) material control; and (4) quality control.

Whether or not the control system is computerized, it should include standards of performance, progress reporting, and analysis of reported data to assure that proper action is initiated and carried out. The control system is based upon the assumption that standards of performance, such as schedule, budget, scope, or target productivity, may be established. (6:70) The system should be designed to serve corporate and project management. To be most effective, project control should be started during early planning and function in a "timely" manner during the construction and start-up phases.

5.1 PROJECT COST CONTROL

For any type of cost control to be most effective it should start at the conceptual design phase and continue throughout the life of the project. Cost control may help to avoid cost overruns. Major causes of cost overruns include (22:86): (1) inflationary increases in the labor

wages and fringe benefits for construction workers; (2) increased complexity of the construction technology required over that which was anticipated; (3) a reduction in productivity of construction labor; (4) schedule delays during construction; (5) more stringent standards for safety and quality assurance; (6) new environmental and ecological requirements; (7) equipment and material delays and shortages; (8) increased equipment and material costs; (9) licensing delays; (10) new regulatory bodies to be dealt with; (11) labor shortages; (12) higher interest rates; (13) increased material and quality requirements; and (14) in some cases a poorly developed estimate to begin with.

Effective cost control systems generally require (1) a well-defined scope of work in sufficient detail to allow any change from the scope to be identified and its effect on the project cost to be determined and evaluated and (2) control estimates against which actual performance is measured and evaluated.

5.1.1 Development of Cost Control System

In order to obtain an effective cost control system, the following prerequisites must be obtained and implemented (13:13):

1. Upper management support of the cost control procedures.
2. Implementation of the control system at the inception of the project.
3. Specific written assignment of responsibility among the various organizations and individuals involved.
4. Pre-defined work breakdown structure defining deliverable end products into specific "work packages" (i.e., specifications, drawings, etc.).

5. Pre-defined written procedures for change control (i.e., change in scope of work, quantities, etc.).
6. An effective cost recording and analysis system.

5.1.2 Types of Cost Estimates

There are several types of estimates which may be used in an effective cost control system. A classification system of one author included the following types of estimates (13:68):

Order-of-Magnitude Estimates, which are normally prepared during early stages of the project and updated regularly. These estimates are based on historical data and have a low degree of accuracy. Order-of-magnitude estimates are applied during the conceptual engineering and design phase.

Preliminary Detailed Estimates are issued shortly after the PSAR submittal. These estimates are established for the purpose of monitoring the full range of project costs at all levels of detail. Detailed estimates are updated periodically (normally every six months).

The Budget or Definitive Estimates are prepared on or about the award of the construction permit. The budget estimate represents the greatest degree of accuracy obtainable at the time of preparation. They are based on quotations for major pieces of equipment, many construction materials, and a complete labor survey.

5.1.3 Implementation of the Cost Control System

Whether the development and implementation of the cost control system is prepared by the engineer-constructor, utility, or both, a computerized system is generally used. Based on the control estimates prepared and the actual costs recorded, the computer will develop

different reports for the use of corporate management, project management, and field personnel.

The control of the costs is not only the responsibility of the Project Cost Engineering Staff, but of the Project Manager, and all of the individuals in the supporting disciplines of engineering design, and construction. (13:74)

The Project Cost Engineer has the basic functional responsibility of monitoring the cost and manhour expenditures associated with a project. These costs include materials purchased, contracts awarded, the expenditure for effort in the Headquarters Office and also the project site for supervision and construction craft labor. (13:74)

Project Cost Engineers in the Headquarters Office are assigned to specific projects to perform the functions of identifying, coding, and comparing costs with the control estimates to develop reports to assist construction supervision and management in controlling the cost of the project. The Headquarters Project Cost Engineers and Field Cost Engineer Staff work closely during the project construction period by frequent communication and job visits.

5.2 PROJECT SCHEDULE CONTROL

Project schedule control is normally included as a part of the total project control system. It is noted that major schedule slippages, often of several years in duration have occurred on almost every nuclear power plant originally planned since the mid-1960's. The causes of the schedule slippages are in many cases identical to those caused by the cost overruns. These include (22:109): (1) increased technological complexity;

(2) reduced productivity of construction labor; (3) labor shortages; (4) more stringent standards for safety and quality assurance; (5) new environmental and ecological requirements; (6) equipment and material delays and shortages; (7) licensing delays; (8) new regulatory bodies to be dealt with; (9) increased material and quantity requirements; (10) prolonged lead time extensions; and (11) in some cases a failure to develop a realistic schedule at the outset.

The primary result of schedule slippages is additional cost to the owner. The magnitude of the cost will depend on the amount of delay, the size of the plant being constructed, and the stage of construction.

5.2.1 Development of the Schedule Control System

The planning and scheduling of a nuclear power plant construction project is based on the use of the Critical Path Method (CPM) of scheduling, or some other form of network analysis. These tools are used in the preparation of a series of project schedules which form the basis of the schedule control system.

In the case of General Public Utilities Service Corporation (GPU30), the Project Planning and Scheduling Engineer prepares, using historical data, an initial, time-phased, Main Event Schedule illustrating the main events and milestones required to complete the project. After approval of the Main Event Schedule, the Planning and Scheduling Engineer develops a fully integrated engineering, procurement and construction schedule. The procedure followed is shown in Figure 5.1. The Planning and Scheduling Engineer simulates the CPM based schedule logic on the computer by iterative operations until a schedule that is acceptable to Project Management is produced. This schedule is the Official Project Schedule. (16:3)

Figure 5.1. GPUSC Flow Chart for Schedule Preparation (16:71)

5.2.2 Types of Project Schedules

The different types of schedules prepared by the Project Planning and Scheduling Engineer at GPUSC are the following (16:2):

Main Event Time Scaled Schedule. This is the initial and principal schedule since all other project schedules evolve from the Main Event Schedule. It is a manually prepared schedule that contains from 40 to 100 main events. The Main Event Schedule does not contain any non-event related schedule contingencies such as strikes, abnormal weather, design changes, etc.

Official Project Schedule. This is a detailed computerized schedule which incorporates all essential engineering, procurement and testing activities. The Official Project Schedule is the only "official" schedule for the project until it is formally superseded by another Official Project Schedule.

Simulation Schedule. A Simulation Schedule is an interim step between a proposed change in the existing Official Project Schedule and the production of a new Official Project Schedule. It is basically a series of iterative computer runs to update the Official Schedule.

Schedule Status Report. These status reports are physically identical to an Official Project Schedule, but reflect the current status of the project and indicate the computed deviation from the Official Project Schedule.

5.2.3 Implementation of the Schedule Control System

Project Managers and Project Planning and Scheduling Engineers implement the Official Project Schedule.

The Project Planning and Scheduling Engineer after the issuance of

the Official Project Schedule updates the computer logic, on a periodic basis, to reflect the current status of the project. The "Schedule Status Report" is then issued. This report reflects the deviations from the Official Project Schedule that may occur if corrective steps are not taken to correct the deficient activities. When Project Management thinks that this deviation from the Official Project Schedule cannot be corrected by logic changes, additional manpower, or improved productivity, the Planning and Scheduling Engineer makes simulation runs to develop a new simulated schedule that can be submitted for approval by Project Management. Upon approval, a new Official Project Schedule is issued and the aforementioned cycle repeated throughout the life of the project.

(16:4)

5.3 PROJECT MATERIAL CONTROL

A third form of construction project control is the control of materials. For the control of materials a series of computer programs and files may be developed to permit the assignment of direct responsibility for the on-time procurement to an individual within the responsible organization. By identifying all significant equipment items, each item may be tracked by computer from procurement through expediting and final delivery to the job site.

There are three reports that are prepared by the Material Control Record (6:24):

Master Listing. This is a listing of the entire file sorted by section code indicating the following data elements: system code; description, QA/QC code; drawing number; responsible organization or

individual; vendor name; purchase order; quantity data; purchase order dates; package number; and special codes.

Warehousing Report. This is a listing of all ordered items which have not been received as yet.

Expediting Report. This report itemizes for expediting review and update those items which are overdue or due to be shipped in the next ninety days.

5.4 QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance and quality control (QA/QC) are direct forms of project control dealing with the quality of the constructed plant.

Quality assurance and quality control have been defined in Title 10, Part 50, Appendix B, of the Code of Federal Regulations as follows (22:129):

Quality Assurance. All those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily in service.

Quality Control. Those quality assurance actions related to the physical characteristic of a material, structure, component, or system which provide a means to control the quality of the material, structure, component, or system to predetermined requirements.

The following discussion presents an overview of the QA/QC programs as they relate to the construction of nuclear power plants.

5.4.1 Purpose of QA/QC

The primary purpose of the quality assurance programs in the construction of a nuclear power plant is to provide assurance that the health and safety of the public will not be compromised during the subsequent operation of the plant. Quality Assurance is a discipline which

affects every facet of the engineering, construction and operation of the nuclear plant. It is based on a logical step-by-step method of assuring that the design meets the plant criteria, and that the intent of the designer is carried through construction. For this reason, Quality Assurance should be recognized as a management tool to help achieve specific objectives, and not only as a means to satisfy the requirements of the NRC.

5.4.2 QA/QC Programs and Procedures

The guidelines for quality assurance programs for nuclear power plants were published in March of 1969 (22:131) by the Atomic Energy Commission in Appendix B to Title 10 of the Code of Federal Regulations (10CFR50) entitled "Quality Assurance Criteria for Nuclear Power Plants". Made effective on July of 1970, the requirements and responsibilities of 10CFR50, Appendix B are delineated in the form of 18 criteria. Each point deals with a specific area. The following indicates the major emphasis of each section (23:11):

1. Organization. The applicant shall be responsible for the establishment and execution of the quality assurance program. The applicant may delegate to other organizations the work of establishing and executing the quality assurance program, of any part thereof, but shall retain responsibility therefore.
2. Quality Assurance Program. The applicant shall establish at the earliest practicable time, consistent with the schedule for accomplishing the activities, a quality assurance program which complies with the requirements of this appendix.
3. Design Control. Measures shall be established to assure that applicable regulatory requirements and the design basis, ... as specified in the license application, for those structures, systems, and components to which this appendix applies are correctly translated into specifications, drawings, procedures, and instructions.
4. Procurement Document Control. Measures shall be established

to assure that applicable, regulatory requirements, design bases and other requirements which are necessary to assure adequate quality are suitably included or referenced in the documents for procurement of material, equipment, and services, whether purchased by the applicant or by its contractors or subcontractors.

5. Instructions, Procedures and Drawings. Activities affecting quality shall be prescribed by documented instructions, procedures, or drawings, of a type appropriate to the circumstances and shall be accomplished in accordance with these instructions, procedures, or drawings.
6. Document Control. Measures shall be established to control the issuance of documents, such as instructions, procedures, and drawings, including changes thereto, which prescribe all activities affecting quality.
7. Control of Purchased Material, Equipment and Services. Measures shall be established to assure that purchased material, equipment, and services, whether purchased directly or through contractors and subcontractors conform to the procurement documents.
8. Identification and Control of Materials, Parts and Components. Measures shall be established for the identification and control of materials, parts, and components, including partially fabricated assemblies.
9. Control of Special Processes. Measures shall be established to assure that special processes, including welding, heat treating, and nondestructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements.
10. Inspection. A program for inspection of activities affecting quality shall be established and executed by or for the organization performing the activity to verify conformance with the documented instructions, procedures, and drawings for accomplishing the activity.
11. Test Control. A test program shall be established to assure that all testing required to demonstrate that structures, systems, and components will perform satisfactorily in service is identified and performed in accordance with written test procedures which incorporate the requirements and acceptance limits contained in applicable design documents.
12. Control of Measuring and Test Equipment. Measures shall be

established to assure that tools, gages, instruments, and other measuring and testing devices used in activities affecting quality are properly controlled, calibrated, and adjusted at specified periods to maintain accuracy within necessary limits.

13. Handling, Storage and Shipping. Measures shall be established to control the handling, storage, shipping, cleaning and preservation of material and equipment in accordance with work and inspection instructions to prevent damage or deterioration.
14. Inspection, Test, and Operating Status. Measures shall be established to indicate, by the use of markings such as stamps, tags, labels, routing cards, or other suitable means, the status of inspections and tests performed upon individual items of the nuclear power plant.
15. Nonconforming Materials, Parts, or Components. Measures shall be established to control materials, parts, or components which do not conform to requirements in order to prevent their inadvertent use or installation.
16. Corrective Action. Measures shall be established to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances are promptly identified and corrected.
17. Quality Assurance Records. Sufficient records shall be maintained to furnish evidence of activities affecting quality.
18. Audits. A comprehensive system of planned and periodic audits shall be carried out to verify compliance with all aspects of the quality assurance program and to determine the effectiveness of the program.

5.4.3 Organizational Structures for the Implementation of the QA/QC Program

According to 10CFR50, Appendix B, the owner is responsible for the formulation and implementation of the quality assurance program. The owner can delegate to the various contractors the implementation of the program, but is responsible for the quality of the final product to the NRC. It is important that the implementation of the quality assurance

program be made by a group independent of design, procurement and construction, to insure that QA personnel are free to determine if the proper quality has been attained. (23:11)

Figures 5.2 through 5.6 present a number of quality organizations currently in use.

5.5 SUMMARY AND CONCLUSIONS

Due to the complexity, duration, and nuclear nature of the work, a very effective form of control is necessary in the nuclear power plant construction process.

Quality control is necessary to defend the interests of the public. Cost control, schedule control, material control and quality control are management tools for the benefit of the owner. These four forms of control have been discussed in this section.

Figure 5.2. Construction Quality Assurance Plan for Organizational Structure (23:65)

Figure 5.3. Construction Quality Assurance Plan for Organizational Structure (23:65)

Figure 5.4. Construction Quality Assurance Plan for Organizational Structure (23:65)

Figure 5.5. Construction Quality Assurance Plan for Organizational Structure (23:65)

Figure 5.6. Construction Quality Assurance Plan for Organizational Structure (23:65)

Section 6

ALTERNATE APPROACHES TO THE DESIGN AND CONSTRUCTION PROCESS

In the nuclear power plant construction process there are many organizations and agencies involved representing the different interests associated with the design construction and commercial operation of a nuclear plant. Due to the magnitude of the work and the characteristics of the construction industry in general; there is no right or pre-established method to deal with the distribution of functions, selection, and coordination of all the parties involved.

In this section, the different parties involved, the organizational structures that they form, and the contractual agreements that tie them together, are discussed.

6.1 PARTICIPANTS IN THE DESIGN AND CONSTRUCTION PROCESS

Due to the magnitude of the projects, the amount of money involved, the many different types of equipment needed, and the need for external regulation, there are a great number of different parties involved in the nuclear power plant construction process. The main participants include: utility; designer; suppliers; constructor(s); labors; and local, State, and Federal agencies.

The different tasks to be accomplished by these participants may be combined, thereby reducing the number of parties involved in the process.

The following describes the different organizations involved in

the design and construction of a nuclear power unit.

6.1.1 The Utility Owner

The utility plays a main role in the nuclear construction process. The utility or owner decides to build the plant, finances the construction, and operates the unit after final approval. The utility company, as purchaser, operator, and licensee, has the ultimate responsibility and authority for all phases of the design and construction of the nuclear power plant. Generally, the utility's responsibility and authority expands to the following phases of the project: (1) plant capacity determination; (2) financing; (3) conceptual design; (4) siting; (5) design; (6) construction permit authorization; (7) construction; (8) start-up and testing; (9) operating license authorization; and (10) commercial operation. (22:4) The utility typically looks to other functional organizations to assist it in its design, and construction endeavors. Table 6.1 provides a list of the leading utilities in terms of total MWe of committed new generating capacity. It should be noted that all of the leading utilities are relying heavily on the nuclear option.

6.1.2 The Designer

The typical utility, having reached the decision to build a nuclear power plant, hires an architect-engineer (A/E) or designer-constructor to provide the services needed for the design of the plant.

The main function of the designer is the design of the facility to be built. Design includes the generation and control of specifications, drawings and all the necessary support documents. Often the utility will also hire the services of the designer to perform the load

UTILITY	FOSSIL	NUCLEAR	HYDRO	TOTAL
Tennessee Valley Authority	—	19,270	1,530	20,800
Duke Power Co.	—	12,346	1,000	13,346
Commonwealth Edison Co.	2,500	8,876	—	11,376
Ontario Hydro	3,600	7,760	—	11,360
L. A. Dept. of Water & Power	3,000	5,200	1,250	9,450
Carolina Power & Light	2,160	6,721	—	8,881
Georgia Power Co.	1,137	3,140	996	8,273
General Public Utilities	1,926*	1,200	1,850	7,976*
Public Service E. & G. Co.	—	7,915	—	7,915
Virginia Electric & Power	—	5,544	2,100	7,644

*Includes combined cycle commitment of 126 MW not shown elsewhere.

Table 6.1. Ten Leading Utilities in Total MWe of Committed
New Generating Capacity, April 1977 (19:65)

growth analysis, to determine the siting for future stations, and to develop the environmental statements.

The selection of the designer by the utility may be based on the following: (1) long association; (2) availability of acceptable people for a design team; (3) economic considerations; (4) capabilities of the firm; and (5) past history. (22:51)

Table 6.2 presents the leading engineers and/or constructors by total volume of committed capacity. Table 6.3 presents the leading engineers and/or constructors by number of plants. It should be noted that the leading corporations in the nuclear power construction industry are also the leading firms in the general construction industry.

6.1.3 Equipment Suppliers

The responsibility for the procurement of the necessary plant equipment is dictated by the organizational structure of the project. The manufacturing of this equipment is done by firms specialized in the necessary types of equipment. Major pieces of equipment include the Nuclear Steam Supply System (NSSS) and the turbogenerator. The manufacturer's responsibility is mainly the compliance with the specifications, the QA/QC requirements, and the timely delivery of the equipment. A list of reactor and turbine-generator suppliers is presented in Tables 6.4 and 6.5.

6.1.4 Construction Management

The owner may also hire the services of a construction manager (CM) for designated professional services. These services generally include the selection of the various trade contractors, and the coordination and monitoring of the entire construction process.

ENGINEER/CONSTRUCTOR	MW OF COMMITTED CAPACITY	% OF ** COMMITTED MW	NO. OF PLANTS	% OF ** COMMITTED PLANTS
Bechtel Corp.	50,077	17.7	57	14.4
Sargent & Lundy	29,817	10.5	44	11.1
Stone & Webster	23,943	8.5	31	7.8
United Engineers & Constructors	23,418	8.3	25	6.3
Elbasco	18,494	6.5	24	6.1
Gilbert-Commonwealth	17,190	6.1	21	5.3
Black & Veatch	13,168	4.7	21	5.3
Southern Company Services	11,953	4.2	16	4.0
Brown & Root	11,732	4.1	16	4.0
Daniel International	11,175	3.9	12	3.0
Atomic Energy of Can.	8,360	3.0	12	3.0
Burns & Roe	7,521	2.7	13	3.3
Stearns-Roger	7,276***	2.6	16***	4.0
Chas. T. Main	7,065	2.5	10	2.5
Townsend & Bottum	5,635	2.0	6	1.5
Gibbs & Hill	4,738	1.7	6	1.5
Offshore Power Systems	4,600	1.6	4	1.0
Burns & McDonnell	4,514	1.6	12	3.0
Mid-Valley Inc.	3,387	1.2	6	1.5
Kaiser Engineers	3,220	1.1	3	0.8

*Based on announcements by utilities. May be incomplete because of unreleased information and exceeds actual committed capacity due to separate listing of engineer and constructor.

**Percentages of committed MW and fossil and nuclear plants where engineer/constructor firm is named.

***Includes one 141-MW plant in Hawaii not shown in totals or other figures.

Table 6.2. Leading Engineers and/or Constructors by Total MWe of Committed Capacity - Fossil and Nuclear Combined, and by Percent of Total Committed MWe and Plants, April 1977 (19:66)

ENGINEER/CONSTRUCTOR	FOSSIL PLANTS	MW CAP.	COMMITTED PLANTS **	NUCLEAR PLANTS	MW CAP.	% OF COMMITTED PLANTS **
Atomic Energy of Canada	—	—	—	12	8,360	7.8
Bechtel Corp.	18	7,970	7.4	39	42,107	25.3
Black & Veatch	19	10,868	7.9	2	2,300	1.3
Brown & Root	12	6,932	5.0	4	4,800	2.6
Burns & McDonnell	12	4,514	5.0	—	—	—
Burns & Roe	9	3,600	3.7	4	3,921	2.6
Chas. T. Main	10	7,065	4.1	—	—	—
Daniel International	3	2,125	1.2	9	9,050	5.8
Ebasco	13	6,891	5.4	11	11,603	7.1
Gibbs & Hill	4	2,438	1.7	2	2,300	1.3
Gilbert-Commonwealth	15	10,535	6.2	6	6,655	3.9
Kaiser Engineers	—	—	—	3	3,220	2.0
Mid-Valley	6	3,387	2.5	—	—	—
Offshore Power Systems	—	—	—	4	4,000	2.6
Sargent & Lundy	31	16,416	12.8	13	13,401	8.4
Southern Company Services	13	9,413	5.4	3	2,540	2.0
Stearns-Roger	15***	6,156***	6.2	1	1,120	0.1
Stone & Webster	10	3,093	4.1	21	23,850	13.6
Townsend & Boltum	4	3,115	1.7	2	2,520	1.3
United Engineers & Constructors	12	8,302	5.0	13	15,116	8.4

*Percentage of total plants (fossil or nuclear) that have named engineer/constructors.

**Based on announcements by utilities. May be incomplete because of unreleased information.

***Includes one 141-MW plant in Hawaii.

Table 6.3. Leading Engineers and/or Constructors by Number of Plants - Fossil and Nuclear - MWe Capacity, and Percentage of Total Plants Committed, April 1977 (19:66)

SUPPLIER	BOILERS			REACTORS		
	TOTAL PLANTS	TOTAL MW	% OF TOTAL PLANTS	TOTAL PLANTS	TOTAL MW	% OF TOTAL PLANTS
Babcock & Wilcox (not including B&WL)	59	30,680	30.9	33	32,134	29.4
Combustion Engineering (not including CEC)	64	39,060	36.1	22	25,959	13.6
Foster-Wheeler	29	16,877	15.2	—	—	—
General Electric Co	—	—	—	43	47,564	26.3
Riley Stoker	25	7,909	13.1	—	—	—
Westinghouse Electric	—	—	—	59	63,697	36.4

* Based on information received for 191 of 292 committed fossil plants and 162 of 172 committed nuclear plants.
Not all boiler suppliers shown

Table 6.4. Leader Boiler and Reactor Suppliers in MWe, Number of Plants Involved, and Percentage of Total Plants for which Supplier Has Been Named, April 1977 (19:68)

SUPPLIER	FOSSIL			NUCLEAR		
	TOTAL PLANTS	TOTAL MW	% OF TOTAL PLANTS	TOTAL PLANTS	TOTAL MW	% OF ** TOTAL PLANTS
Allis-Chalmers Power Systems Inc.	12	7,260	6.2	8	8,900	5.3
Brown Boveri	4	1,565	2.1	10	12,606	6.7
General Electric Co.	110	55,606	56.7	67	73,701	44.7
Hitachi	3	900	1.5	—	—	—
James Howden & Parsons	2	1,000	1.0	7	4,560	4.7
M.A.N.	3	1,820	1.5	—	—	—
Westinghouse Electric	55	26,912	28.4	50	53,971	33.3

*Based on information received for 194 of 292 committed fossil plants and 150 of 172 committed nuclear plants.
 Not all suppliers shown.

Table 6.5. Leading Turbine - Generator Suppliers by Number of Plants and Percentage of Total Plants for which Supplier Has Been Named, April 1977 (19:68)

The construction manager participates in and contributes to aspects of project planning. The CM will often handle the procurement of materials. As a general rule, the CM does not carry out any of the construction operations with his own forces except for project supervision and general conditions construction. (5:10)

The CM is typically responsible for job inspection, safety, labor relations, payment procedures, field time and cost control, and general administration of the construction contracts. (5:10)

Construction management services are usually performed by leading architect-engineer or designer-constructor firms.

6.1.5 The Constructor

After the planning and the design, the physical construction of the nuclear power plant is generally performed by the designer-constructor or general contractor.

The constructor is that party who brings together all of the diverse elements and inputs of the construction process into a single, coordinated effort. (5:2) The essential function of the constructor is close management control of field operations. (5:2) Although the utility is responsible for the quality of all work performed, the constructor is responsible for providing the utility a quality product in accordance with the contract.

6.1.6 Construction Labor

Labor is an important party to consider in the nuclear construction process. At the present time, labor construction costs represent 30 to 35 percent of the direct construction capital costs. (17:8.2) Peak manpower requirements for a large, one-unit nuclear plant, are in

the order of 1500 men. Estimated construction manpower requirements for an average unit in the 800 to 1150 MWe range are in the order of 11 to 12 mh/KWe. This represents a total for the completed project of about 12 million craft manhours.

The distribution of the crafts for a typical power plant construction project is shown in Figure 6.1. Figure 6.2 presents the actual manhours by craft for two double-unit nuclear power plants. Unit sizes are 1050 MWe for one plant and 1150 MWe for the other. Figures in parentheses are the peak number of men in each craft at each plant during construction.

Labor can be provided by a union under contract or can be hired from the open market. A more detailed discussion of this topic is presented in Section 6.3.3.

6.1.7 Other Parties Involved

There are other parties involved at different stages of the nuclear power plant construction process. The general public is represented by different agencies whose function is the protection of the safety and the surrounding environment. These local, State, and Federal agencies have been previously treated in Section 3.

6.2 ORGANIZATIONAL STRUCTURES

Many of the companies actively engaged in the nuclear power industry are capable of performing one or more of the three basic functions (design, procurement, and construction) required to build a nuclear power plant. Various organizational alternatives must be considered by the utility when deciding who will design, procure

Figure 6.1. Percent Distribution of Crafts in a Typical Power Plant Construction Project (10:63)

Figure 6.2. Actual Manhours by Craft for Two Double-Unit Nuclear Power Plants (22:324)

materials for, and construct a new generating facility. The decision should depend mainly on the utility's technical and physical manpower available, other work being undertaken by the utility at the time, and the time available to complete the power plant. Even within the same utility, there are many variations in the distribution of responsibility from project to project. Though minor variations occur, there are five basic organizational structures now used by the utilities. The five approaches are given below, with some of the advantages and disadvantages commonly attributed to each. No attempt will be made to draw any conclusions as to the best approach or alternative. The appropriate organizational structure for a given utility may not be the right approach for another utility.

6.2.1 Total Design, Procurement and Construction by Utility

Personnel

This totally "in-house" approach, also referred to as a Utility Force Account approach, is rarely used today since very few utilities have the manpower necessary to undertake the design and construction of a large plant with their own forces. The Tennessee Valley Authority and the Duke Power Corporation are the only two utilities currently using this approach.

There are several possible advantages to the Utility Force Account approach: The fee paid to outside firms is eliminated; there may be greater motivation inherent in the company's own employees to do a better job; the levels of productivity may be increased; there may be a high degree of control over details in the entire process; and there may also be the benefit of intimate knowledge of the company's Operating Depart-

ment's requirements to eliminate any later changes. (7:6)

The main factors that limit the use of this "in-house" approach are that few utilities have the necessary volume of construction to justify the overhead manpower required, and that the utilities, in general, lack the experience of nationally known constructors and A/E's.

6.2.2 Total Design, Procurement and Construction by an Engineer-Constructor

This approach, also known as an Engineering Procurement and Construction (EPC) approach. (22:117), is commonly used today. The entire project is designed and constructed by the engineer-constructor, and the procurement is carried out by the engineer-constructor.

Under this approach the engineer-constructor may do all the construction work on a cost-plus-basis or subcontract all or portions of the job on either a cost-plus or firm price contract basis.

The design-construction combination may be advantageous because the interface between the A/E and the constructor, being one and the same party, should be smooth and timely. Often the construction of a nuclear plant is started when only a small percentage of the design is completed. In this case, the availability of drawings at the construction site, and the good communication between the design and the construction are of a high priority. Good communication should facilitate design changes as well as the resolution of problems that occur in the field. A second advantage of the EPC method may be that the utility can decide its involvement in the project.

The disadvantages to the utility include the added cost to the project due to the fees which the engineer-constructor charges for its

services, and diminished control exerted by the utility on the project caused by the reduced utility participation.

Table 6.6 shows the number of committed plants and MWe capacity by engineer-constructor compared to utility-designed or utility built plants.

6.2.3 Design by Architect-Engineer and Construction by General Contractor

Under this approach the design and construction are carried out by different organizations each holding a separate contract with the utility. The separate contracts method is frequently used in nuclear construction. The procurement of materials can be made by the A/E, general contractor, or utility, or in combination.

This method may provide the utility with the opportunity to exert greater control over the construction process. The main disadvantage may be in the coordination effort necessary by the utility to bring the work of all the parties together.

6.2.4 Design by Architect-Engineer and Construction Management by Utility

In this approach, the utility engages an A/E as in Section 6.2.3, but performs the functions of a construction manager. The utility may subcontract all the work on competitive bidding on a lump-sum or unit price basis, or on a cost-plus type of contract.

In practice, the utility construction management approach has not been commonly used in the construction of nuclear power plants.

6.2.5 Design by Architect-Engineer, Construction Management by CM as Agent for Utility

	FOSSIL		NUCLEAR		TOTALS**	
	PLANTS	MW	PLANTS	MW	PLANTS	MW
Engineer/Constructor	242	123,770	154	158,763	396	282,533
Self	36	20,729	52	56,141	88	76,870

*Excludes combined-cycle and geothermal.

**Exceeds survey total of committed plants and capacity due to overlap in reports for engineers and constructors.

Table 6.6. Committed Plants and MWe Capacity for Engineer/Constructor Compared to Utility-Designed or -Built Plants, April 1977 (19:67)

In this variation of the preceding approach, the utility hires the professional services of a construction manager, generally on a cost-plus basis. The owner enters separate contracts with the A/E, construction manager, and specialty contractors. Although the contractors are directly responsible to the owner, their selection and coordination, as well as the procurement of materials is the function of the construction manager.

6.3 CONTRACTUAL AGREEMENTS

Contractual agreements in the nuclear construction industry are different from those in most types of construction. The form of compensation is one example of a major difference, for the typical contract in nuclear plant construction provides for compensation on a cost-plus basis. Contractual agreements for design and construction, and labor contracts are discussed below.

6.3.1 Contractual Agreements for Design

The typical contract between the utility and the A/E used in the design of a nuclear power plant provides for compensation on a cost-plus basis. The A/E is reimbursed for all expenses including salaries, materials, etc. plus a markup to cover employee fringe benefits, taxes and insurance, office space, and the profit for which the designer works. (7:12)

Under the cost-plus type of contract the designer has no significant amounts of money invested in the project. This situation may result in low motivation to minimize costs for the utility during the design process. However, it should be recognized that the designer may

be motivated by several factors, such as competition for future projects, and the reputation of the company.

6.3.2 Contractual Agreements for Construction

Contract Management. Under the contract management approach the utility will generally hire the Construction Manager on a cost-plus type of contract. The Construction Manager may subcontract all of the construction work on competitive basis on a lump-sum or unit price basis.

Construction Contracts. When the design and construction are performed by the same party, the utility will usually engage the engineer-constructor on a cost-plus basis. The engineer-constructor may do all the construction work on a cost-plus basis, or subcontract all or part of the job on either a cost-plus or firm price contract basis. If the A/E and the constructor enter into separate contracts with the owner, both are usually on a cost-plus basis. The constructor can do all the construction work, or subcontract part of the job as above.

6.3.3 Labor Contracts

Labor contracts vary depending on the project. In general, the utility has the choice to work with two types of contractors that use two different approaches in their labor agreements.

Closed-Shop Contractors. Closed-shop contractors are those whose labor relations are controlled and regulated by a labor contract. By agreement with the union, they can only employ union workers. Closed-shop contractors operate mainly in the Northern part of the United States, and employ about four million tradesmen. (17:4)

Labor contracts of closed-shop contractors may contain restrictive work practices, specified crew sizes, etc.

Open-Shop Contractors. Open-shop contractors hire workers from the open market. Presently there are about three million workmen employed by open-shops, located mainly in the South and Southwest.
(17:4)

Open-shop contractors do not have to comply with any of the union agreements and, therefore, need not be restricted by such agreements. Work practices, crew size, and other conditions of employment are established by the contractor.

6.4 SUMMARY AND CONCLUSIONS

Because of the multitude of organizations involved in the nuclear power plant construction process, they can combine into many organizational structures for the construction of a power unit. The four most common structures, the parties involved, and the contractual agreements that they form have been reviewed in this section.

Section 7

TIME REQUIRED FOR NUCLEAR PLANT CONSTRUCTION

The time required to bring into operation a nuclear power plant has increased from the five year projections of the mid-1960's to the 11 or 12 year lead times for plants going into commercial operation in the 1980's. The reasons for the increase in the time required are varied. The barriers to reversing the upward trend, that is, the barriers to shortening construction schedules and the research needed to eliminate or minimize the effects of these barriers are the subject of research currently being conducted by others. It is the intent of this section to acquaint the reader with the past, present and projected future as it relates to the time required to produce a nuclear power plant and to comment on the cost impact of these ever increasing schedules.

7.1 PAST, PRESENT AND FUTURE PROJECT SCHEDULES

The lead time for the construction of nuclear plants committed during the early 1960's was five years (14:59) "... Florida Power & Light found out in mid-1967 that a 1972 nuclear plant was impossible to deliver. At the same time Middle South found that even a 1973 nuclear plant had an uncomfortably tight delivery situation". (14:59)

In 1968, the Atomic Energy Commission (AEC) was anticipating a lead time of seven and one half years from NSSS order to commercial operation for the near future. (14:59) In fact, nuclear plant delays

in the 1960's caused large generators during 1968-70 to be delayed by two years.

Three different estimates of the lead time required for operation of a nuclear plant were published in 1971: (1) the recommendation of a NSSS manufacturer; (2) the recommendation of the AEC; and (3) the recommendation of Sargent & Lundy, an A/E firm. The three schedules are reproduced in Figure 7.1. Table 7.1 presents the A/E firm recommendation for nuclear plant schedule in tabular form.

In 1974, Engineering News Record reported that "Reactor units under construction have experienced delays ranging from 5 to 61 months, with an average of 24 months per unit". (25:18) The same encountered delays were reported and commented on by Budwani. The results of his four year study " ... shows that the time for actual physical construction is between 58 and 66 months. This takes the plants to commercial operation". The " ... anticipated total lead time for a nuclear plant is 10 years or more". In spite of many efforts to reduce schedules " ... more schedule slippage will occur". (2:60) This referenced article provides a construction schedule analysis for new plants shown in Table 7.2.

Another 1974 study reflects the schedule experience between 1965 and 1975. (15:36) Table 7.3, based on the data presented in the original article, shows that in a period of ten years, the average estimated schedule for the design and construction of a nuclear plant had increased from 5 to 9.4 years.

Today, utilities are faced with lead times ranging from 10 to 12 years. According to NRC schedules, the average construction duration

NUCLEAR UNIT PROJECT SCHEDULE

Figure 7.1. 1971 Nuclear Plant Project Schedule Recommendations (18:40)

ACTIVITY	MONTHS
- Specify, bid, order NSSS	6
- Prepare PSAR	6
- Licensing	24
- Post-permit construction and testing	42
- Fuel loading, power testing	6
	—
TOTAL FOR EXISTING SITE	84
- New site environmental review	6
	—
TOTAL FOR NEW SITE	90

Table 7.1. 1971 Nuclear Plant Schedule (18:41)

ACTIVITY DESCRIPTION	MONTHS FROM START
Start site preparation and excavation	0
Start reactor building foundation	6
Start auxiliary building foundation	10
Start T-G building foundation	11
Start installation of T-G	25
NSSS equipment installation	31.5
NSSS hydrostatic test	49
Fuel loading	55
Commercial operation (into 1980)	60
<hr/>	
Construction duration - 60 months	

Table 7.2. Construction Schedule Anticipated for
1100 MWe Nuclear Power Plant in 1974

	Year Contract Let	No. of Plants	Average Size-MWe	Estimated		Updated	
				Schedule Range-Years	Average Schedule - Years	Schedule Range-Years	Average Schedule - Years
2 96	1965	8	591	4 to 6	5	5 to 8	6.3
	1966	21	790	4 to 7	5	4 to 9	6.7
	1967	30	811	4 to 10	6	5 to 13	7.5
	1968	17	920	5 to 9	6	6 to 13	8.7
	1969	7	1021	6 to 8	5.7	6 to 13	9.2
	1970	14	1010	5 to 8	6.5	6 to 10	8.4
	1971	21	991	5 to 11	8	6 to 12	8.7
	1972*	35	1062	6 to 10	8.2	7 to 11	8.5
	1973	38	1120	6 to 13	8.8	6 to 13	8.8
	1974	8	1215	8 to 12	9.4	8 to 12	9.4
(3 mo.)							

Table 7.3. Schedule Ranges for Nuclear Plants Between 1965 and 1974 (15:37)

of the units that received operating licenses in 1976 was 95 months.
(12:3)

7.2 MANPOWER REQUIREMENTS

The stretch in nuclear plant schedules has been accompanied by a great increase in the engineering and construction manhours required for the design and construction of such facilities.

The manpower requirements for the construction of a nuclear power plant in the mid-1960's were in the order of 3 to 4 mh/KWe. (3:42) Manhours of professional engineering services in 1967 were estimated at $\frac{1}{2}$ million for a 1000 MWe nuclear plant. With increased complexity and added requirements for environmental and quality control, this figure rose to 1 million manhours in 1971 and to 1.4 million in 1973. (2:62)

Planned construction manhours for nuclear plants schedule for commercial operation in the 1980's are now up to 11 to 12 mh/KWe for an average unit of 800 to 1150 MWe, which represent a total of 12 million construction manhours. (3:42) Design manhours for the same size range is estimated close to 2 million manhours which represents 1.4 to 1.9 mh/KWe. The increase from the $\frac{1}{2}$ million design manhours in 1967 to the 2 million manhours that is predicted will be required in the 1980's to design a nuclear power plant means that, in less than 20 years, design manpower requirements will have quadrupled.

Total craft manpower requirements for single-, double-, and triple-unit plants of 1150 MWe capacity are shown in Figure 7.2.

Figure 7.2. Total Craft Manpower Requirements for Single- and Multi-Unit Plants of 1150 MWe Capacity (22:322)

7.3 FINANCIAL IMPACTS OF PROJECT DURATIONS

The increases in time and manpower necessary for the completion of a nuclear power plant have made the costs associated with the plant to go up at even faster rates. Projections of power plant costs have been escalating at a rate of about 26 percent annually since 1970.

(15:36)

The average of the estimated costs for nuclear plants in 1965 was \$119/KWe. The December 1976 estimate for Carolina Power & Light Company's Shearon Harris Plant was \$1100/KWe. (12:7) Table 7.4 presents the increase in the average cost of nuclear power plants from 1965 to March of 1974.

Two major factors contributing to the increased cost of nuclear power units are escalation costs and interest on the funds necessary to finance the project. Both factors are impacted by project duration. To illustrate the impact that actual project duration has on nuclear plant costs, a hypothetical project analysis is presented. (21:162):

The analysis involves a plant of 1100 MWe nominal capacity with an estimated 1970 plant costs of \$360 million or \$330/KWe.

It is assumed that the project will be developed over a 10-year period (1974 to 1983) with expenditure following a typical S-curve. A capital structure of 50 percent debt and 50 percent equity, an interest rate of 10 percent, and an escalation rate of 6 percent have been assumed on these assumptions, the total project capital cost, at plant completion is calculated at \$370 million, or \$520/KWe. ... the total capital cost consists of a plant cost of \$360 million, with \$100 million for interest during construction, and \$110 million for escalation. The plant cost has thus been increased by \$210 million, or \$190/KWe, by escalation and financing.

Consequently, financing must be found for \$570 million, about one and one-half times the original plant cost of \$360 million.

Year Contract Let	No. of Plants	Cost Range - \$/KWE		Average Cost - \$/KWe	Percent Increase of the avg.
		Low	High		
1965	8	\$ 91	\$151	\$119	
1966	21	88	169	121	2%
1967	30	91	220	146	21
1968	17	121	252	157	8
1969	7	169	243	209	34
1970	14	188	333	222	6
1971	21	237	390	300	35
1972*	35	268	645	404	35
1973	38	313	650	456	13
1974	8	425	655	558	24
(3 mo.)					

Table 7.4. Nuclear Plant Costs Between 1965 and 1974 (15:37)

To illustrate the distribution of costs for a nuclear power plant construction project, Table 7.5 is presented. The Brunswick Plant belongs to Carolina Power & Light Company. It consists of two 821 MWe units. Construction was started in 1969 and operating licenses were obtained in December 1974 and September 1976. The 34 percent of the total cost expended for materials may seem low, but most of the material cost represents major orders placed at the front of the lengthy process, and many of the orders were not subject to the same escalation which was experienced on labor costs. The second largest cost associated with the project was The Allowance for Funds Used During Construction (AFUDC), which represents the cost of money. This 20 percent of the total cost seems to be distorted because of the length of the project.

(12:2)

7.4 SUMMARY AND CONCLUSIONS

Nuclear power plant projects, because of the immense capital requirements and long times associated with them, are becoming a challenge to the utility industry. The success or failure in dealing with these enterprises will have a great impact, not only in meeting the demand for electrical generating capacity, but also in the overall rate of economic growth.

PROJECT COSTS

COST PER KW		\$438
Material	34.4%	
Direct Labor	18.5%	
Construction Equipment	1.3%	
Subcontracts	5.1%	
Overhead & Indirects	8.3%	
Design Engineering, Property Tax, Insurance CP&L Administration	12.2%	
AFDC	20.2%	
	<hr/>	
TOTAL	100.0%	

Table 7.5. Carolina Power & Light Company Brunswick Units 1 & 2

Section 8.

SUMMARY AND CONCLUSIONS

The magnitude and complexity of nuclear power plant construction projects, with estimated costs over a billion dollars, and lead times in the 12 year range, makes them unique. They are also unique in the regulatory requirements that govern the design, construction and operation of the plant. In this report an overview of the nuclear power plant construction process has been presented, based on an extensive literature review. The subjects of (1) planning, (2) regulation, (3) design, (4) project control, (5) organizational structures, and (5) time required for the process have been addressed.

The planning phase is the first part of the process. Due to the long lead times required for the construction of large power plants, especially nuclear facilities, it is important that the utilities be able to accurately predict future demands for electric power.

Regulation and licensing is a long and complicated process that exerts a predominant influence on the entire construction industry.

The design of a nuclear facility is also a long and time consuming process requiring a great number of participants and manhours. Standardization may be a means by which to reduce the manhours and lead times required.

The complexity and duration of the nuclear power plant construction process requires an effective form of cost, schedule, material and quality control.

Many organizational structures and different contractual agreements can be formed by the multitude of organizations involved in the nuclear construction process.

Nuclear power plant projects require much capital and have long lead times. The money and time needed for the design and construction of a nuclear facility are two critical concerns. The future energy supply and economic growth of the United States may depend on how successful the industry is in dealing with these two important issues.

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VOLUME I SECTION 3

BARRIERS TO SHORTENING CONSTRUCTION SCHEDULES

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Note: This section, in draft form, has been written in partial fulfillment of degree requirements at Ohio State University. After review and comment the section will be rewritten to conform to the needs and organization of the final report.

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Section 1

INTRODUCTION

1.1 IMPETUS FOR THE STUDY

By the start of 1975, there were 53 licensed nuclear power plants in the United States, representing a total generating capacity of 35,000 MWe. There were 180 additional nuclear plants in the construction or planning stage, bringing the total combined capacity of 233 plants to 232,000 MWe. (2:39)¹

Nuclear power plant size has evolved from the small, single-unit plants of the early 1960's to the present day multi-unit complexes having a minimum per-unit capacity of about 1000 MWe. Planned construction man-hour requirements have reportedly risen from 3-4 mh/KWe in the mid-1960's to 11-12 mh/KWe for plants scheduled for commercial operation in the 1980's. (2:42) Accordingly, nuclear plant cost has reportedly escalated from \$240/KWe for plants commissioned in 1969 to about \$750 to \$800/KWe in 1975 for plants scheduled for completion in the early 1980's. (2:39) Previous studies have shown that the time required for actual physical construction of a nuclear plant is between 58 and 66 months. However, the anticipated total leadtime for a new nuclear plant is ten years or more. (1:60)

The cost and time requirements associated with present day nuclear power plant construction projects are threatening the economic feasibility of nuclear power as a continuing alternative to power generation.

1. Page 39 of Reference 2 in Bibliography

1.2 PURPOSE

This report presents the findings of Part One of a two-part research project sponsored by the United States Energy Research and Development Administration (ERDA). The objective of Part One was to identify and codify the barriers to shortening nuclear power plant construction schedules. Based on the findings of Part One, the objective of Part Two of the research effort was to identify the research needs to minimize or eliminate these barriers to shortening construction schedules.

In fulfillment of the Part One objective, this report presents the major factors contributing to the lengthy, and thus costly, construction schedules currently associated with nuclear power plant construction. The major emphasis is on those problem areas associated with the construction process, which will be defined to mean actual construction, including the design-construct interface. No attempt is made herein to address the second objective of the overall research effort.

1.3 PROCEDURE

The prime contractor for the ERDA-based study was The Ohio State University. There were four subcontracts, involving three universities (The Ohio State University, Clemson University, and The University of Texas at Austin) and one private firm (Kellogg Corporation). Subcontracts were awarded on the basis of proposals submitted to The Ohio State University and ERDA.

The actual information gathering stage was comprised of two phases: (1) a review of existing literature on nuclear power plant construction, and (2) a series of interviews and conferences involving

representatives of utilities, A-E's, constructors, and suppliers involved in the construction of nuclear power plants.

This report presents the findings of The Ohio State University and each of its subcontractors. The detailed subcontractor reports are reproduced in Appendices A, B, and C.

1.4 SCOPE AND ORGANIZATION

The stated purpose of this report is to present and discuss barriers which hinder efforts to reduce nuclear power plant construction schedules. As previously explained, the scope has been limited to the construction process. For the purpose of this report, the barriers to shortening construction schedules have been grouped into one of four broad problem areas:

- (1) Design-Construct Interface
- (2) Construction Materials and Methods
- (3) Construction Coordination and Communication
- (4) Manpower Availability and Productivity

1.4.1 DESIGN-CONSTRUCT INTERFACE

Section 2 of this report presents barriers associated with the design-construct interface, i.e., the design-related factors which impact upon the construction schedule. It is believed that many of the schedule difficulties encountered during actual construction can be reduced or eliminated through a more responsive design effort. Major problem areas associated with the design-construct interface are discussed.

1.4.2 CONSTRUCTION MATERIALS AND METHODS

The first part of Section 3 presents barriers associated with the permanent materials used to construct nuclear power plant facilities. The major topics of discussion are selection, availability, quality requirements, and material content. The second part of the section is devoted to the discussion of construction methods. Major problem areas presented include work site accessibility and methods improvement.

1.4.3 CONSTRUCTION COORDINATION AND COMMUNICATION

Coordination and communication among principle project teams is essential to the organization of a smooth-running construction project. Failure in this respect can result in inefficiencies, leading to a more lengthy and costly construction schedule. Section 4 provides insight into the more frequently offered criticism surrounding coordination and communication within the nuclear power plant construction process.

1.4.4 MANPOWER AVAILABILITY AND PRODUCTIVITY

Approximately 30-35% of the direct capital cost associated with the construction of a nuclear power plant is attributable to manpower. (8:8.2) Thus, problems associated with the acquisition and performance of manpower can have a crippling effect on the success of a project. Section 5 addresses some of the problems related to manpower availability and productivity in the nuclear power plant construction industry and the corresponding effects on project schedules.

Section 2

DESIGN-CONSTRUCT INTERFACE

2.1 INTRODUCTION

As previously implied, no attempt is made herein to provide an exhaustive discussion of the design process. It is important, however, to understand how design-related actions can impact upon the construction phase of a nuclear power plant project. This interface between design and construction is critical to the success of a project.

Design scheduling is an area that significantly affects performance in the field. Design plays an important role in dictating the sequence in which construction activities are carried out. Serious problems can, therefore, arise when required drawings and specifications are not available in the field as scheduled. Design changes that are required during construction can also result in costly design-construct coordination problems.

Difficulties can also be encountered in the field as a result of failure on the part of designers to adequately consider the constructability of the project as designed. As one constructor has noted, "All too often designs are formulated in a vacuum without consideration of constructability". (3:7)

And finally, communication between design and construction teams is instrumental in preventing and/or resolving problems or misunderstandings which may arise during on-site execution of the design.

The following subsections present what are believed to be major design-related problems which, in turn, add unnecessary length to construction schedules.

2.2 DESIGN SCHEDULING TO SUPPORT CONSTRUCTION

2.2.1 TIMELY RECEIPT OF "ISSUED FOR CONSTRUCTION"

DRAWINGS AND SPECIFICATIONS

The design of a nuclear power plant involves the generation of literally thousands of major drawings and specifications which must carefully define that which is to be constructed in the field. In order to insure uninterrupted execution of construction operations, required drawings and specifications must be completed and made available to the constructor as given work activities are scheduled to commence. Some project organizations, however, have experienced costly schedule delays because badly needed design information has not been made available on a timely basis. In fact, representatives of one construction organization presently working in the mid-west United States revealed that this was the number one cause of construction delay on the project in question.

When design information is not relayed to the field for implementation as scheduled, construction operations are interrupted. If the activities affected are critical, a costly delay will undoubtedly result while necessary drawings and specifications are being forwarded.

Although the timely flow of design information is primarily the responsibility of the Architect-Engineer (A-E), it is believed that the major problem arises out of the fact that actual plant construction generally begins after only a small percentage of design has been completed. Ramesh N. Budwani of United Engineers and Constructors has contended that engineering should be at least 50%, preferably 55-60%, complete prior to issuance of the construction permit. "A higher percentage of early engineering, done in sufficient detail, will assure adequate flows of

information to support an orderly construction sequence and hold schedule interruptions to fewer numbers". (2:43) In contrast, construction may often commence with as little as 15% of the design work having been completed. (12:60) Consequently, as design-construct leadtime decreases, adequate flow of drawings and specifications to the constructor becomes increasingly difficult to achieve.

2.2.2 LACK OF CONSTRUCTION FLEXIBILITY

Further limitations may be placed on construction progress by virtue of the physical aspects of design. The physical design plays a significant role in determining the sequence in which construction activities must be performed, sometimes leaving little flexibility in the construction process. Most constructors, however, would probably prefer a design which provides as much latitude as possible for planning and scheduling work activities. In contrast, such flexibility is seldom attained.

Structural materials to be used in the construction of plant facilities may or may not provide flexibility in construction sequence, depending on what materials are to be used and how they are to be incorporated into the structure. The following alternative building designs are provided as examples:

1. Consider a building for which design dictates that all walls and slabs be constructed of reinforced concrete, and provide direct bearing support for additional structural materials to be erected overhead. This design provides little

flexibility, since all walls and slabs on one level must be completed before work on subsequent levels can commence.

2. Now consider a design which employs a structural steel framing system and interior shield walls which are to be constructed of cast-in-place concrete. This design provides a considerable amount of flexibility, since framing operations can continue independent of interior concrete wall erection. In addition, many interior walls can be erected following installation of certain equipment and piping systems, therefore enhancing constructability.

As implied, design can strictly limit the flexibility of the construction process by forcing dependence among work activities. Such is the case for the reinforced concrete building proposed in the above cited example, whereby failure to complete a single wall can result in delayed construction of successive levels. If critical activities are involved, an extension of the construction schedule may result.

2.2.3 CHANGES REQUIRED DURING CONSTRUCTION

Design changes that are required during construction can be particularly disruptive, often resulting in costly delay. The amount of delay experienced can vary considerably, depending upon the extent and nature of the change and when the need for the change is recognized. The sources of design change are many. One project organization revealed

that, for the project in question, 40% of the changes were due to regulatory requirements; 35% were requested by the utility; 10% were engineering initiated; 10% were contractor requested; and the remaining 5% were requested by vendors. (App. A:65)²

M. M. Fitch of Brown & Root, Inc. has listed the "inability to define and freeze the design and physical scope of the plant prior to commencement of construction" as a major barrier to shortening nuclear power plant construction schedules. (3:2) As changes continue to occur during the construction phase, the schedule can be seriously jeopardized. With any type of change, some delay may be experienced while all necessary modifications to drawings and specifications are made and approval is granted. Such modifications, for example, may be required to correct errors in design. If errors of this nature are encountered by the constructor in the field, it may be found necessary to disassemble or tear out already completed work in order to implement the change. In other cases, it may be necessary to backfit successfully completed work due to changes requested by the utility or made mandatory by the Nuclear Regulatory Commission (NRC). In addition, when design modifications call for new or revised equipment to be installed, further delay can be incurred while lengthy procurement cycles are being carried out. Delays of this nature can be quite costly when, for example, forged components are involved.

Changes are difficult to cope with even when initiated prior to field implementation of the design. But when changes must continue to occur throughout the construction process, the project schedule can be

2. Page 65 of Appendix A

significantly affected.

2.3 DESIGN FOR CONSTRUCTABILITY

2.3.1 SPACIAL CONFLICTS

The construction of a single-unit, 1100 MWe nuclear power plant may require the incorporation of 250,000 to 350,000 L.F. of piping, 2,500,000 to 4,000,000 L.F. of power and control cable, and 325,000 to 550,000 L.F. of conduit. (1:63) In addition, reinforcing steel is a major constituent of plant facilities. The A-E is charged with the responsibility of determining the intricate patterns to ultimately be assumed by massive quantities of materials. Space limitations further complicate this task.

Nonetheless, it is the responsibility of the design team to generate drawings and specifications which will promote uninterrupted flow of construction operations. As one might expect, however, significant problems can be encountered when undetected design interferences are forwarded to the field. It is not uncommon for construction workers to encounter spacial conflicts among permanent materials during on-site execution of the design. For example, as relayed to the field, design may dictate that two components occupy the same space. Another example might be material connections that can't possibly be accomplished as designed.

Interferences such as those mentioned above will most assuredly result in delay, since conflicts must be resolved and revised blueprints must be made available in the field. In some cases, additional delay can be experienced if extensive backfitting is required to adequately resolve

the problem. In any event, the failure to uncover design inconsistencies prior to construction can result in an extended project schedule.

2.3.2 PLANT LAYOUT

At the onset of the design phase, considerable thought must be given to the relative arrangement that is to be assumed by permanent plant facilities. The failure to consider constructability can often result in havoc during the construction process. The layout which is adopted will play a significant role in determining what major construction equipment and methods must be employed. Equipment access and rigging requirements are often not adequately taken into consideration in the design phase, therefore requiring inordinate amounts of time and expense during subsequent stages of the project. In addition, if on-site modularization is to take place, inadequate space within the confines of the plant can result in inefficient working conditions.

A site which is hastily planned may experience low productivity. For example, a layout which does not allow for adequate storage of materials in the proximity of eventual use will result in the movement of men and materials over greater distances. Consequently, less time can be spent on productive work.

Problems can also arise when inadequate access is provided for transportation of major pieces of permanent equipment (e.g., turbines) to where they are to be ultimately lifted into position. The same applies when off-site modularization is employed.

The cost of land is high. An overabundance of space will also require additional lengths of interconnecting materials, along with all

of the costs and time associated with installation. The problem, however, is not only the lack of space, but also the need to make the most effective use of what space is available.

2.3.3 INTERFACE BETWEEN CONTRACTORS

Another factor which can draw from the efficiency of day-to-day operations is the requirement that contractors work closely together during construction activities. This problem can arise as a result of the way in which bid packages are formulated. For example, if embedded pipe and electrical conduit are the responsibility of one contractor, and reinforced concrete is the responsibility of another, inefficiency may occur, since embedments must be closely interfaced with rebar placement and formwork prior to concrete placement. In such instances, several contractors may be in competition for the same space, which makes all tasks involved more time consuming and difficult to perform.

2.3.4 DESIGN TO SUPPORT PREASSEMBLY

Some representatives of the nuclear industry have expressed the view that insufficient design effort has been directed toward promoting the use of modularization in nuclear power plant construction. Modularization has been defined as preassembly of components at either a manufacturing facility (shop modularization) or preassembly of components at or near a plant site location (site modularization). (8:8.54)

Table 2.1 provides a list of such components which are believed amenable to preassembly (8:8.55):

Table 2.1

Potential Preassembled Construction Modules

1. Containment and Pool Liners	8. Cable Tray Modules
2. Reinforcing Steel	9. Polar Crane Supports
3. Precast Concrete	10. Primary Loop Piping
4. Structural Steel w/Attachments	11. Pretubed Condenser
5. Pipe Racks w/Pipe	12. Cable Installation
6. Pipe Modules	13. Large Tanks
7. Skid Mounted Modules	

While a given module is being preassembled, either on- or off-site, preparation could be made for installation of the module. Reduced field installation time could, therefore, be reflected in a shorter project schedule.

2.3.5 STANDARDIZATION

Concern has been expressed in recent years over the nuclear industry's reluctance to fully examine the potential benefits of standardization in nuclear power plant design. Earl Bourque of Ebasco Services, Inc. has stated, "The advantages of standard plants and standard components have been touted by many, but experience is limited. Therefore, the true savings that can be realized from standardization is not known. All of us know that it's got to be there, but no one is sure enough of the magnitude of savings to do a good job of selling the concept". (8:8,36)

Numerous papers have addressed the possible benefits to be derived from standardization of nuclear power plant design. W. W. Gartman of C. F. Braun & Co. and D. B. Weaver of The Tennessee Valley Authority view construction as a major area of time and cost reduction. (4:1) It has been proposed that the principal savings to be realized by utilities during construction will result from reduced field labor requirements.

"The labor savings will stem directly from the use of proven designs that have already been used in nuclear power plants. To emphasize this point, there has been considerable discussion in the last few years of the construction benefits that may be realized from modeling nuclear plants. With sequential construction of standardized plants, there are in effect full-scale or 1:1 models to use for planning the follow-on plants." (4:9)

2.4 DESIGN-CONSTRUCT COMMUNICATION

Another factor which can hinder efforts to shorten nuclear power plant construction schedules is the failure to establish proper channels for communication between design and construction teams. Aside from the timely receipt of drawings and specifications, as construction becomes more complex, traditional orthographic drawings become less adequate. (7:30) Serious problems can arise when design intentions are not thoroughly understood in the field. Considerable expense can be incurred, since it may be necessary for crews to sit idle while misunderstandings are being cleared up. "Similarly, written specifications are continuously subject to ambiguity and misinterpretation. Example consequences are pipes and ducts with impossible penetrations, etc." (7:30)

Design-construct communication is also important for resolution of previously mentioned problems that may be encountered in the field. For example, a considerable amount of time can be lost if prompt action is not taken to resolve design inadequacies such as spacial conflicts and the like. In addition, field crews must be immediately notified of all changes made to the design, so as to minimize costly backfitting.

Boyd C. Paulson, Jr. of Stanford University has stated, "Regardless of contractual approach, there continue to be communication barriers between engineering design and field construction". (7:26) Such barriers can only result in reduced efficiency of construction operations.

2.5 SUMMARY AND CONCLUSIONS

The purpose of this section was to present the major design-related areas which can impact upon the efficiency of the construction process. Discussion of the design-construct interface centered around design scheduling, constructability, and communication. Design can have a significant effect on the flexibility of the construction sequence. The untimely flow of drawings and specifications will reduce the efficiency of field operations, and of course, design changes can be costly in terms of both time and money.

The design which is adopted will substantially impact constructability. Spacial conflicts which go undetected can have definite detrimental effects in the field. The importance of permanent plant layout is gaining rapid recognition, as are the potential benefits to be derived from greater acceptance of modularization and standardization in nuclear power plant design.

It is believed that substantial improvement could be realized through a design effort which is more responsive to the problems encountered during the construction phase.

Section 3

CONSTRUCTION MATERIALS AND METHODS

3.1 INTRODUCTION

Since the first nuclear power plant was completed in 1957, the nuclear industry has experienced significant change. As a result of rapidly diminishing energy supplies, coupled with increased energy consumption, the United States has become increasingly dependent upon the nuclear industry to satisfy demands for electric power. In order to meet these demands, utilities have found it necessary to construct larger, more complex nuclear power units. The nuclear industry, however, has experienced serious problems associated with the permanent materials which must be incorporated into nuclear power plant facilities. Some of these problems have been common to the construction industry, in general, for many years. Others have emerged as a result of government-imposed regulation of nuclear affairs, and are peculiar to the nuclear construction industry.

The evolution of present day super-projects such as nuclear power plants has caused growing concern over the adequacy of current methods of layout and execution of construction operations. The construction of a nuclear power plant requires that many individual operations, involving hundreds of workmen, be carried out in relatively confined areas. Construction methods, as well as the layout of temporary jobsite facilities, can have a significant effect on the efficiency of the entire construction operation.

The following subsections present what are believed to be major areas of concern associated with construction materials and methods.

3.2 CONSTRUCTION MATERIALS

3.2.1 SELECTION OF PERMANENT MATERIALS

An important decision to be made in the early stages of a nuclear power plant project is what permanent materials should be used in the construction of plant facilities. Two major time-related factors which must be carefully considered in making this decision are:

- (1) the anticipated availability
of various materials
- (2) the relative time and effort
associated with the installation of the proposed materials
in the field

The choice of concrete versus steel for use in the structural support system of the reactor or turbine building will illustrate the impact of the above factors. The availability of concrete for use as a structural material is much better than is the availability of structural steel. However, the erection of a structural steel support system requires considerably less time and less manhours than does the concrete structural system.

There are many similar material choices which can be made throughout the early stages of a project for which the same situation applies. It is believed that much time can be saved during actual construction given that appropriate decisions are made on materials to be used.

3.2.2 QA/QC REQUIREMENTS

During the latter 1960's as nuclear power plants became larger and

more prevalent, the need was recognized for the enactment of rigid QA/QC programs into the nuclear construction industry. In March of 1969, the Atomic Energy Commission (now the Nuclear Regulatory Commission) published Appendix B to Title 10 of the Code of Federal Regulations, entitled "Quality Assurance Criteria for Nuclear Power Plants". This document established the basic requirements and responsibilities of the applicant (usually a utility company) to develop QA/QC programs on nuclear power plant construction projects. As defined in Appendix B, "quality assurance comprises all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. Quality assurance includes quality control, which comprises those quality assurance actions related to the physical characteristic of a material, structure, component, or system which provide a means to control the quality of the material, structure, component, or system to predetermined requirements". (10:10A.10)

Although the need for nuclear regulation has been generally recognized and accepted, the required degree of regulation has been the subject of continuous debate. Present QA/QC requirements have no doubt had a significant effect on the performance of constructors in the field. Work done in the field is governed by strict quality assurance codes which dictate performance levels that must be attained. Materials manufactured on the jobsite must meet particularly high levels of quality, levels that are, in fact, much higher than those required of comparable materials used in non-nuclear areas of the construction industry.

Constructors must also work within rigid tolerances which allow

virtually no variation from engineering specifications. Physical and engineering aspects of plant materials (e.g., size, spacing, and strength requirements) must be achieved precisely as dictated by specifications. For example, placement of reinforcing steel prior to concrete pours is subject to considerable inspection to assure that the arrangement and spacing of bars reflects exactly what specifications dictate. Welded splices used in the erection of reinforcing mats must satisfy rigid strength requirements, as do welds used in the fabrication of piping systems and the like. Concrete mixes to be used in power plant structures are also scrutinized. Rigid tolerances for such mix properties as compressive strength, slump, air content, and temperature must be satisfied.

In order to assure that required levels of material performance have been achieved, demanding quality control procedures must be implemented. Some representatives of the nuclear industry have expressed the need for re-evaluation of current requirements for material testing. The first question to be asked might be whether the extent to which testing is now required is actually necessary to assure compliance with the codes and specifications. Many people from industry do not think so. In addition to the direct cost of performing the tests, a considerable amount of time can be consumed, since items of work under investigation must be discontinued while tests are being conducted.

Of particular concern are the costly destructive testing methods presently being employed. For example, a survey of two nuclear projects revealed that of 1400 cadweld splices tested for tensile strength, only one failed to meet the required standards. The one joint that did fail

was stronger than the reinforcing bar and only two percent below the acceptable standard. (5:4) Nonetheless, in order to perform such tests on 1400 welds, it is necessary to destroy spliced joints which have already been incorporated into the reinforcing network. Once the joints have been removed for testing, it is then necessary to redo these work items. To further add to the amount of work involved, each weld originally removed must be replaced by two similar welds. As implied by the above cited example, such testing methods can result in the unnecessary destruction of acceptable work, which in turn increases the amount of work that must be performed.

The documentation requirements for QA/QC is another source of construction delay. This documentation is required as evidence that all QA/QC standards and procedures have been satisfactorily accomplished. Although the need for proper documentation is evident, again it might be questioned whether the amount of documentation currently required is indeed necessary. For example, one respondent to the study revealed that the painting of one bolt for the reactor required seven pages of documentation. The painting subcontractor's supervisor said he spent 75% of his time providing the necessary paper work, while this time may amount to 10% on non-nuclear projects. (App. A:68) Every weld and every foot of pipe and wire must be documented from manufacturer through receipt, installation, and final approval. For example, records from the Limerick nuclear power plant project indicate the location of every large pipe weld in the plant, the name and qualifications of the welder that made it, and the origin and chemical and physical properties of the welding rod used. (9:4.4)

The following table is provided to emphasize the abundance of documentation that must be generated in the field (12:164):

Table 3.1

Total QA/QC Documentation Required at Three Mile Island Unit 2

<u>Group</u>	<u>No. of Documents</u>
QC documents generated in field	
- Structural	44,000
- Electrical and Instrumentation	2,100
- Mechanical	1,260
- Piping	23,000
EDR/ECM's	14,300
General Surveillance	11,100
Estimate to complete	80,000
	<hr/>
TOTAL	175,760

Average pages per document = 3; Total number of pages = 527,280 (field)

The time lost while producing such overwhelming amounts of documentation is a major concern of industry. Work must often be ceased while proper documentation is being generated and approval is being granted for each step in the construction procedure. When one considers that literally hundreds of thousands of records are accumulated prior to plant startup, not to mention the records generated during operations, the concern may be well founded.

Changes in QA/QC requirements have also had a serious effect on the ability of constructors to perform satisfactorily. During the last

few years, there has been an avalanche of new and revised codes and standards governing material performance. Important changes and additions have been made to Section III of the ASME Boiler and Pressure Vessel Code. Roughly 1000 new and revised codes and standards applicable to nuclear power plants were issued during a three year period from August, 1973, to August, 1976. In addition, the ANSI N.45.2 Standard on Quality Assurance is being continually expanded upon by an extensive series of daughter quality assurance standards. (3:3)

Consequently, designers and constructors, not directly involved in writing the codes, have experienced increasing difficulty in keeping up with the continual expansion and modification of quality assurance requirements. Perhaps the most costly outcome is the effect that such changes can have on work already in place, since NRC inspectors have generally expected work to conform to additional standards as they are published. It may, therefore, be necessary to backfit work that is rendered unacceptable by new codes. This backfitting requirement can be especially costly when it involves such massive items as reinforced concrete and the like, which was the case on one nuclear power plant project visited.

Changes such as those described above are difficult to cope with even during the early phases of a project. But when QA/QC requirements continue to change during the latter phases of construction, the schedule can be seriously jeopardized.

3.2.3 AMOUNT OF PERMANENT MATERIALS REQUIRED

A factor which has significantly impacted construction schedules

is the quantum increase that has been experienced in the amount of material required for construction of a nuclear power plant. Aside from plant complexity, there is simply more material that must be placed in the field. To a great extent, increased material content can be attributed to rapid advancements in plant generating capacity, which have required that larger and more numerous facilities be built. Regulatory requirements have also been responsible. For example, increased seismic requirements are reflected in thicker, more heavily reinforced concrete walls and base mats. Concrete placement rates can be significantly affected by high concentrations of reinforcing steel. In addition to having more steel to place, placement of concrete mix around tightly woven reinforcing mats can become extremely cumbersome.

Other design requirements have been responsible for requiring multiple backup systems for most mechanical and electrical systems in the plant. This factor has greatly increased the quantities of materials required. For example, a few years ago a lighting system in a power plant might have looked similar to the conventional system illustrated in Figure 3.1. The conventional system involves a simple power source, switch, light and protective fuse. Figure 3.2, on the other hand, illustrates a safety-related system such as might be found in a nuclear power plant today. In addition to the conventional requirements, the safety-related system employs a second switch and light coupled to a separate power source. Also included are emergency generators as backup to each system and a battery as a final backup. Even this description fails to convey the complexity of the wiring required to produce a light in a nuclear power plant. When one considers that this type of approach

Figure 3.1 Conventional Lighting System (11:19.23)

Figure 3.2 Safety-Related Lighting System (11:19.24)

must be taken for nearly all aspects of construction, the enormity of the problem can be appreciated.

Plants going on line in 1979 have up to 25% to 39% more manhours planned per KWe than plants that were scheduled for completion in 1972-73. For example, two plants completed a few years ago required 7.5 and 8.15 construction MH/KWe respectively, compared to an estimated 11.0 MH/KWe for a plant to be completed in 1979. (1:63) Although a great number of variables are responsible for these differences, increased material content is believed to contribute significantly.

There is no question as to the essential role of quality assurance in assuring public health and safety. One question that has been raised, however, is whether these extreme quantities of material are indeed necessary to provide a "safe" nuclear power plant. Some representatives of the nuclear industry do not believe so, but instead regard many of these requirements as causes of unnecessary over-design.

In conclusion, it is evident that the sheer abundance of materials that is required for construction of a nuclear power plant has a substantial impact on schedule length. What is not so evident is that the resultant plants are indeed correspondingly safer.

3.2.4 AVAILABILITY OF PURCHASED MATERIALS

Another factor which has hampered the progress of nuclear project schedules is the non-availability of purchased materials. Like other facets of the construction industry, the nuclear field has experienced difficulty in obtaining such materials as large valves and castings. The nuclear industry, however, must contend with other factors not found

elsewhere in construction. For example, QA/QC requirements have affected material supplies. Many otherwise capable manufacturers are unable to compete in the nuclear industry due to their inability to cope with strict QA/QC standards and procedures. Other suppliers have simply chosen not to become involved in nuclear-related production due to the amount of effort required. This is especially true if these manufacturers can do business elsewhere.

Other factors result in a reluctance on the part of manufacturers to stock nuclear-related lines. For example, manufacturers have experienced considerable variability among product requirements requested by the utilities. In part, this variability is a result of differing interpretations of unclear QA/QC requirements. Product requirements also differ from plant to plant by virtue of differences between design organizations employed, i.e., design experience, professional judgment, methods of design, etc. Suppliers have found it difficult to produce surplus components due to this non-standardization of product requirements.

The following points made by a nuclear material supplier summarize the major problems in specifications faced by the manufacturing segment of the nuclear industry as they attempt to meet the demand in a timely manner. Included are (5:7):

- (1) No common format
- (2) Unclear code references
- (3) Lack of concise wording that is familiar or common to the industry
- (4) Generalized statements

- (5) Generic or general references
to Federal Regulatory Guides
such as ANSI, ASME, etc.

Changes in regulatory requirements have also had an effect on material availability. Manufacturers are reluctant to stock nuclear-related materials which may be rendered obsolete due to non-compliance with new and revised codes. Consequently nuclear power plant construction schedules have been interrupted by extended leadtimes for procurement of badly needed materials.

3.3 CONSTRUCTION METHODS

3.3.1 WORK SITE ACCESSIBILITY

"The older generation nuclear plants, which were in the 400-600 MW range, were constructed in three to four years with a maximum site population of up to 1000 people. Present day nuclear stations in the 1100-1300 MW range under construction or in the planning stage will take six or more years to build with a site population of approximately 2500 people." (10:15.3) This dramatic increase in manpower requirement has come about as a result of substantial increases in plant size and complexity that have been experienced in recent years. Permanent plant facilities have become larger and more massive. The construction of a nuclear power plant now requires a greatly increased number of activities. The size and number of temporary work site facilities have also risen significantly.

Consequently, temporary work site layout has assumed an increasing role in governing the efficiency of construction operations. First

of all, the above mentioned advancements in nuclear power plant construction have placed serious limitations on space available to carry out work activities. Although the overall project site is generally quite large, most construction activity is concentrated around major structures such as the reactor building or screen house, resulting in what can be serious congestion problems.

Additionally, poor accessibility to a greatly increased number of temporary facilities can draw from the efficiency of the operation. For example, present day operations have become more dependant upon large open and covered areas for the storage of such materials as structural and reinforcing steel, pipe, cable and cable tray. Projects are also making greater use of laydown areas and fabrication shops for on-site fabrication of piping and rebar schemes. In addition, some projects employ on-site production of concrete. Heavy construction equipment has also assumed a greater role in present day operations; and, of course, there is a multitude of offices, shops, and testing facilities.

Consequently, the layout of these facilities to promote accessibility has become increasingly important, yet difficult to attain. In view of the magnitude of work involved in the construction of a nuclear power plant, the inefficient layout of temporary work site facilities can significantly impact the construction schedule.

3.3.2 APPROACH TO METHODS IMPROVEMENT

The major problem associated with construction methods lies not in the adequacy of the methods that are currently being employed. That is to say, these methods have been employed quite successfully, most for

many years. Rather, it is felt that the problem is the lack of a formalized approach to the development, evaluation, and implementation of new methods that could possibly prove more cost- and time-effective than current practices.

It has often been said that the construction industry continues to employ the same methods today as were used many years ago, the only difference being that construction equipment is now made much bigger. In a recent keynote address at the Pennsylvania State University, Earl Bourque of Ebasco Services, Inc. stated, "It is my judgment that we have only scratched the surface of innovative techniques which could be developed to improve the construction processes... Too many times I'm sure we lull ourselves into complacency by simply being content with the way it was successfully done on the last job. We are not willing to gamble the time and money necessary now to be cost-effective tomorrow". (8:8.35)

Some of the new methods which have been developed in the nuclear field have contributed substantially to reducing costs and schedules. To mention a few (8:8.35):

1. The slip forming of nuclear shield walls has resulted in a substantial reduction of the overall schedule.

2. In another instance by moving a crane and knuckle radius plates into a reactor building, work on the erection of the steel containment was able to proceed while the containment guy derrick was being erected.

3. "Tops" off construction of a reactor

building was made feasible by the installation of a temporary insulated metal barrier below the dome to permit stress relieving before erection of the dome.

It is believed that the continued development of innovative construction methods could prove quite effective in reducing nuclear power plant construction schedules.

3.4 SUMMARY AND CONCLUSIONS

The purpose of this section was to address the major problems associated with construction materials and methods which serve as barriers to shortening nuclear power plant construction schedules. Discussion of permanent materials began by stressing the importance of material selection. Availability of materials has placed limitations on construction progress, as has the amount of materials now required for construction of a nuclear power plant. And finally, QA/QC requirements have also played a significant role in stretching construction schedules.

The evolution of present day super-projects has caused growing concern over current construction methods. Work site layout has also received greater attention in recent years.

Altogether, the above mentioned factors are believed to have a significant effect on the length of nuclear power plant construction schedules. It is further believed that improvement can be made through research in the areas of construction materials and methods.

Section 4

CONSTRUCTION COORDINATION AND COMMUNICATION

4.1 INTRODUCTION

The sheer magnitude of work involved in the construction of a nuclear power plant has placed extreme importance on coordination and communication among principle project teams. Control of the construction process is characterized by an inundation of data and information. To assure compliance with the construction schedule, project teams must be aware of all information that affects their performance. For example, it goes without saying that information pertaining to schedule control is a concern of everyone associated with the project. Cost control is of utmost importance on present day projects costing as much as one billion dollars. In addition, material control information is mandatory to assure that quality materials and components are available when required in the field. All matters pertaining to quality control must be thoroughly implemented and documented. It is also essential that all information pertaining to changes in the work be recognized and disseminated promptly.

Considering the amount of information that must be manipulated throughout the construction process, it is understandable how some project organizations could experience costly coordination and communication problems. It has been proposed that the organizational structure employed on a nuclear power plant project may, in part, be responsible for inefficient coordination and communication efforts leading to extended construction schedules. Concern has also been expressed over the growing need for technical and managerial personnel who have the necessary

skills and training to manage present day projects.

The type of contract arrangement established between the utility and the A-E and/or constructor may also be responsible for excessive schedule length. It has been argued that the cost plus type contracts employed on most nuclear power plant projects do not provide sufficient incentive for design and construction teams to perform in the best interest of the utility.

The following subsections present what are believed to be major areas of concern surrounding coordination and communication on nuclear power plant construction projects.

4.2 SHORTAGE OF SKILLED TECHNICAL AND MANAGERIAL TALENT

In view of the growing manpower requirements for nuclear power plant projects, some representatives of industry appear to feel that one of the most critical problems facing many sectors of construction is a future shortage of skilled technical and managerial talent. (7:19) In addition, some industry people have expressed a greater need for highly qualified personnel on nuclear projects currently underway. For example, it has been noted that increased quality assurance requirements has created the need for larger numbers of skilled technicians, particularly in the non-destructive testing and other inspection areas. In addition, owing to the magnitude of present day projects, there is a need for highly capable supervisors who can plan and schedule the work, and who have the necessary management skills and training to manage the project in such a way that the schedule does not suffer. (7:20) One subcontractor reported that, although top supervision of Owners, A-E's, CM's, and Con-

structors was rated as excellent, on-site construction management seemed to lack experienced personnel in the middle management levels. (App. B:98)

The sheer magnitude of present day projects may have an effect on the supply of highly capable personnel available for nuclear power plant construction. For example, it has been noted that managers of outstanding reputation on smaller projects may not be adequately equipped to manage a project as involved as a nuclear power plant. (7:23) In addition, owing to the duration of large projects, it may not be possible to get involved in a sufficient number of such projects to obtain well rounded experience. With regard to management and technical personnel alike, there is concern over the amount of time required to adequately train and educate these people. Further research in this area could result in improvement, which in turn could promote greater efficiency in nuclear power plant construction.

4.3 EFFECTIVENESS OF PROJECT ORGANIZATIONAL STRUCTURE

In the broadest sense, the organizational structure for a nuclear power plant project may appear to be nothing out of the ordinary. In most cases, the project is financed by the utility, designed by either the utility or a consulting firm, and constructed by either the utility or a construction firm. However, due to the vast amount of work and the general complexity associated with such a project, specific tasks may be performed by a number of separate departments within different organizations. Typical departments which may be established on a nuclear power plant project are (App. C:145):

1. Licensing	11. Document Control
2. Civil Design	12. Civil Construction
3. Mechanical Design	13. Mechanical Installation
4. Electrical Design	14. Electrical Installation
5. Design Scheduling	15. Quality Control
6. Cost Estimating	16. Quality Assurance
7. Expediting	17. Modeling
8. Procurement	18. Warehousing
9. Manpower Estimating	19. Construction Scheduling
10. Cash Flow	20. Procurement Scheduling

If all activities are performed by the utility/owner (e.g., The Tennessee Valley Authority), coordination and communication among departments may be well established. Most nuclear power plant projects, however, do not fall under this category, but instead employ at least two organizations, the utility and a designer-constructor. Many projects employ separate design and construction firms. Further complications may arise due to the temporary nature of most project organizations which requires that problems in coordination and communication be ironed out once the project has commenced. In such cases, it is understandable how the development of an effective organizational structure becomes increasingly important, yet difficult to accomplish.

Reporting the results of a workshop sponsored by The Stanford Construction Institute, Prof. Boyd C. Paulson, Jr. of Stanford University stated, "Construction generally has a project-type organization with typical matrix organization problems. There is a need for a better under-

standing of how project structures should change for different kinds of projects". (7:24) Nuclear power plants represent a relatively new breed of super-projects with peculiarities (esp. magnitude) that set them apart from other industrial and commercial projects. The question is whether traditional organizational methods used on smaller projects can be effectively employed on nuclear power plant projects. "...Many companies are finding that existing organizational structures cannot adequately cope with growing needs." (7:20)

Coordination and communication on nuclear power plant projects can be very cumbersome due to the sheer number of personnel involved. For example, a two unit, 2200 MWe plant such as the Susquehanna plant requires about 400 full time home office engineering and support personnel, and as many as 400-500 field office administrative and supervisory personnel. (9:4.3) On such projects, it is essential that the authorities and responsibilities of each of these personnel be clearly established. In addition, all necessary channels to be used for the dissemination of information must be properly established and taken advantage of to insure that all personnel are fully aware of all that affects their performance. In conclusion, it is believed that sub-optimal organization of project structures is, in part, responsible for the length of nuclear power plant construction projects.

4.4 PROJECT CONTROL METHODOLOGY

The sheer magnitude of work involved in the construction of a nuclear power plant has made essential the development and implementation of effective methods of project control. Such control is largely

based upon extensive data and information which must be manipulated throughout the construction process. It has been noted that, "In both volume and content managers often have difficulty absorbing, let alone applying, information provided to them, sometimes are overwhelmed by it, and frequently must manage in spite of analytical models and systems". (7:27)

Although the need for effective schedule control methods is universally accepted, there have been differing thoughts as to what constitutes the best method. The development and implementation of methods and procedures for scheduling has been subject to considerable re-invention from one project organization to another. As one constructor noted, "The point I would like to see researched is the optimum scheduling process. I'm sure all of us have our own ideas of the best method of scheduling, but somewhere there has to be an optimum schedule which may well be a combination of systems. To what degree of detail should schedules be developed and what types of people are best suited to develop them?" (8:8.37)

Material control is another area which requires serious attention throughout the course of a project. Costly delay can result when materials are not available in the field when needed. This requires extensive monitoring from design through procurement. Material control continues to be important once the procurement cycle is completed. For example, it has been noted, "Time studies on construction projects have proven that an unbelievable amount of time is wasted by craftsmen either waiting for or fetching material". (8:8.36)

In recent years, the nuclear industry has found it necessary to direct considerable attention toward quality control of power plant construction. Some organizations, however, have experienced difficulty in developing and implementing effective quality control programs which can satisfy the rapid growth of nuclear regulation. Regulation requires documentation of literally everything related to the design and construction of a nuclear power plant that could potentially be associated with public health and safety. "Millions of documents are involved for each plant, and associated with them are periodic revisions, cross-referencing, retrieval, refiling, and security systems to preserve the records." (13:48) This requirement has placed an additional burden on utilities, A-E's, and constructors while attempting to effectively control the project.

Design changes represent another source of information which requires a considerable amount of effort to control. Regardless of the source of the changes, it is to everyone's benefit to respond promptly and implement changes in the most expeditious manner. The manner in which changes are implemented in the field will determine how much delay, if any, will result.

4.5 CONTRACTUAL INCENTIVE

On nuclear power plant projects, contractual arrangements for employment of design and construction services are usually some variation of the so called time-and-material or cost plus contract form. Engineering design services are usually engaged on a professional basis. The Architect-Engineer (A-E) is reimbursed for all expenses, including salaries, materials, etc. plus a markup to cover employee fringe benefits,

taxes, insurance, office space, etc.

Payment for construction services is, also, usually established on a cost plus basis. The constructor is reimbursed for all direct costs incurred, including material and equipment purchases, payment to subcontractors, the cost of operating field office facilities, plus wages and fringe benefits for non-manual field office personnel and manual craftsmen. Usually a markup is applied to the non-manual personnel wages only. (9:4.12)

It has been argued that the use of traditional cost plus type contracts for nuclear power plant projects (as well as other types of projects) can have a marked impact on construction schedules. The defense of this argument is that there is little incentive for A-E's and/or constructors to work most efficiently to keep cost and time requirements to a minimum, other than consideration of company reputation.

The contract type which perhaps provides the most incentive to the contracting company is the fixed price contract. Although a few nuclear projects have successfully employed a fixed price contract, design and construction firms have been reluctant to undertake such arrangements on nuclear power plant projects due to the extreme amount of uncertainty surrounding cost and time requirements for plant completion. Utilities have been equally reluctant to adopt fixed price arrangements due to the high bid prices that A-E's and constructors must submit in order to assure success on such a risky undertaking. The utilities have, therefore, found it necessary to assume the major risk associated with the project, and at the same time, experience possibly unnecessarily long construction schedules.

4.6 SUMMARY AND CONCLUSION

The purpose of this section was to address the major problems associated with coordination and communication which serve as barriers to shortening nuclear power plant construction schedules. One such problem appears to be a lack of skilled technical and managerial talent qualified to meet the growing demands of the nuclear industry. With the evolution of present day super-projects, it has been questioned whether traditional project organizational structures used on smaller projects can be effectively employed on nuclear power plant construction sites. Project control has also become extremely important as a result of increased project magnitude. Serious problems can be encountered while attempting to effectively control information pertaining to scheduling, materials, quality, and changes. With rapidly escalating construction costs, attention has also been directed toward incentive provided through current contractual relationships, which are generally some form of cost plus.

Section 5

MANPOWER AVAILABILITY AND PRODUCTIVITY

5.1 INTRODUCTION

Perhaps most often cited for disruption of nuclear power plant construction schedules are factors pertaining to manpower. Figure 5.1 illustrates the total manpower requirements for single-, double-, and triple-unit plants having a generating capacity of 1150 MWe per unit. The figure shows that the peak manpower requirements for single-, double-, and triple-unit plants are 1500, 2400, and 3300, respectively. The cost of providing craft manpower has been reported to represent 30-35% of the direct capital cost for construction of a nuclear power plant. (8:8.2) In view of the above stated figures, it is evident that the availability and performance of manpower can have a sizable impact upon the cost and time requirements associated with nuclear power plant construction.

The remainder of this section is devoted to the presentation and discussion of the more significant manpower-related problems known to affect construction schedules.

5.2 MANPOWER AVAILABILITY

5.2.1 DEMAND FOR QUALIFIED MANPOWER

In recent years inflation and the recession have forced a substantial slowdown in the construction of new nuclear power plants. However, concern has been expressed over the adequacy of present manpower supplies in meeting future needs, should nuclear construction once again pick up. The magnitude of future manpower requirements is a matter of concern for labor leaders as well as management. Martin Ward, general president of

MANPOWER - NUMBER OF MEN

Figure 5.1 Total, year by year, craft manpower requirements for construction of typical one-, two-, and three-unit nuclear power plants having a capacity of 1150 MWe per unit (2:40)

the United Association of the Plumbing and Pipefitting Industry (UA), speaking at a nuclear energy industry conference stated that figures "show that before the end of this century, the U. S. must build 700 new twin 1100 MWe power plants... Some 600 pipefitters and welders will be needed on each of those twin 1100 MWe units for five and six years at a time. So we are talking about scores of thousands of additional, highly trained building tradesmen". (14:18)

Nuclear power plant size has evolved from the small, single-unit plants of the early 1960's to the two- and three-unit facilities common today. Along with this advancement in size has come a substantial increase in the material content of a nuclear power plant. This increase in material content alone has played a significant role in the rising demand for qualified manpower.

Also responsible for the growing concern surrounding manpower supply and demand is the complexity that has accompanied the evolution of nuclear power plants. By virtue of this complexity and the ever-growing concern over quality assurance, the skill level required of craftsmen on nuclear construction sites is higher than that required by non-nuclear areas of the construction industry. Since not all craftsmen are of the required caliber, the nuclear industry must, therefore, compete with all other facets of the construction industry for those highly skilled craftsmen capable of meeting nuclear power plant standards.

Although manpower availability does not currently present a major barrier to shortening nuclear power plant construction schedules, there is concern over whether future needs will be met satisfactorily. Advancements in the nuclear power plant industry have placed an increasing burden

on existing manpower supplies to meet nuclear construction demands for highly skilled manpower. In order to meet this demand, it is believed that future research should be directed toward building the supply of, or decreasing the demand for, nuclear qualified manpower.

5.2.2 ABSENTEEISM

The effective supply of manpower on the project level is decreased by absenteeism among workers on nuclear power plant construction sites. One project organization reported an average daily absenteeism of 20 percent. This absentee figure rose to as high as 50 percent during cold or wet weather. (App. A:66)

Perhaps these values could be best expressed in terms of the number of workers involved. At the peak of the construction period, a nuclear power plant construction project may require the skills of some 2000-3000 laborers and craft personnel. In view of these manpower requirements, an average daily absentee rate of 20% results in an average of 400-600 workmen absent from work each day.

In the case of such high absentee rates, scheduled work must be carried out with a workforce which is substantially smaller than anticipated. The result is that production proceeds more slowly, which in turn can result in a longer construction schedule.

5.2.3 LABOR PRACTICES

Although the open shop philosophy has received growing recognition in recent years, a majority of the nuclear power plant construction done today can be attributed to unionized labor. One factor contributing to

increased time and cost of construction is labor strikes, which arise when labor and management are unable to come to an agreement concerning wages or conditions of employment. On a power plant construction project spanning a period of six years, there is the potential for about 100 work stoppages due to strikes, assuming every contract is renegotiated each year. (8:8.6) In the case of such work stoppages, the effective workforce on the construction site is cut abruptly, and some times severely.

Closely akin to the labor strike are jurisdictional disputes, which arise when two or more crafts claim responsibility for a given item of work. If a jurisdictional dispute results in a work stoppage, the resultant workforce is smaller than originally anticipated and required to satisfactorily perform the work. One nuclear power plant organization reported 55 work stoppages during a three year period, most of which could be attributed to jurisdictional disputes. (12:335)

While strikes and jurisdictional disputes may reduce the effective number of workmen on the jobsite, some labor agreements also require more workers on the job than management might believe to be necessary for a particular operation. Contract clauses, for example, may require an operator for certain pieces of automatic equipment, or wage-earning standby labor for such owner-furnished services as compressed air or electric power. Labor agreements may also include provisions which determine crew sizes and foremen-to-journeymen ratios, or limit the amount of off-site prefabrication which can be done. (8:8.16) While these factors may limit the effective labor force, it must be kept in mind that they are conditions which are agreed upon by labor and management. It must also be kept in mind how these factors have evolved over the years.

5.2.4 MANPOWER TURNOVER

A problem which can significantly affect the availability of manpower on large, longterm projects such as nuclear power plants is turnover. Manpower turnover refers to the number of persons hired within a period to replace those leaving or dropped from the workforce. For example, an analysis made by the utility representing a double-unit plant in a mid-Atlantic state revealed that 11,000 men had to be employed over a seven year period to achieve a peak manpower requirement of 2700. (8:8. 17) Another nuclear project organization in the southwest reported a turnover of 300% for carpenters, 400% for pipefitters, 350-400% for electricians, and 250-300% for ironworkers. (App. A:66)

Turnover rates of the magnitude given above not only increase the demand on manpower supplies, but also affect the continuity of the construction process. The construction schedule can be placed in serious jeopardy due to this continual need to hire new workmen to fill vacant positions.

5.3 MANPOWER PRODUCTIVITY

5.3.1 METHODS OF MEASUREMENT

Current literature often regards low manpower productivity as a major factor hindering efforts to shorten nuclear power plant construction schedules. In recent years, attempts have been made by management to boost manpower productivity. However, most have been futile. Much of the difficulty surrounding attempts to improve productivity arises because truly effective methods of measuring and evaluating productivity have yet to be developed.

Various methods of quantifying productivity have been employed, all of which have been unsatisfactory in one sense or another. For instance, one indicator of worker efficiency is the percentage of a work day's time that is devoted to direct work. However, this method gives no indication of how much work is accomplished (e.g., how much piping has been erected or how much wiring has been installed). Another efficiency indicator which has been used is the performance factor. A performance factor is the number of man-hours required to complete a unit of work. This method also has shortcomings, since a meaningful comparison of performance factors is dependent upon similar work conditions.

Too often, in hopes of getting a feel for current productivity, contractors will look to past job records for comparison. However, there are many variables associated with each construction project. Included in this variable list are such factors as type and location of the project and the materials employed, coupled with varying design considerations arising from the employment of different design teams. These and other factors make comparison with past jobs very difficult and often of little meaning.

5.3.2 IMPACT OF ABSENTEEISM

Presented earlier in this section was a discussion of the effect of absenteeism on manpower availability. An example was given of how absenteeism among workers on nuclear power plant construction sites could reduce the number of men present for work on a given day.

Original construction schedules are built, in part, around the assumption that a predetermined number of men will be required to perform

the necessary work. However, in anticipation of absenteeism, a greater number of workers are employed than may actually be required given complete workforce attendance each day. Consequently, on some days there may be more than the required number of workers present, and on others there may be too few.

Accordingly, productivity can drop sharply as a result of absenteeism. This drop in productivity can, in part, be attributed to the simple fact that optimum crew sizes cannot be maintained. When there are too few workers, it may be difficult, if not impossible, for those workers which are present to satisfactorily perform. In addition, since the same workforce is not present each day, the learning curve is not fully taken advantage of. In any event, reduced productivity can mean a longer and more costly construction schedule.

5.3.3 UNION VS. OPEN SHOP CONSTRUCTION

In recent years, utilities have experienced rapidly escalating construction costs. Of particular concern are cost increases associated with construction labor, since this area constitutes such a large portion of the total direct cost of a nuclear power plant. In an attempt to reduce labor costs, some utilities have begun to favor open shop operations. One reason for this shift is that the hourly wage rates associated with non-union labor are generally lower than those of its union counterpart.

In addition, greater attention is being directed toward claims of large productivity differences between union and non-union labor. It has been contended that such differences exist as a result of "restrictive" work practices employed by organized labor. (8:8.16) Some of these work

practices were mentioned earlier in this section, as they pertained to manpower supply and demand. Union control of work supervision has also been offered as a contributing factor, the argument being that divided loyalty may exist as a result of commitments to both the contractor and the union. (8:8.24)

The possibility of such productivity differences, however, has yet to be fully explored. Even by employing current methods of productivity measure, comparison is extremely difficult, since there exists no systematic collection of data for either open or closed shop construction.

5.3.4 IMPACT OF MANPOWER TURNOVER

Presented earlier in this section was a brief discussion of the effect of turnover on the availability of manpower. Examples were given to show how manpower turnover on nuclear power plant construction sites can counteract efforts of management to keep the required number of workmen on the job.

In addition to the effect on manpower availability, turnover can also significantly affect the continuity of the project. In part, this discontinuity results from declining productivity which accompanies turnover. With the occurrence of turnover, construction operations must be carried out by a workforce of lower than desirable efficiency. The constant need to hire new men results in a continual erosion of the learning curve. Familiarity with the job site and knowledge of procedures are lost. As new workmen are brought in to fill vacant positions, varying periods of low productivity are experienced while the required new-employee learning process takes place. The efficiency of the operation may be

eroded yet further since it may be necessary for workmen already familiar with the job to dilute their productive capabilities in order to help educate new members of the workforce. In turn, the decline of labor productivity on nuclear power plant construction sites due to manpower turnover can have a sizable impact upon nuclear power plant construction schedules.

5.3.5 IMPACT OF MOTIVATION AND MORALE

Another factor believed to contribute to low productivity on construction projects is the lack of motivation among workmen. For a number of reasons, insufficient motivation is particularly inherent in nuclear power plant construction work. One reason for this apparent lack of motivation on nuclear plant sites is the increasing role that QA/QC specifications have assumed in nuclear power plant construction. Due to the extent of regulation, the construction worker no longer has the control over his work that he is accustomed to on non-nuclear construction. Engineering codes dictate how the work must be performed and provide strict tolerances which must be satisfied.

Another factor contributing to poor motivation is the continual rush to get work done only to find that, in many instances, the work can not be inspected for a number of days. Since work cannot resume until after inspection, there may have been no need for expediting the work.

Also believed responsible for insufficient motivation on nuclear construction sites is the inability of the craftsmen to identify with the work. It is extremely difficult for workers to comprehend what they are actually building, let alone the importance behind the work. One reason for this inability to identify with the work is the way that new

workmen are introduced into the project knowing very little about what is involved. The phenomenal size of nuclear power plant projects also plays a significant role. While it requires an extreme amount of effort to construct a nuclear power plant, the responsibility charged to any one workman is minimal.

Work changes can also have a considerable effect on worker motivation and morale, especially when these changes involve ripping out and replacing previously completed work. This backfitting is required when work quality does not meet the standards set by rigid QA/QC specifications, therefore, rendering the finished product unacceptable. The constant evolution of new QA/QC codes and modification of existing ones present further complications, since guidelines for work acceptance may not be known at the time the work is performed.

5.3.6 IMPACT OF SCHEDULED OVERTIME

Scheduled overtime is also believed to have a significant effect on the productivity of manpower on nuclear power plant construction sites. An example of scheduled overtime might be the adoption of 10 hour work days rather than the standard eight hour work day. Another example might be the incorporation of an additional work day per week into the schedule, resulting in a six-day work week. Overtime schedules are sometimes adopted in an attempt to boost the total production associated with a given period of time. Additional work hours at overtime wage rates may also be used to attract qualified workers to the project.

Regardless of the nature of the overtime or the reason for its use, a serious argument can be brought up in opposition to the adoption of

scheduled overtime on a continual basis. Although little research has been directed toward the effect of work hours on labor efficiency, it has been argued that extended work hours can result in a significant drop in labor productivity. Productivity, in this context, refers to the quantity of work accomplished per unit of time (e.g., cubic yards of concrete per hour or lineal feet of pipe per hour).

An overtime schedule may be adopted, as previously mentioned, to increase the total production for a given period of time. It is believed, however, that in cases where scheduled overtime is adopted for extended periods of time, productivity may drop to a point where total cumulative production may be even lower than that experienced for similar work done over the same time span under a standard schedule involving a straight 40 hour work week. This is to say, a schedule incorporating additional overtime work hours may result in an even lower total production.

Scheduled overtime also results in higher labor costs, owing to the required payment of overtime premiums ranging as high as twice the normal wage rate. If scheduled overtime results in an increase in production for a given time period, increased labor costs may be warranted. These increased labor costs may also be necessary to draw the required number of qualified workers to the project. However, regardless of the amount of overtime cost incurred, a drop in total cumulative production can only result in an extension of the construction schedule.

5.4 SUMMARY AND CONCLUSIONS

The purpose of this section was to address the more significant manpower-related barriers believed to hamper the progress of nuclear

power plant construction projects. Manpower-related problems are believed to contribute substantially to the length of present day nuclear power plant construction schedules.

Pursuant to the discussion, manpower-related problems were presented in two parts. The first general topic addressed was manpower availability. The availability of qualified manpower can have a considerable impact upon job progress. The ability of management to man nuclear construction projects is affected by many factors, including the ability of current manpower supplies to meet growing demands. Advancements in the nuclear power plant industry have brought about significant increases in the material content and complexity of nuclear power plants. Labor turnover, absenteeism, strikes, and jurisdictional disputes are also known to affect the supply and demand for qualified manpower.

The second part of this section was devoted to manpower productivity. The lack of effective methods of measuring and evaluating productivity makes improvement of productivity very difficult, even though low productivity is believed to have considerable adverse effect on job progress. Factors known to significantly reduce manpower productivity include absenteeism, turnover, scheduled overtime, and the motivation and morale of construction workers. Much attention has also been directed toward claims of differences between union and non-union productivity. Such possible differences, however, have yet to be fully explored.

Experience has shown that with the nuclear industry's extreme dependence upon qualified manpower, any one of the above mentioned factors can be responsible for a costly extension of a nuclear power plant construction schedule. It is believed that a considerable amount of both

time and money can be saved through improvement of manpower availability and productivity.

Section 6

SUMMARY AND CONCLUSIONS

6.1 DESIGN-CONSTRUCT INTERFACE

Section Two of this report presented the major design-related factors which can impact upon the efficiency of the construction process. Discussion of the design-construct interface centered around design scheduling, constructability, and communication. Design can have a significant effect on the flexibility of the construction sequence. The untimely flow of drawings and specifications will reduce the efficiency of field operations, and, of course, design changes can be costly in terms of both time and money.

The design which is adopted can substantially impact constructability. Spatial conflicts which go undetected can have definite detrimental effects in the field. In addition, the way in which bid packages are formulated can result in several contractors competing for the same space. The importance of permanent plant layout is gaining rapid recognition, as are the potential benefits to be derived from greater acceptance of modularization and standardization in nuclear power plant design.

It is believed that substantial improvement could be realized through a design effort which is more responsive to the problems encountered during the construction phase.

6.2 CONSTRUCTION MATERIALS AND METHODS

Section Three addressed the major problems associated with construction materials and methods. The time and effort required in the field will, in part, be determined by the permanent materials selected

for construction of plant facilities. Availability of materials has placed limitations on construction progress, as has the amount of materials now required for construction of a nuclear power plant. In addition, QA/QC requirements have played a significant role in stretching construction schedules.

The evolution of present day super-projects has caused growing concern over construction methods currently employed. Work site layout has also received greater attention in recent years.

It is believed that significant improvement could be realized through research in the areas of construction materials and methods.

6.3 CONSTRUCTION COORDINATION AND COMMUNICATION

Section Four addressed the major problems associated with coordination and communication on nuclear power plant construction sites. One such problem appears to be a lack of skilled technical and managerial talent qualified to meet the growing needs of the nuclear industry. With the evolution of present day super-projects, it has been questioned whether traditional organizational structures used on smaller projects can be effectively employed on nuclear sites. Project control has also become extremely important as a result of increased project magnitude. Serious problems can be encountered while attempting to effectively control information pertaining to work scheduling, materials, quality, and changes. Due to rapidly escalating construction costs, attention has also been directed toward incentive provided through presently employed contractual arrangements, which are generally some form of cost plus.

It is believed that substantial time savings could be realized

through improvement of coordination and communication efforts on nuclear power plant projects.

6.4 MANPOWER AVAILABILITY AND PRODUCTIVITY

Section Five addressed the major manpower-related barriers believed to hinder progress on nuclear power plant construction projects. Manpower-related problems were presented in two parts. The first general topic addressed was manpower availability. The availability of qualified manpower can have a considerable impact upon job progress. The ability of management to man nuclear construction projects is affected by many factors, including the ability of current manpower supplies to meet growing demands. Advancements in the nuclear power plant industry have brought about significant increases in the material content and complexity of nuclear power plants. Labor turnover, absenteeism, strikes, and jurisdictional disputes are also known to affect the supply and demand for qualified manpower.

The second part of this section was devoted to manpower productivity. The lack of effective methods of measuring and evaluating productivity makes improvement of productivity very difficult, even though low productivity is believed to have considerable adverse effect on job progress. Factors known to significantly reduce manpower productivity include absenteeism, turnover, scheduled overtime, and the motivation and morale of construction workers. Much attention has also been directed toward claims of differences between union and non-union productivity. Such possible differences, however, have yet to be fully explored.

It is believed that substantial time savings could result from

research aimed at reducing the impact of barriers associated with manpower availability and productivity.

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VOLUME I SECTION 4

RESEARCH NEEDS
DESIGN/CONSTRUCT INTERFACING

By

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Note: This section, in draft form, has been written in partial fulfillment of degree requirements at Ohio State University. After review and comment the section will be rewritten to conform to the needs and organization of the final report. Note that chapter three of this draft will be included in Volume 1, Section 8 (Other Research Needs) of the final report.

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CHAPTER 1

INTRODUCTION

1.1 Subject of This Thesis

This thesis presents two segments of an interim report for a major study of delays in the construction of nuclear power plants. The first segment concerns delays associated with the interfacing of persons in design and other persons in construction. The second segment concerns delays which are not within the design/construct interface area. The major study is explained in the following section of this chapter. Topics included in the interim report are briefly described in Section 1.3. Topics excluded from the interim report are summarized in Section 1.4.

1.2 Purpose of the ERDA Study

The study of delays in the construction of nuclear power plants originated through the efforts of the Construction Research Council (CRC) of the American Society of Civil Engineers (ASCE). This council is one of a group of specialty research councils under the direction of the Technical Council On Research (TCOR) of the ASCE. The function of the CRC is to stimulate and foster research into the construction process. It does not itself act as a research contractor. The CRC brings together people who have research needs with people capable of doing the research.

The CRC identified the United States Energy Research and Development Administration (ERDA) as a group with research needs in the area of nuclear power plant construction. Consequently, the CRC formulated and

proposed a four phase plan for stimulating research in this area:

1. Phase I - Conduct studies aimed at identifying the major problem areas and research needs;
2. Phase II - Conduct a dissemination conference to make these research needs known to prospective researchers;
3. Phase III - Perform research to solve the problems associated with the major areas identified in Phase I;
and
4. Phase IV - Test the solutions suggested in Phase III by application in pilot demonstration projects.

ERDA subsequently agreed to sponsor the first phase of study as proposed by the CRC. The research reported in this thesis is a portion of this ERDA supported study.

Phase I is composed of two parts. The objective of Part One is to identify and codify the barriers to shortening nuclear power plant construction schedules. The objective of Part Two is to identify the research needed to minimize or eliminate the identified barriers.

The organization formed to perform the Phase I research consists of one prime contractor and four subcontractors. The Ohio State University is the prime contractor. The subcontractors are Clemson University, The Ohio State University, The University of Texas at Austin, and the Kellogg Corporation. The subcontractors were selected on the basis of the varied interests and expertise of their investigators, and the need for

total geographic coverage of the continental United States. Figure 1.1 illustrates the geographic division of subcontractor responsibilities.

In Part One of this project, the barriers to shortening construction schedules were identified by the subcontractors through meetings, interviews, studies, and other means. These barriers were then classified into four major generic problem areas: 1) Design/Construct Interface; 2) Construction Methods, Equipment, and Materials; 3) Construction Coordination and Communication; and 4) Manpower and Productivity.

In Part Two, the subcontractors divided the responsibility for identifying research needs in the generic problem area. The Ohio State University was responsible for research in the Design/Construct Interface area; Clemson University was responsible for the Construction Methods, Equipment, and Materials area; the Kellogg Corporation was assigned to the Construction Coordination and Communications area; and the area of Manpower and Productivity was the responsibility of The University of Texas at Austin. The subcontractors also shared responsibility for identifying "Other Specific Research Areas" which are not included in the four major generic divisions.

1.3 Topics Included

This thesis presents an interim report of the research needs associated with the Design/Construct Interface and other specific areas in nuclear power plant construction.

The Design/Construct Interface which is addressed in Chapter 2 deals with the design related factors which impact the construction process. The problem areas discussed are: 1) Plant Layout to Facilitate Construction; 2) Constructability Review in Design; 3) Plant Standardization; 4) Modularization; 5) Modeling; 6) Design Changes During Construction;

Figure 1.1 Geographic Coverage by Subcontractor

7) Design Communication; 8) Computerized Design; and 9) Design Scheduling for Constructability.

Chapter 3 addresses other problem areas: 1) Plant Siting; 2) Cash Flow; 3) Economies of Scale; 4) Disaggregation; and 5) Transferability of Macro Management Methods.

In Chapters 2 and 3, the presentations concerning problem areas include a problem statement, a discussion of the importance of the problem area, and one or more research topics. Each of these research topics is presented in a standard five part format: 1) Problem Statement; 2) Importance; 3) Research Approach; 4) Anticipated Results; and 5) Implementation/Cooperative Parties.

Chapter 4 includes a summary and recommendations concerning future research.

1.4 Topics Excluded

This thesis will not address the following portions of the overall research effort:

1. Part One, which identified and codified the barriers to shortening construction schedules; and
2. The research needs associated with the generic problem areas of Construction Methods, Equipment, and Materials; Construction Coordination and Communication; and Manpower and Productivity.

It is emphasized that this thesis does not constitute the final report to ERDA but rather it is an interim report of a portion of the study of delays in nuclear power plant construction.

CHAPTER 2

THE DESIGN/CONSTRUCT INTERFACE

2.1 Introduction

The Design/Construct Interface refers to those activities which overlap from the design process into the construction process and vice versa. It includes design related actions which impact construction, such as the determination of the plant layout. It also includes construction functions which impact the design process, such as the construction methods to be employed. Most importantly, the Design/Construct Interface refers to the interaction among design personnel and the construction force throughout the project duration.

In the following sections, nine problem areas relative to the Design/Construct Interface will be discussed: 1) Plant Layout to Facilitate Construction; 2) Constructability Review in Design; 3) Plant Standardization; 4) Modularization; 5) Modeling; 6) Design Changes During Construction; 7) Design Communication; 8) Computerized Design; and 9) Design Scheduling for Constructability. Each of these problem areas includes: 1) Problem Statement; 2) Importance; and 3) Research Topics. Each of the research topics is further subdivided into five parts: 1) Problem Statement; 2) Importance; 3) Research Approach; 4) Anticipated Results; and 5) Implementation/Cooperative Parties.

2.2 Plant Layout to Facilitate Construction

2.2.1 Problem Statement

One of the responsibilities of the designer of a nuclear power plant is the layout of the project site, i.e., the positioning of the permanent structures, utilities, and other components. Figure 2.1 illustrates two possible arrangements for the major structures on a site. The positioning of these structures may have a significant effect on construction costs and/or long term operating costs. Figure 2.2 illustrates alternative routes for utility services to the various structures. Route selection may have a significant effect on the cost of construction and/or future operating costs.

One can easily envision a large number of configurations which are possible for the layout of the permanent structures, utilities, and other components. The designer needs a methodology by which one configuration, which meets the objectives of the owner with respect to construction and operating costs, is selected from all of the possible combinations. Ideally, this selection should be based on the analysis of validated cost information. As a practical matter, complete cost information may not be available and constraints on the time and cost of design virtually prohibit the examination of all possible configurations.

2.2.2 Importance

The plant layout may have a significant impact on the methods of construction. Suppose, for example, that it is determined to be most economical for the reactor vessel to be fabricated on the site and lifted into the permanent location. (16:41) This method requires that the site layout be done in a manner to permit fabrication in the proximity

A Centralized/Corner Arrangement

A Decentralized/Corner Arrangement

Figure 2.1 Alternative Positions of Structures

A Shortest Route Arrangement

A Perimeter Route Arrangement

Figure 2.2 Alternative Routes of Utilities

of the permanent location with easy access for the movement of men, equipment, and materials, and in a manner to simplify the positioning operation. If the necessary space cannot be allocated, more expensive methods must be considered.

The importance of plant layout in the nuclear industry has been expressed by several persons who are knowledgeable in the area of nuclear power plant construction. Richard G. Patrick (8:8) has stated that, "Site evaluation and consideration of basic construction requirements can have a significant effect on the project plan". Dr. Jack H. Willenbrock and Robert C. Parsons (14:183) have noted the disruptive effect of a poor layout, "Often a site that has a hastily planned layout will experience low productivity and result in a continual movement of facilities, which is disruptive to job continuity". Finally, M. M. Fitch (2:8) has stated that, "... equipment access and rigging considerations are often not taken into consideration in the design phase, requiring an inordinate amount of time, trouble, and expense during construction". All of these authorities relay the importance of layout relative to the needs of construction.

Initial layout decisions are made early in the design process, long before construction is underway. Early changes in layout will not greatly increase design and construction costs, but changes made at later stages in the design and/or construction process can greatly increase design and/or construction time and costs. Therefore, it is important that a good layout be selected early in the design process.

2.2.3 Research Topics

In the problem area of Plant Layout to Facilitate Construction,

there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Plant Layout Criteria and 2) Plant Layout Information System.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: PLANT LAYOUT TO FACILITATE CONSTRUCTION

RESEARCH TOPIC: PLANT LAYOUT CRITERIA

1. Problem Statement - The objective of this work is to develop a case study manual illustrating criteria for plant layout to facilitate construction. The manual is for use in continuing education and degree programs.
2. Importance - The combined industry experience in plant layout should be available to current and future designers who want to better facilitate the construction of nuclear power plants.
3. Research Approach - Criteria and case studies will be provided by companies involved in past and present projects. The investigators will classify, select, and organize the criteria and case studies into a draft manual. The draft manual will be submitted for review and comment by all funding parties. The investigators will prepare the final version of the manual.
4. Anticipated Results - The case study will be circulated to funding parties and educational institutions. It is anticipated that these manuals will be used by decision makers and their staff for training and as a guide in the process of plant layout.
5. Research Implementation/Cooperative Parties - The responsibility for implementing the work is National (or Federal) since the required information must be provided by all segments of the industry. The degree of cooperation of all major A-E firms, contractors, utilities, and others will determine the quality and value of the manual.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: PLANT LAYOUT TO FACILITATE CONSTRUCTION

RESEARCH TOPIC: PLANT LAYOUT INFORMATION SYSTEM

1. Problem Statement - The objective of this work is to develop an information system for persons in government and industry who wish to assure that the plant layout is one which will facilitate construction activities. The system and its data base, will be for use by designers, constructors, utilities, and others during the plant layout process.
2. Importance - Reliable and complete information concerning plant layout is not readily available to many designers, analysts, consultants and decision makers. Spatial requirements, cost impacts, and other data are necessary to select a suitable plant layout.
3. Research Approach - An information system for plant layout will be designed. Data sources will be identified. Data which is needed but is not available will be identified.
4. Anticipated Results - The information system will be made available for use by persons in government, industry, and education.
5. Research Implementation/Cooperative Parties - The responsibility for initiating the work is National or Federal since the information system will be used by all parties involved in plant layout processes.

2.3 Constructability Review in Design

2.3.1 Problem Statement

Competent designers seek practical solutions which meet the requirements of the owner and applicable standards for safety, health, and general welfare. In the classical approach to design, it is presumed that the designer will be familiar with all of the industry practices and costs, and that a "constructable" design will be produced, i.e., that the design will be practicable and desirable from the point of view of those who must supply materials and equipment or perform the work.

There are a number of contemporary approaches to design which presume that the designer is not familiar with all practices and costs of the industry. Constructable designs may be produced by a process called constructability review in design. This is a process which enables manufacturers, suppliers, labor, and contractors to review a design and evaluate its constructability while the design is being conceived and executed.

In the design of nuclear power plants, the design team must focus on current and everchanging regulatory and quality assurance standards. Matched with this situation are the stringent tolerance requirements which are inherent in nuclear power plants. Consequently, the designer must formulate a constructable design which also meets the stringent standards and tolerances.

The constructability review enables the contractor and other construction-related parties to assess a particular design. This review will help to determine whether the facility can be built at all, whether

the facility can be built efficiently and economically, and whether the particular contractor and other construction-related parties have the necessary expertise, manpower, materials, and equipment available to them to build the facility efficiently and economically.

2.3.2 Importance

The objective of the constructability review of design is to identify potential construction problems at a time when they may be resolved easily and inexpensively. Ideally, construction review should begin when design begins. The review is important at all levels of any project, but in the area of nuclear power plants it is especially important because slight design modifications may save millions of dollars.

Constructability review is useful in the layout of piping, electrical and HVAC routings. The contractor can review the design to ascertain possible interferences (situations where the design calls for two or more objects to occupy the same space) and resolve them before they occur in the field. The contractor might, for example, help the designer avoid serious future congestion in work areas by suggesting routings which eliminate prospective competition for available work space, or the contractor may suggest routings which will enable two or more trades to work simultaneously within the same general area without interferences.

The contractor might review the design, evaluate the access to the site, and suggest alternatives which would permit contractors to better utilize the available men, materials, and equipment. Contractors might also suggest other alternatives which would permit the use of the most economical methods of construction. At this level, even small modifications to the design can result in significant dollar savings.

Constructability review in design is important at all levels of any project, but it is vitally important in projects, such as nuclear power plants, which are massive and extremely complex. The need to construct these projects in very short time periods increases the importance of this review.

2.3.3 Research Topics

In the problem area of Constructability Review in Design, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Design Curriculum Improvement and 2) Designer Training in Constructability.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: CONSTRUCTABILITY REVIEW IN DESIGN

RESEARCH TOPIC: DESIGN CURRICULUM IMPROVEMENT

1. Problem Statement - The objective of this work is to develop constructability lesson plans and learning aides for adoption by instructors of design courses. Materials will be developed for design related to structural steel, reinforced concrete, and piping.
2. Importance - Constructability review in design is a technique used in nuclear power plant construction to minimize the time and cost of construction. The need for review by contractors is due in part to the present lack of information and training concerning constructability in engineering design courses.
3. Research Approach - The investigator will survey instructors to determine present course content and needs relative to constructability. Lesson plans and learning aides will be developed and pre-tested by application in courses taught by cooperative investigators. The students will be pre-tested and post-tested and the effectiveness of the instructional material will be evaluated.
4. Anticipated Results - Curriculum materials will be published and distributed to design instructors in educational institutions. The materials will include the results of test programs, pre- and post-test instruments, and problems with solutions.
5. Research Implementation/Cooperative Parties - Funding for this work should be provided by the Federal Government and/or a consortium of A-E design firms with the cooperation of educators and constructors.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: CONSTRUCTABILITY REVIEW IN DESIGN

RESEARCH TOPIC: DESIGNER TRAINING IN CONSTRUCTABILITY

1. Problem Statement - The objective of this work is to develop in-service programs to improve designer knowledge in constructability. The in-service programs will be made available for use by companies and agencies responsible for the design of nuclear power plants.
2. Importance - The need for this work (constructability review in design) is due in part to the need to improve the designer's knowledge of constructable and non-constructable designs. In the design of nuclear power plants, slight modifications to facilitate construction may save millions of dollars in construction costs.
3. Research Approach - Investigators will develop instruments for measuring designer knowledge of constructability. Representative detailers will be selected and pre-tested. Investigators will develop in-service programs for improving this knowledge by laboratory training, on-site training, and actual performance of the work. The design detailers will be trained by one of these three methods and post-tested at periodic intervals to measure long-term results.
4. Anticipated Results - Design firms will be provided with research results which will include an evaluation of the relative effectiveness of alternative programs. Information needed for the implementation of successful application programs will be provided.
5. Research Implementation/Cooperative Parties - This work should be implemented jointly by the federal government and a consortium of the major A-E design firms with the cooperation of general and specialty contractors. Facilitators and/or consultants will be needed by A-E firms who wish to implement company-wide programs.

2.4 Plant Standardization

2.4.1 Problem Statement

Standardization is a technique that is used in a limited manner in the construction of nuclear power plants. It is employed as a means of reducing costs, shortening design and construction schedules, and increasing plant availability.

The movement toward standardization began in 1972 when the Atomic Energy Commission (now the Nuclear Regulatory Commission) issued the Commission Policy Statement on Standardization of Nuclear Power Plants. (10:935) This movement has evolved into the licensing of four types of standardized designs: reference design; duplicate design; replicate design; and license to manufacture.

The first three of these standardized designs are defined as (1:10):

A duplicate design is an exact duplicate design constructed in a limited time frame at different sites under one license application. A single set of detail drawings is prepared and all equipment is procured at one time so that each unit built has the same make and model of all items. The only differences allowed are those forced by the differences in site. Where other requirements -- such as seismic requirements -- vary among the plants, the most severe one is met by the design...

A replicate design is a nearly exact duplicate of an established design constructed in a later time frame at the same or different sites under separate license applications. Equipment is procured to the same performance specifications as were used in the earlier plant, but because it is not ordered at the same

time, some items may be of different model or manufacturer. Detail drawings are modified to suit variations in equipment...

A reference design is the adaptation of a standard licensable NSSS with a matching approved BOP, in any time frame, licensed by the AEC for a certain specified range of site parameters independent of an owner and/or his specific site. It is intended that such a design be granted a construction permit within the specified range of parameters. Since the PSAR contains all of the important system level drawings, the standardized plants built in conformance with a given PSAR will be functionally identical, except for site-sensitive features, and may be identical in outward appearance. However, they may not incorporate the same equipment models throughout nor will they necessarily be built to identical sets of detail drawings. This is because details will have to change if a given unit does not incorporate exactly the same equipment models as another unit built to conform with the same PSAR. There will also, of course, be the necessary adaptations to fit a given site. Because of the need to accommodate possible variations in equipment, the one PSAR for a BOP design submitted so far to the AEC contains separate, different-colored pages for each NSSS vendor. Other portions of the design have been left not entirely defined to permit use of three different makes of turbine-generator.

The fourth of these standardized designs, the license to manufacture concept, provides for a licensing review of total plant facilities that are to be repetitively manufactured at sites different from the location of operation. An example of this concept is an off-shore barge-mounted power plant called an Offshore Power System (OPS). (15:10)

Some of the objectives of standardization are (4:51):

1. Establish an effective management;
2. Standardize and optimize systems;
3. Minimize limitations on choice of equipment vendors;
4. Choose a design compatible with a reasonable number of sites;
5. Achieve maximum man-hour cost and schedule savings;
6. Establish reliability goals to achieve a plant availability of 86 percent or better; and
7. Implement procedures and meet these availability goals.

If one is willing to agree that standardization contributes to the achievement of these objectives, then the limited use of standardization is a major problem.

There are those who oppose standardization on the grounds that it limits innovation, competition, and utility involvement (14:64):

1. Innovation - The standardized designs are frozen at some point in time and, hence, the latest further technological advancements are not incorporated into on-going projects. This is at the project level. On an industry-wide basis, standardization tends to

stifle design innovation.

2. Competition - Standardization may further limit the ability of new companies to enter the nuclear power plant construction market.
3. Utility Involvement - Standardization may result in a reduced need for utility involvement in a project. This involvement has been a major aid to the utility in gaining the technical expertise necessary to gain the operating license.

The positions for and against standardization indicate that the industry is unsure of the relative merits of standardization. Research is needed to investigate the standardization approach to determine the impact upon the industry.

2.4.2 Importance

Standardization has been suggested as an important means of reducing the time to get nuclear power plants on line. According to F. C. Olds, "New plant schedules could be cut from the present ten years to five or six years with standardization". (6:49) Time savings such as those suggested by Mr. Olds would tremendously lower the capital costs of a nuclear power plant. The savings would result from the reduced cost of licensing, engineering, and construction and reduced risk through cost assurance and schedule assurance.

The reduction of engineering costs depends, to a great extent, upon the degree to which the utilities accept the standardization. These reductions have been conservatively estimated at about six percent of the overall job cost. (3:11) For a \$1 billion nuclear plant, that

would be a savings of \$60 million. Examples of such cost savings are (3:8):

1. In one actual case of duplication, the figures indicate that second-site units require only 34 to 40 percent of the engineering time used for initial units. The bulk of this effort is site oriented.
2. The published data on the Standard Nuclear Power Plant System (SNUPPS) reveals plant design costs to be about 40 percent of that for a single custom-design unit.

SNUPPS (10:935) is a group of five utility companies that has joined forces to build five standardized nuclear power plants on four sites in the U. S. The electric utilities are: Kansas City Power and Light Company and Kansas Gas and Electric Company, who are jointly building one unit near Burlington, Kansas; Northern States Power Company with one unit near Oswego, New York; and Union Electric Company with two units on a site near Fulton, Missouri.

The savings that can be realized in construction are primarily achieved through reductions in man-hours and schedules. Standardization helps to freeze designs which eliminates backfitting due to new regulatory requirements and advances in technology. Standardization also reduces the number of changes. Both of these result in less rework and disruptions. The result is fewer manhours and closer adherence to the schedule.

It has been estimated that a savings of 7 percent in the amount of

labor used could be realized by the application of standardization. (3:11) On a billion dollar plant approximately 30 percent or \$300 million would be construction labor. A 7 percent reduction would result in a savings of \$21 million.

The use of standardization reduces the risk to the utilities through cost assurances resulting from:

1. Reliable estimates for engineering, licensing, and other technical services;
2. Reliable estimates of construction labor and material, plant equipment, and all other elements of plant cost; and
3. A realistic evaluation of the total financial commitment prior to making a final decision. (3:13)

Schedule assurances also reduce the risk of building a nuclear power plant. This results mainly from the freezing of the design and the minimization of backfitting and rework resulting from regulatory and design changes.

The reduction of licensing, engineering, and construction costs and the reduction of risk through cost and schedule assurances depict the significance of standardization. These suggested reductions can play an important role in providing energy to the consumer more efficiently and at less cost.

2.4.3 Research Topics

In the problem area of Plant Standardization, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two

such research topics. These are 1) Cost Increases in Duplication and
2) Learning and Delivery Benefits.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: PLANT STANDARDIZATION

RESEARCH TOPIC: COST INCREASES IN DUPLICATION

1. Problem Statement - The work required in this study is an analysis of cost increases associated with the use of duplication in nuclear power plant construction. The cost increases which are of concern are those which may be due to overdesign.
2. Importance - The benefits of standardization are well documented and generally concern savings related to design and licensing. The prospective time and cost savings may be more than offset by the overdesign when the duplication technique is used. In particular, the size, type, location, and date of delivery of power from a new plant is based upon projected demand. A compromise with any of these four criteria to fit a group scheme may offset the savings related to design and licensing.
3. Research Approach - A review of SNUPPS and similar duplication applications will be conducted to collect and analyze data to estimate cost impacts of overdesign or other aspects relative to size, timing, type, or location. A review of demand needs of participants will be undertaken to identify any compromises made relative to the above four criteria to fit a group scheme. Cost impacts of these compromises will be assessed.
4. Anticipated Results - Cost information concerning the impacts of duplication would be published and distributed to government, utilities, and others for consideration in future duplication application decisions.
5. Research Implementation/Cooperative Parties - Funding for this work should be handled by the Federal Government together with EPRI with the cooperation of utilities, A-E contractors, and others involved with SNUPPS and other duplication projects.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: PLANT STANDARDIZATION

RESEARCH TOPIC: LEARNING AND DELIVERY BENEFITS

1. Problem Statement - The objective of this work is to estimate the learning and delivery benefits due to standardization.
2. Importance - The time and cost savings resulting from the use of standardization are due largely to decreases in the amount of design manpower used and decreases in the time of licensing. One might reasonably expect that standardization would lead to improved productivity and reduced delivery times for materials. Since the decision to standardize is based, in part, on anticipated savings in these areas, it is important to know the actual savings.
3. Research Approach - The investigators will select work activities and long delivery items for study. The productivity and delivery times for the first plant and subsequent plants will be found utilizing data provided by the A-E, contractor, and utility. Differences will be quantified, where possible, and suggestions for improvement will be presented.
4. Anticipated Results - A report of the findings will be published and distributed to utilities, designers, contractors, government agencies, and educational institutions. The findings may be used in assessing future benefits due to standardization. They may also be used to guide future efforts to improve productivity and/or delivery times.
5. Research Implementation/Cooperative Parties - Funding for this work should be provided by the Federal Government and EPRI with cooperation from contractors, utilities, and A-E firms on projects which use the different types of standardization.

2.5 Modularization

2.5.1 Problem Statement

Nuclear power plant construction projects present unique and particularly complex work assignments. Craftsmen often require specialized skills to be able to perform the work associated with the construction of a nuclear power plant. Management and engineering personnel are confronted with the task of simplifying the work assignments to reduce the costs of training tradesmen, to enable the craftsmen to perform the work in an efficient manner, and to better meet the requirements of quality assurance programs.

A technique that is often utilized in the construction industry to handle repetitive problems is modularization. Generally, this method of construction consists of the fabrication, either on the site or in an off-site fabrication shop, of sub-assemblies of a particular piece of equipment, system, or facility. These sub-assemblies are then assembled into the final unit.

Modularization should be distinguished from standardization discussed in the previous section of this report. The use of a standardized design does not mean that modularization techniques have or have not been employed, but rather it means that the overall project design is similar to a previously approved design. The fact is, modularization can be practicable in standard and non-standard designs. The present problem is that modularization is presently not fully utilized in either standard or non-standard designs. Research is needed to investigate the present usage of modularization and to ascertain other beneficial uses.

2.5.2 Importance

Modularization can result in significant time and cost savings on a construction project. This technique enables fabrication operations to be done in a controlled environment. This may result in better usage of labor and material because project supervision may oversee an operation that is being executed in a centralized, on-site location.

Modularization can be employed to have a larger portion pre-fabricated and shipped to the jobsite. The off-site fabrication is generally less costly than on-site fabrication. Fabrication shops are generally better equipped to handle fabrication tasks which require the latest manufacturing tools, equipment, and methods.

Whether the modularization is done on-site or off-site, the modules can be assembled in the permanent location to comprise the unit desired. The entire process minimizes the movement of men and materials and generates savings in both time and costs.

A unique characteristic of nuclear power plants is the stringent quality assurance requirements that are imposed upon the constructor. The modularization technique enables the contractors to better handle this difficult constraint. The use of this technique will generally mean that components are being fabricated in controlled environments. This results in easier inspection and correction of defective material and workmanship. In addition, supervision is better able to oversee the fabrication operation than is possible in construct-in-place operations. Fewer occurrences of poor workmanship should result.

2.5.3 Research Topics

In the problem area of Modularization, there are many research

topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Principles and Practices of Modularization and 2) Time/Cost Savings Comparisons.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: MODULARIZATION

RESEARCH TOPIC: PRINCIPLES AND PRACTICES OF MODULARIZATION

1. Problem Statement - The objective of this study is to prepare a loose-leaf manual illustrating the major principles and practices of modularization in nuclear power plant construction. Successful and unsuccessful cases will be included as well as untried and unproven applications.
2. Importance - There is a need to formalize a modularization manual because the modularization technique can be a significant source of time and cost savings in the construction of nuclear power plants. It would also help eliminate the instances where different designers suggest different modularization schemes for identical items.
3. Research Approach - The investigators will collect data and case studies from companies using (or having used) modularization. These inputs will be selected, classified, and organized into a reference manual which will be published and distributed to utilities, government agencies, A-E firms, contractors, and others. A follow-up and updating will be done periodically.
4. Anticipated Results - An illustrated manual will be formulated for reference in modularization decisions.
5. Research Implementation/Cooperative Parties - The funding for this work should come from the Federal Government and the utilities with cooperation and input provided by A-E firms, contractors, manufacturers, and others.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: MODULARIZATION

RESEARCH TOPIC: TIME/COST SAVINGS COMPARISONS

1. Problem Statement - The objective of this work will be to compare the time and cost of modularized construction to the time and cost of conventional methods.
2. Importance - The time and cost savings of modularization are not well established. These benefits can be quantified by controlled experiments in which modularized and conventional methods are compared. Validated information is an important need of decision makers in nuclear power plant construction.
3. Research Approach - The chief investigator will coordinate a number of investigations at different sites. In the site investigations, activities will be studied with half of the work modularized and the other half constructed by conventional methods. Reports from each investigator will be compiled into a final report.
4. Anticipated Results - A report will be prepared showing the results of the studies of the individual activities. Generalizations, if any, concerning the results will also be presented.
5. Research Implementation/Cooperative Parties - The funding for this study must come from the Federal Government with utility support. Cooperating parties should be the designers (who will have to prepare two designs), contractors, labor, manufacturers, and others.

2.6 Modeling

2.6.1 Problem Statement

A planning and design aid that has gained considerable acceptance in the construction industry is the scale model. Models are built to show an entire project or portions of a project on a smaller scale. This small scale replica is a three dimensional representation of the project which helps workers, designers, builders, and others to visualize the end product.

The use of models has recently become more applicable in the nuclear industry but has still not gained full acceptance. One reason for the non-acceptance may be the tremendous cost associated with constructing a model for a project as large as a nuclear power plant. Such a model could cost in the neighborhood of \$1 million.

Three important research questions concerning modeling are:

- 1) Why are models not widely used in the construction of nuclear power plants?
- 2) Who should pay for the models and whose property do they become upon completion of the project?
- 3) What dollar benefits are achieved using models?

The answers to these questions and other findings relative to modeling will be of benefit to those parties on future nuclear power plant projects when deciding whether to employ models.

2.6.2 Importance

The use of models results in many benefits to the users in the construction industry. According to W. F. Sailer of Gilbert/Commonwealth some of these benefits are (11: 5.21):

- Communication between design and management
- Coordination of engineering and construction
- Coordination between disciplines via a common visual medium
- Sequencing of equipment placement, rigging, crane erection, etc.
- Schedule confirmation
- Interference checks between piping, heating, and ventilating ducts, and electrical raceways
- Operator training
- Training aid for new project team members
- Utilization by construction forces to simulate equipment installation.

The above-mentioned benefits may help to lower the cost of construction of nuclear power plants when they are experienced.

Models also may be helpful in improving productivity. In the field, workers can be given photographs taken of the model to depict particular design layouts. This may increase the workers' abilities to visualize the work assignments and decrease some of the nonproductive time.

In view of the prospective benefits which have been outlined above, it is important that studies be initiated to gain more acceptance of modeling techniques.

2.6.3 Research Topics

In the problem area of Modeling, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research

topics. These are 1) Utilization of Plant Models and 2) Application of Modeling at the Crew Level.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: MODELING

RESEARCH TOPIC: UTILIZATION OF PLANT MODELS

1. Problem Statement - The objective of this work is to examine the present constraints limiting the access to plant models and to suggest methods of eliminating the constraints and ways to better utilize the plant model.
2. Importance - The cost of the plant models of nuclear power plants reportedly runs between \$1/2 million and \$2 million. This investment may be more than offset by time and cost savings during design and construction provided the model is used to the greatest extent possible.
3. Research Approach - Projects utilizing plant models will be identified. Data concerning access to these models will be collected. Additional applications (such as photography and close circuit TV) will be developed and tested in pilot studies.
4. Anticipated Results - A report will be published presenting the findings of the pilot studies and recommendations for the maximum utilization of the plant model.
5. Research Implementation/Cooperative Parties - Funding for the study and the pilot tests should come from the Federal Government and the utilities with the cooperation of designers and contractors.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: MODELING

RESEARCH TOPIC: APPLICATION OF MODELING AT THE CREW LEVEL

1. Problem Statement - The objective of this work will be to evaluate the costs and benefits of utilizing scale models to simulate construction operations prior to the actual construction. Simple models can be employed to better illustrate construction methods. The model will be changed to represent conditions at various times and plans for accomplishing objectives will be generated and examined.
2. Importance - Reports of low productivity, high rate of turnover, and high levels of absenteeism are common on nuclear power plant projects. Modeling may be utilized at the crew level to improve crew performance and increase crew involvement in the planning process.
3. Research Approach - Crews will work with their foremen and modeling technicians to prepare work plans, evaluate needs and resources, and report concerns and recommendations. The investigators will monitor the operation and document the modeling methods developed. The impact on productivity, turnover, and absenteeism will be assessed.
4. Anticipated Results - A report will be prepared illustrating the different modeling techniques, training methods, and other cost/benefit findings. Recommendations concerning the most effective use of these techniques will be given.
5. Research Implementation/Cooperative Parties - The funding for materials, supplies, training, and research should come from the Federal Government with the cooperation of labor, contractors, utilities and others for the on-site implementation.

2.7 Design Changes During Construction

2.7.1 Problem Statement

The typical nuclear power plant takes about ten years to build. (6:49) This is the time from conception until the plant is on line. During the ten year span there will be changes due to numerous technological advances which will occur in the area of nuclear power generation. These will include improvements in nuclear power generation as well as the evolvement of additional safety requirements.

Frequently, in the construction of nuclear power plants, the construction phase is started in the early stages of the design process. Changes result from this situation due to incomplete drawings and design errors.

The continual change of regulatory requirements, codes, quality assurance requirements, and environmental restrictions also result in numerous design changes which necessitate retrofitting during construction.

There are numerous areas of needed research related to design changes. Some of the important areas are:

1. What are the cost impacts of changes and how does the timing and the method of implementation affect these costs?
2. Are cost studies of the impact of the changes upon construction made prior to implementation?
3. Who sets design change implementation priorities?
4. What is the role of the contractor in setting design change priorities?

It appears that research concerning changes would be productive since

answers to these and many other questions dealing with changes may lead to significant time and cost reductions in the construction of nuclear power plants.

2.7.2 Importance

The construction of a project of the magnitude of a nuclear power plant requires a large amount of planning to best utilize limited supplies of the basic resources - labor, material, and equipment. Once a plan is developed, any change will have a disruptive effect.

Handling the changes is a problem itself. The contractor must assess the impact on the time and costs for the project. It is not uncommon for a construction firm to have a department specifically for handling changes. This leads to increased administrative and overhead costs.

Changes that result in revised material requirements due to changes in specifications may produce significant delays. These delays are more quantifiable and are, generally, equal to the length of time required to procure and receive new material.

The inability to define and freeze the design and physical scope of the plant prior to commencement of construction has been suggested as a source of many changes to the construction plan. According to M. M. Fitch, "We are presently seeing changes in design to meet regulatory requirements continuing all through the construction phase". (2:2)

Changes also affect manpower productivity. When a change is required, shifts in job assignments may be necessary. The result is a less efficient usage of manpower. This result is especially critical in light of the limited availability of qualified craftsmen with the

skills necessary to handle nuclear power plant construction work assignments.

Research conducted into the area of changes and the effects of changes may greatly increase the capability of utilities, designers, contractors, and other involved parties to collectively shorten the construction schedules of nuclear power plants.

2.7.2 Research Topics

In the problem area of Design Changes During Construction, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Impacts of Changes and 2) Time Interval Distributions.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN CHANGES DURING CONSTRUCTION

RESEARCH TOPIC: IMPACTS OF CHANGES

1. Problem Statement - The objective of this work is to quantify time and cost impacts of design changes during construction. The relative importance of the magnitude of the change, the timing of the change, and the frequency or rate at which changes are received will be investigated.
2. Importance - Design changes during construction can have devastating impacts on time and costs of construction. These impacts must be better quantified to illustrate that the magnitude of the changes is often not as critical as the timing and frequency of the changes.
3. Research Approach - The investigators will select representative classes of work on a number of projects. The time and cost of activities which were not affected by changes will be compared to the time and cost of activities which were affected by changes. The scope, timing, and rate of change will be quantified and their relative impacts on time and costs will be estimated.
4. Anticipated Results - A report will be prepared describing the activities studied and the results of the study. General recommendations will be presented concerning handling, minimizing, and timing the changes.
5. Research Implementation/Cooperative Parties - The funding of this study should come from the utilities and contractors with cooperation with designers, manufacturers, federal government and others.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN CHANGES DURING CONSTRUCTION

RESEARCH TOPIC: TIME INTERVAL DISTRIBUTIONS

1. Problem Statement - The objective of this work is to quantify the distribution of time between the date that information is needed and the date when the information is received in the field. The study will be limited to those cases in which the information provided required one or more change orders.
2. Importance - The rate of completion of construction work is very sensitive to the time interval between the time when information is needed in the field and the time when that information is received. Delays resulting from slow action increase the time and cost of construction.
3. Research Approach - The investigators will collect time interval data for various classes of work at a number of projects. Changes required will be noted and classified. Time distributions will be found for various classes of work, projects, locations, and types of changes.
4. Anticipated Results - A report will be prepared which will present the data and time distributions found. The report will present suggested methods for reducing the mean and variability of the time distributions.
5. Research Implementation/Cooperative Parties - The funding for this research should come from the federal government together with the utilities. The cooperation of contractors and designers will determine the success of the study.

2.8 Design Communication

2.8.1 Problem Statement

In the construction of nuclear power plants, the complexity of the design may cause numerous interferences and complications in the field during construction. These problems require solutions by the design engineer. While the designer decides on a solution, the field personnel must wait until the solution is developed and communicated. This is particularly significant when the design personnel are physically removed from the site of the project. This increases the turn around time and, hence, it increases the time that construction forces are delayed in the field.

Similar delays result when the drawings are issued in an incomplete stage. Field personnel are delayed while additional design details are acquired. Any lack of clarity or inconsistencies in the specifications have the same effect on the construction process. Field construction personnel are delayed or hampered in doing efficient work while inconsistencies in the specifications are resolved and the meanings of the specifications made clear.

The construction process involves the usage of design drawings compiled by the design firms. This usage necessitates the transformation of the design from the two dimensional state on the drawing to the three dimensional reality. This transformation process is done by countless numbers of field construction personnel including supervisors, foremen, and craftsmen. This transformation process takes time and the amount of time depends upon the person's ability to visualize two dimensional drawings as three dimensional entities. This trait, called visual

acuity is a necessary ability for all those who deal with design drawings on a regular basis. Presently, there is no standard procedure for testing individuals who will be employed on nuclear power plant construction projects to determine whether they possess these skills.)

The communication of the designer's wants are relayed through the design drawings. The drawings characteristic to a nuclear power plant are so complex that this communication may not be as effective as it should be. The limits of the two dimensional drawings are recognized throughout the construction industry. This is the main reason for the use of scale models in the construction process.

It is noted that research concerning the topic of design communication may lead to significant improvements in design methods and techniques. It is also possible that research could lead to the incorporation of computer design tools, closed circuit television, modeling and other graphic display mechanisms into everyday design and construction practice.

2.8.2 Importance

The importance of good design communication is predicated upon the necessity of having good productivity and efficient operations. Delays resulting from design complexity, incomplete drawings, and unclear or inconsistent specifications are causes for concern in any type or form of construction. However, they are especially troubling in nuclear power plant construction due to the substantial costs associated with the financing of these projects. Any time that is spent resolving communications problems will cause work suspensions that will have significant impacts upon the costs of construction.

The productivity of the worker depends not only on the training he has received but also on his ability to quickly interpret complex prints. The same holds true for engineers, managers, and others connected with the project. Lower productivity may be one result of this inability of workers and others to effectively understand the intent of the designers.

Conventional design communication techniques may be ineffective at conveying the complex designs characteristic to nuclear power plants. The interpretation of these designs are affected by the abilities of the construction forces. Good design communication is, therefore, influenced by worker aptitudes as well as the designer's ability to convey his intent clearly.

Improvements in the construction process are a likely result of improvements in the design communication methods. Improved construction techniques leads directly to lower first costs of the nuclear power plants.

2.8.3 Research Topics

In the problem area of Design Communication, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Drawings and Specifications Reading and 2) Communicating Design Requirements to Workers.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN COMMUNICATION

RESEARCH TOPIC: DRAWINGS AND SPECIFICATIONS READING

1. Problem Statement - The objectives of this work are to develop a computerized testing program for evaluating drawings and specifications reading skills of persons working in nuclear power plant construction; and to evaluate the skill levels of persons presently employed in this segment of the construction industry.
2. Importance - Design concepts are communicated to workers through drawings and specifications. The inability of workers, supervisors, and managers to properly read and interpret these documents may partially explain many productivity and quality control problems.
3. Research Approach - The investigators will work with representatives of contractor associations and labor organizations to develop test items, an interactive testing program, and testing materials. Materials shall be developed for pipefitters, welders, ironworkers, carpenters, millwrights, and electricians.
4. Anticipated Results - The test program and materials shall be published for use by interested organizations. The investigators shall recommend industry-wide or other levels of training as shown to be needed by the test results.
5. Research Implementation/Cooperative Parties - The funding for the work should come from the federal government, contractor associations, and professional societies. The cooperation of labor, A-E firms, contractors and utilities will be needed.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN COMMUNICATION

RESEARCH TOPIC: COMMUNICATING DESIGN REQUIREMENTS TO WORKERS

1. Problem Statement - The objective of this work is to test the effectiveness of present methods of communicating design requirements to workers and to test the effectiveness of promising alternatives.
2. Importance - Design requirements may be communicated by many methods. Engineering and shop drawings are the common means of communication down to the foreman level. While some workers work with both of these means, others work with sketches prepared by their foremen, and others receive only verbal instruction.
3. Research Approach - The investigators will identify, document, and classify various methods of communicating design requirements to the workers. Experiments will be conducted to study the impacts of the amount of information, language, form, timeliness, and other factors which impact on worker performance.
4. Anticipated Results - A report will be prepared to show how the amount, form, and timing of information provided to the workers may impact on productivity and the quality of work performed. Differences among trades and worker skills will be given.
5. Research Implementation/Cooperative Parties - The federal government should fund the investigation, analysis, and report. Cooperation of the utilities, labor, A-E firms, and contractors will be necessary for the success of the study.

2.9 Computerized Design

2.9.1 Problem Statement

The aerospace industry has developed many computer based systems which facilitate the design process. These computerized design systems may be used to store design information and prepare drawings. The computer can be used to identify interferences and other design problems.

Computerized design systems could be especially useful in handling design changes. The initial design can be stored in the computer and the impacts of proposed changes can be evaluated. Finally, the computer can incorporate approved changes into the initial design and prepare revised drawings.

Computerized design systems are widely applied in the aerospace industry but they have only recently been made available to other industries. One such system developed by McDonnell-Douglas came onto the market on January 1, 1977. Research is needed in the construction industry to assess the application of the computerized design system and to find ways to speed the introduction of the system into the construction industry.

2.9.2 Importance

Throughout the course of construction of a nuclear power plant, there will be a vast number of design changes. These changes can affect more than one construction discipline. For example, a change in a piping run may also affect the location of electrical conduit and the placement of wall penetrations. The dissemination of the change information to all parties involved is a complicated task due to the number of disciplines involved. This is further amplified by the large number

of changes. The process of transferring the change information to the design drawings is a costly and time consuming process. A computerized design system might incorporate these changes into the design more quickly.

Presently, in the design process, many problems such as interferences are not determined until the problem is experienced in the field. Likewise, when a change is incorporated into a design, the total impact of the change may not be known until the change is handled in the field. Both of these situations may be improved with the use of computerized design.

Research into the area of computerized design may result in significant advances in the construction industry. In addition, the use of computerized design systems on nuclear power plant projects may have a significant impact on the time and costs of construction.

2.9.3 Research Topics

In the problem area of Computerized Design, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Principles and Practices and 2) Imbedded Items, Interferences, and Penetrations

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: COMPUTERIZED DESIGN

RESEARCH TOPIC: PRINCIPLES AND PRACTICES

1. Problem Statement - The objective of this work is to prepare a manual containing the principles and practices of computerized design.
2. Importance - Many governmental and proprietary computerized design systems have been developed in recent years. Though greater use of computerized design is needed in the construction of nuclear power plants, there is a danger of investing large sums of money to develop programs and systems which are presently available through government and other industries. A "state of the art" manual should be prepared before proceeding with the development of new systems.
3. Research Approach - The investigators will solicit data and examples concerning principles and practices of computerized design from the nuclear industry, other segments of the construction industry, the aerospace industry, manufacturers of computer hardware and software, and government agencies. These materials will be organized into a "state of the art" manual.
4. Anticipated Results - The manual would be published for use in training and in the design of improved computerized design systems. The investigator will identify types of programs and systems which are presently needed but not available to the nuclear power industry.
5. Research Implementation/Cooperative Parties - Financial support should be provided by the federal government, major computer hardware manufacturers, and major companies providing software and/or other computer services. The cooperation of A-E firms, contractors, CERL, NASA, and other agencies will be required.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: COMPUTERIZED DESIGN

RESEARCH TOPIC: IMBEDDED ITEMS, INTERFERENCES, AND PENETRATIONS

1. Problem Statement - The objective of this work will be to develop computer programs which may be used to identify interferences. The program will also locate imbedded items which may interfere with penetration.
2. Importance - One of the important prospective benefits of computerized design is the early identification of interferences. A computerized system will enable these interferences to be resolved before they are experienced in the field where they are costly to correct.
3. Research Approach - The investigators will review available computerized design programs. Generalized programs for accomplishing the research objectives will be developed. A-E firms and contractors will be provided copies of the program and will assist in the testing of nuclear power plant design applications. The program will be revised as necessary to accommodate the needs of the A-E firms and contractor firms.
4. Anticipated Results - Generalized programs with complete documentation will be published for use by interested parties for training and/or application in nuclear power plant construction.
5. Research Implementation/Cooperative Parties - The federal government should support the development of these programs. A-E firms and contractors should provide cooperation in development and trial applications.

2.10 Design Scheduling for Constructability

2.10.1 Problem Statement

In nuclear power plant construction, the start of construction generally occurs when the design is approximately 15% complete. (14:60) This means that much of the design and construction work will be progressing simultaneously. The sequencing of the construction will depend upon the methods to be employed to perform the construction. It is easy to see that the design and construction progress should be well coordinated. It is also easy to see the criticality of the design sequencing.

The designers will want to sequence design activities to allow for the best and most efficient utilization of human or physical resources and to allow for the smooth progression of the design.

The contractors, on the other hand, will want to sequence the construction operation to best utilize the available manpower, equipment, and material. This sequencing will consider the methods to be employed, the delivery of major equipment items and materials, weather, and owner preferences.

The problem arises from the fact that the sequencing which best utilizes design resources is not necessarily the sequencing which best facilitates construction. Research is needed in the area of design scheduling for constructability to assess the current industry practices and to suggest a methodology to determine job sequences on these nuclear power plants.

2.10.2 Importance

The finance charges associated with the construction of nuclear power plants are phenomenal. The savings generated by an efficient design

sequencing which allows an efficient construction operation may be very significant.

One important aspect of the design sequencing is to provide the contractor with sufficient time to run the construction process more efficiently. Shop drawings for the fabrication of materials and equipment must be prepared well in advance of the actual fabrication. If sufficient lead time is provided by the designers, these drawings can be prepared more thoroughly assuring lower costs, better quality, and better workmanship.

Sufficient design lead time will allow the constructors to thoroughly review a design to investigate the many possible construction methods. The best method can then be chosen to make the most efficient use of the available manpower, materials, and equipment.

Sufficient design lead time will better enable the contractors to cope with the long delivery times experienced in the purchase of materials and equipment. These long delivery items can be ordered as early as possible and the work can be scheduled to minimize the effects of the delivery times.

Weather is another important consideration in the sequencing of construction operations. If the plant is to be constructed in an area that experiences changes of seasons, then the design should be sequenced to minimize any adverse effects on the construction operations. The design sequencing should allow excavation and site work to be done during the drier seasons. Likewise, the design should be sequenced so that construction activities during the cold winter months will be constructed inside as much as possible.

Finally, the success of the sequencing of the design will depend upon the input from the construction team. "The designer will be more accurate in establishing the sequence and time frames involved, if he has construction information regarding the methods which will be used in the field." (14:177)

The complexity of a nuclear power plant necessitates a significant amount of planning by the contractor to assure efficiency. The design should be scheduled to accommodate this necessary planning as much as possible. The result should be better job efficiency which may lower costs and reduce the time of construction.

2.10.3 Research Topics

In the problem area of Design Scheduling for Constructability, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Start of Construction and 2) Scheduling Algorithms.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN SCHEDULING FOR CONSTRUCTABILITY

RESEARCH TOPIC: START OF CONSTRUCTION

1. Problem Statement - The objective of this work is to evaluate the relative costs and benefits of starting construction at various levels of design completion. The major factors influencing these costs will be examined.
2. Importance - Authorities appear to agree that construction should begin prior to design completion. The amount of design which should be completed is not settled since opinions range from 15% to 50%.
3. Research Approach - The investigators will utilize computer simulation to accomplish the objectives of this study. Representative situations will be investigated utilizing data provided by the nuclear power construction industry and government agencies.
4. Anticipated Results - A report will be published which presents guidelines for finding the percent of design which serves as the optimum starting point of construction.
5. Research Implementation/Cooperative Parties - The funding for this study should be provided by the federal government and EPRI. The cooperation of utilities, A-E firms, and contractors will be necessary for the success of the study.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: THE DESIGN/CONSTRUCT INTERFACE

PROBLEM AREA: DESIGN SCHEDULING FOR CONSTRUCTABILITY

RESEARCH TOPIC: SCHEDULING ALGORITHMS

1. Problem Statement - The objective of this study is to develop recommended algorithms for design scheduling which gives consideration to the impacts of the schedule on the time and cost of construction.
2. Importance - Design scheduling should assure timely completion of the drawings and specifications required in the construction stage. Changes must be expedited and may pre-empt previously scheduled design activities. For these reasons, scheduling algorithms are of great importance to utilities, contractors, as well as to the designers.
3. Research Approach - The investigators will review algorithms for design scheduling. Alternative programs will be developed and the effects on the time and costs of construction will be evaluated. The study will include consideration of alternative objectives, priority systems, updating frequency, and pre-empting procedures.
4. Anticipated Results - The algorithm and related studies will be published in a report which will also include recommended features or algorithms which may lead to reductions in the time and cost of construction of nuclear power plants.
5. Research Implementation/Cooperative Parties - The federal government and utilities should provide the funding for this study. The cooperation of A-E firms and contractors will be required.

2.11 Summary

In this chapter, the problems associated with the Design/Construct Interface in the construction of nuclear power plants were discussed. These problems were: 1) Plant Layout to Facilitate Construction; 2) Constructability Review in Design; 3) Plant Standardization; 4) Modularization; 5) Modeling; 6) Design Changes During Construction; 7) Design Communication; 8) Computerized Design; and 9) Design Scheduling for Constructability.

The discussion presented the Problem Statement, the Importance, and the Research Topics for each area.

The objective of all of the research topics is to prevent or mitigate the effects of construction delays associated with the Design/Construct Interface.

CHAPTER 3

OTHER SPECIFIED RESEARCH AREAS

3.1 Introduction

This chapter presents the research needs in those specific research areas not included in the four major generic problem areas as described in section 1.2. Once again those four areas are: 1) Design/Construct Interface; 2) Construction Methods, Equipment, and Materials; 3) Construction Coordination and Communication; and 4) Manpower and Productivity. The specific research areas to be discussed in this chapter are: 1) Plant Siting; 2) Cash Flow; 3) Economies of Scale; 4) Disaggregation; and 5) Transferability of Macro Management Methods.

As in Chapter 2, the discussion of each research area will be divided into three parts: 1) Problem Statement; 2) Importance; and 3) Research Topics. Likewise, the Research Topic will be further subdivided into five parts. These are: 1) Problem Statement; 2) Importance; 3) Research Approach; 4) Anticipated Results; and 5) Implementation/Cooperative Parties.

3.2 Plant Siting

3.2.1 Problem Statement

When a utility company has determined that its energy production capability must be increased, a tentative decision is usually made concerning the size, type, and the time frame for the new facility. The final decision concerning these factors may hinge upon the site that is chosen. The decision process by which the utility chooses the location of the facility is termed plant siting.

Site selection is critical because licensing, design, and other subsequent functions cannot be started until the site is chosen. The problem is to select a site in the least time with the least amount of money which will sufficiently meet the utility's needs and protect public interests.

3.2.2 Importance

In the site selection process, possible sites are identified and an evaluation process is then undertaken. The criteria for the evaluation generally concerns the following areas (3:5.8):

1. Acreage
2. Water Availability
3. Seismic Constraints
4. Distance Constraints from Power Source to User Centers
5. Socioeconomic and Geopolitical Factors, Including
Zoning and Community Planning Constraints
6. Property Acquisition Conditions
7. Environmental Factors Such as Biological Inventories
and Effects
8. Archaeological and Historical Site Locations
9. Population Distributions
10. Transportation and Communications Limitations
11. Land Use Patterns
12. Meteorological and Climatological Patterns

Once the criteria and possible sites have been identified, a screening is performed to eliminate obvious undesirable, unusable, and impractical sites. From this screening, a list of potential sites evolves of which

a more thorough evaluation is conducted.

In the evaluation of the sites, the number of selection criteria necessitates the involvement of many qualified scientists and engineers. One author has formulated a list of the responsibilities of the eighteen types of scientists and engineers who are involved in the site evaluation process. (5:5.10)

Finally, after much analysis a site is selected upon which the permanent facility will be constructed upon approval and licensing. A detailed outline of a typical site selection and evaluation program is included in Appendix A.

The detailed nature of the site selection process illustrates the importance of the task. Many factors are considered by many different people within the limits of many constraints. Another indication of this importance is the time duration involved. The site selection process can take a year or more to complete and can add six months or more to the total project duration. (9:41) In some cases, locations are being abandoned due to local pressure from environmentalists and other intervenors which lengthen the site selection duration. The Seabrook, New Hampshire nuclear powerplant is a good example of this. The plant has experienced much delay as a result of environmental demonstrations and the environmental review process of the Environmental Protection Agency. (18:-)

Probably the most important aspect of the site selection process is that it precedes the design and construction process. Very little of the design can be initiated until the site selection is finalized and any delay in the selection process will ultimately move the design

and construction schedules further into the future.

The important task in site selection becomes one of choosing a site that is technically and environmentally feasible while at the same time meeting all of the federal, state, and local licensing and regulatory requirements. In addition, the selection process must make efficient use of precious and costly time.

3.2.3 Research Topics

In the problem area of Plant Siting, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Impacts on Construction Time and Costs and 2) Computerized Information System.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: PLANT SITING

RESEARCH TOPIC: IMPACTS ON CONSTRUCTION TIME AND COSTS

1. Problem Statement - The objective of this work will be to estimate the site selection impacts on construction time and costs. Data from nuclear power plants which are completed or are presently under construction will be collected and analyzed.
2. Importance - Prior successes and failures may offer valuable guidelines in future decision making concerning site selection.
3. Research Approach - The investigators will study the time and cost of construction as a function of site conditions and criteria for site selection. Data concerning the factors which existed at the time of the site review and the criteria upon which the site selection was made will be gathered from records of hearings and other sources. Data concerning problems which were experienced and actual conditions which were experienced will be gathered from utilities, A-E firms, and contractors.
4. Anticipated Results - A report will be published which identifies the significant conditions and criteria of the site selection and their impacts upon the time and cost of construction of nuclear power plants. The report will serve as a reference in future selection processes.
5. Research Implementation/Cooperative Parties - The federal government along with EPRI should fund this study. The cooperation of A-E firms, contractors and utilities will be necessary for the success of the study.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: PLANT SITING

RESEARCH TOPIC: COMPUTERIZED INFORMATION SYSTEM

1. Problem Statement - The objective of this work is to develop a computerized information system for use by all parties concerned with site selection. The purpose is to reduce the time and cost of site selection and/or reduce the likelihood of selecting a poor site.
2. Importance - The nuclear power industry now has a wealth of experience in site selection. Information concerning this experience should be assembled, computerized, and utilized to reduce the time and cost of site selection as well as improve the quality of the site selection.
3. Research Approach - The investigators will examine and evaluate computer systems, such as the CERL environmental impact statement system and other similar systems. The investigator will then collect information required in the site selection design and implement a computer based information system, and test the system on representative projects.
4. Anticipated Results - The study will make available a computer based information system which will facilitate the consideration of the major criteria in the site selection process.
5. Research Implementation/Cooperative Parties - The funding for this research should come from the federal government and EPRI. The cooperation of the utilities, designers, and constructors will be required.

3.3 Cash Flow

3.3.1 Problem Statement

Cash flow is defined as the movement of money through an organization. These funds come into a firm from revenues generated by operations, from outside lending institutions, from investors through the purchase of stocks and bonds, and from other similar means. These funds flow out of an organization through purchases of goods and services, through expansion undertakings, through operating expenses, through payments of debts, through payment of taxes, and through other similar means.

In the construction of nuclear power plants, the utilities finance the project with funds generated by present operations, with outside funds raised through issuance of utility bonds, through funds raised through stock issues, and through loan agreements with lending institutions.

One problem associated with the cash flow on nuclear power plant projects is the timing of the cash flow. A typical nuclear plant may require ten years from the time of conception until the plant is on line and producing. The payments are deferred until the plant is on line, but eventually the consumer must pay for the costs of financing. The consumer is paying premiums on these deferred payments and these premiums are increasing due to the fact that investing in the nuclear power plants is becoming a riskier venture.

Another cash flow problem arises due to two views of the nuclear power plant construction process. One view purports that in the life of a project, the loss of a few days does not greatly impact on the

total job. The other view purported by those responsible for raising the capital necessary to finance a nuclear power plant is that any delay is significant and impacts on the cost of financing. Both views are common throughout the industry, yet, little is being done to investigate and remedy the consequences of these conflicting views.

The problem associated with the cash flow timing and the problem associated with the two views previously mentioned are both management type problems. The money for research from the organizations concerned with nuclear power is being directed toward hardware related problems and away from management problems. This is in spite of the fact that these management problems increase the first cost of the finished plant.

3.3.2 Importance

Traditionally, investment in the utility industry was characterized by a stable return on investment and low risk. Recent indications are that the financial position of the industry has weakened. Table 3.1 illustrates some of the financial indicators over the past decade. (13:11) The ratios illustrated all have one common ground; that is, they have all worsened since 1965. This deteriorating trend implies greater financial risk to perspective investors. This situation is further complicated by the "capital intensity of a single project, delaying actions by intervenors, safety and licensing questions, and the lack of a national energy policy all add to this uncertainty and risk of the business". (13:2)

This trend of increasing financial risk comes at a time when the need for outside financing is increasing. The cost of the nuclear units are steadily increasing. The average cost reported in December of 1974

<u>Year</u>	<u>Moody's Common Stock Price to Book Value</u>	<u>Fixed Charge Coverage Excluding AFC</u>	<u>Fixed Charge Coverage Including AFC</u>	<u>Payout Ratio</u>	<u>Common Equity Ratio</u>	<u>Return On Year End Common Equity</u>
1975	0.7x	2.2x	2.6	67%	34%	10.5%
1974	0.6	2.2	2.6	68	34	10.2
1973	0.9	2.5	2.8	65	35	10.8
1972	1.1	2.6	2.9	65	35	11.1
1971	1.2	2.7	3.0	67	35	11.0
1970	1.2	3.1	3.4	68	35	11.2
1969	1.5	3.8	4.0	67	36	11.8
1968	1.6	4.3	4.5	69	36	11.9
1967	1.8	4.6	4.8	66	37	12.4
1966	1.9	5.0	5.1	65	38	12.4
1965	2.2	5.2	5.3	65	39	12.2

Source: Moody's & EEI

Table 3.1 Electric Utility Financial Indicators (13:11)

for newly ordered 1974 units was \$562/KWe. In December of 1975 this figure was \$711/KWe. Both of these are compared to the 1965 average of only \$110/KWe. (7:84)

A recent MIT study, "Trends in Light Water Reactor Capital Costs in the U. S.", indicates that light water reactors have been increasing in capital cost in real terms at an average annual rate of about \$30/KWe per year in 1973 dollars. (12:161) Figure 3.1 illustrates the increasing cost trends. (12:162)

Recent findings of the Edison Electric Institute are illustrated in Table 3.2. (13:7) This table shows the capital structure of the utilities at the end of the year in 1975 and the outside financing requirements through 1990. This outside capital represents 2.5 times the investment the institute has attained since inception. (13:2)

The current situation indicates that the cost of constructing nuclear power plants is increasing at the same time that the financial investment risks are increasing and, hence, the availability of outside capital is decreasing. What does this mean to the consumer? Consider the following example. "Current facilities are assumed to be financed with 50 per cent equity and 50 percent debt at the rate of 10 per cent. Equity receives a return of 12 per cent after tax, and dividends of one half of this amount are paid. Depreciation is at a rate of 3 per cent annually. Based on these assumptions, cash flows from current facilities during a ten year planning and construction period can provide about 25 per cent of the funds required for the nuclear addition. These internally generated funds must be augmented by 75 per cent external funds to successfully finance the project. (12:162)

Figure 3.1 Estimated Costs for Nuclear Power (12:162)

	<u>1975 Capital Structure For Electric Utilities*</u>	<u>Ratio Percent</u>	<u>1976 - 1990 External Requirements*</u>
Debt	\$ 69.9	52.6%	\$179.9
Preferred Stock	16.9	12.7%	43.4
Common Equity	46.1	34.7%	118.7
	<hr/>	<hr/>	<hr/>
	\$ 132.9	100.0%	\$342.0

Source: Edison Electric Institute

*Billions of Dollars

Table 3.2 External Financing By Investor
Owned Electric Utilities (13:7)

The costs of construction of nuclear power plants will be recovered by the utilities through the rates charged to the consumer for the generated power. Therefore, it is important that finance costs be minimized to lessen the burden on the consumer.

3.3.3 Research Topics

In the problem area of Cash Flow, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Externally Generated Funds and 2) Simplified Cash Forecasting.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: CASH FLOW

RESEARCH TOPIC: EXTERNALLY GENERATED FUNDS

1. Problem Statement - The objective of this work is to examine the amount and cost of externally generated funds needed to finance nuclear power plant projects and to assess how they are affected by the time and cost of construction.
2. Importance - The time and cost for raising external funds are increasing due to the increase in risk of utility investment which is due in part to the increasing time and cost of construction of nuclear power plants.
3. Research Approach - The investigators will collect data from the utilities, financial institutions, and regulatory agencies to determine the present trends of the time and costs of construction. From this, a projection of future time and costs of construction will be made. Then given the time and cost of future construction, a prediction of the availability of capital will be made. Finally, the point where external funds might not be available will be predicted.
4. Anticipated Results - A report will be compiled for use by the industry showing the sensitivity of external funds to the time and cost of construction. This will be useful in predicting external funds necessary for future nuclear power plants.
5. Research Implementation/Cooperative Parties - The funding for this study should come from EPRI. The cooperation of utilities and financial institutions is especially important for the success of the study and value of the report.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: CASH FLOW

RESEARCH TOPIC: SIMPLIFIED CASH FORECASTING

1. Problem Statement - The objective of this work is to develop a simplified procedure for predicting future cash needed to maintain construction operations. This procedure would be based on the cash flow requirements of prior projects.
2. Importance - The need for reliable cash flow forecasting is well recognized. The present trend is to modify scheduling networks to include cash flow data and algorithms, and then to use these modified programs to produce cash flow forecasts. This approach has proven to be very expensive.
3. Research Approach - The investigator will obtain actual cash flow and progress data from the utilities. Data concerning unused reserves, cash shortages, and methods of prediction will also be collected. The investigators will test a variety of techniques for predicting future cash flow utilizing historical data. The time and cost of these simplified methods will be compared to the time and cost of network predictions.
4. Anticipated Results - A report will be published which will make suggestions for simplified cash forecasting. The findings of the study will also be included.
5. Research Implementation/Cooperative Parties - The funding for this study should come from EPRI. The cooperation of utilities and financial institutions will be necessary for the success of the study.

3.4 Economies of Scale

3.4.1 Problem Statement

In the construction industry, the cost of building a structure or plant which is twice the size of another similar structure or plant is usually less than twice the cost of that similar structure or plant. This is due to discounts on larger material quantities, worker learning curves, duplication of work, and other factors. The resultant savings due to these factors are generally termed economies of scale. For example, the costs associated with a 200 gpm pump are nearly identical to the costs associated with a 100 gpm pump. This is because even though the 200 gpm pump is twice the capacity of the 100 gpm pump, it does not cost that much more to manufacture or install.

A method of forecasting plant costs which accounts for the economies of scale is given by the equation

$$y = c x^k, \text{ where}$$

y = plant costs;

x = plant capacity;

c = constant of proportionality; and

k = economy of scale coefficient

When the value of k is less than one, this equation says that the cost per unit of plant capacity decreases as the plant capacity increases but this decrease occurs at a decreasing rate.

In the petro-chemical industry the rule of thumb used to account for the economy of scale is an economy of scale coefficient equal to 6/10. In general, when there are economies of scale, this coefficient will have a value between zero and one.

Suppose k has a value greater than one. In such a case, the cost per unit of capacity increases as the plant size increases and it is said that there are diseconomies of scale.

In the construction of nuclear power plants there exists the question of whether the plants of the present 1000 to 1300 MW capacities are benefitting from anticipated economies of scale. The high rate of manpower turnover, the fast track schedule requirements, and the duplication of work crews to get work done faster are factors which lead to diseconomies of scale. C

3.4.2 Importance

There is a growing concern that nuclear power plants do not exhibit significant economies of scale. This concern is expressed by Joseph Tenicki, Vice President of The Irving Trust Company. "We are no longer in a decreasing cost business. We have probably exhausted most of the efficiencies and benefits from improved technologies and economies of scale, certainly for the foreseeable future." (13:1) Investigation into the reasons for the unapplicability of the economy of scale to the nuclear construction process is, therefore, extremely important because economies of scale are such an important means of reducing first costs of plants.

The determination of the size of the plant affects the economies of scale that are possible. The marginal change in plant costs decreases as the plant size increases, but the decrease occurs at a decreasing rate. The most optimum savings due to the economies of scale is, therefore, very much dependent upon the chosen plant capacity. This illustrates the need for an investigation into the factors considered

at the time the capacity of the plant is chosen.

The high cost of financing the construction of a nuclear power plant and the contraction of time to construct the plant may be contributing to the diseconomies of scale. In addition, the number of work crews is being increased to perform the construction more quickly. This negates the economies of scale possible from the worker learning curves. At the same time, the worker turnover rate is characteristically very high on nuclear power plant projects. This tends to increase costs relative to smaller projects having negligible turnover. We now have sufficient data from the construction of previous nuclear power plants and from the plans presently being constructed to investigate the situation and determine what kind of economies of scale are achieved in this type of construction. Assumptions concerning economies of scale need to be re-examined.

3.4.3 Research Topics

In the problem area of Economies of Scale, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Impacts of Changes and Hold Points and 2) Plant Capacity.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: ECONOMIES OF SCALE

RESEARCH TOPIC: IMPACTS OF CHANGES AND HOLD POINTS

1. Problem Statement - The objective of this work will be to quantify the impacts of changes and hold points on the direct costs of performing work when these changes or hold points interrupt continuous activities.
2. Importance - The benefits of economies of scale have not been realized in large nuclear power plants. The frequent design changes and the hold points may partly explain the lack of the economies of scale.
3. Research Approach - The investigators, in cooperation with government officials, utilities, and others, will select representative areas and classes of work for study. In these areas, the frequency of hold points will be varied and the impacts assessed. Also, areas in which very few changes were needed, will be compared to those in which many changes were needed.
4. Anticipated Results - The time and cost impacts of changes and hold points will be quantified by class of work. The impacts on the total project time and cost will be estimated utilizing this data.
5. Research Implementation/Cooperative Parties - The funding for this study should come from the federal government and EPRI. The cooperation of utilities, designers, contractors, and others will be necessary for the success of the study.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: ECONOMIES OF SCALE

RESEARCH TOPIC: PLANT CAPACITY

1. Problem Statement - The objective of this study is to quantify the economies of scale associated with plant capacity. If there are no economies of scale, then the reasons should be investigated.
2. Importance - It is not clear that plants in the 1000 to 1300 MW range are benefitting from economies of scale. If the bus bar cost is not significantly reduced when compared to smaller plants, then these larger plants may not be justified.
3. Research Approach - The investigators will examine data concerning the cost and capacities of plants, adjusted for inflation, and estimate the impacts of economies of scale. Special attention will be directed toward explaining the reasons for the diseconomies of scale.
4. Anticipated Results - A report will be published which will present the findings concerning the economies of scale and the reasons for the diseconomies of scale if present. Recommendations will be made concerning the optimum size of nuclear power plants.
5. Research Implementation/Cooperative Parties - The funding for this study should come from the federal government and EPRI. The cooperation of the utilities, designers, and contractors will be required.

3.5 Disaggregation

3.5.1 Problem Statement

Disaggregation refers to the breaking down of a unit into its basic parts. In the planning context, a hierarchy of decisions is made over a given planning horizon. Long range decisions provide the guidelines or constraints for shorter range decisions. Long range decisions must be made in aggregate terms to keep the planning process manageable. Once these plans have been formulated, they must be broken down into a more detailed form so that the goals of the organization are met. The process of decomposing the more aggregate long range decisions to arrive at short range decisions which best accomplish the organizational goals is called disaggregation.

This disaggregation process has application in the construction of nuclear power plants. The unit plant must be broken down into smaller parts to facilitate construction. The problem associated with this application is to determine the most effective way of disaggregating and also to determine the proper level of the disaggregation.

In the construction of nuclear power plants, it is possible to standardize work packages across trade lines to increase competition. This may allow smaller construction companies to be involved in making smaller projects out of the one nuclear power plant. The process of formulating these work packages is a disaggregation process.

The problem associated with these breaking down procedures is to determine the most effective way to divide the plant into smaller work packages and to determine the optimum size of these packages.

3.5.2 Importance

The typical nuclear power plant is a massive and complex facility. The construction personnel must disaggregate the total construction schedule down to shortened phases to facilitate the construction operation. This is not easily done on the complex nuclear projects due to the number of variables involved. The impacts of these decisions, however, have a tremendous effect on the costs of construction. The disaggregation process application must be investigated to discern the feasibility and applicability of the disaggregation process to nuclear power plant construction.

Nuclear power plants are so massive that only a few construction organizations are large enough to handle the work. While these large firms would naturally deny the lack of competition on these big jobs, the level of competition is restricted by the project size. Given the large number of capable construction companies in this country, the level of competition could be increased by partitioning the work to allow capable smaller companies to compete.

Many of the inefficiencies which are characteristic to nuclear power plants are due to disaggregation type problems. Hence, the investigation into this area is important to efficient construction of the nuclear power plants and to the future of the nuclear industry.

3.5.2 Research Topics

In the problem area of Disaggregation, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Size and Number of Firms and 2)

Quality Assurance.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: DISAGGREGATION

RESEARCH TOPIC: SIZE AND NUMBER OF FIRMS

1. Problem Statement - The objective of this work is to evaluate the prospective costs and benefits which might result from more extensive or differing methods of disaggregating the construction work on nuclear power plants. In particular, the possible utilization of smaller contracting companies will be investigated.
2. Importance - One of the obvious characteristics of nuclear power plant construction is the relatively few and correspondingly large contracting companies. If the time and cost of construction can be decreased by increasing competition and involving more smaller companies in the construction, then disaggregation is important.
3. Research Approach - The investigators will review the present methods of disaggregating nuclear power plant work into contract packages. The factors for and against the disaggregation to involve smaller firms will be investigated. Suggestions concerning the methods for performing the disaggregation will be also investigated.
4. Anticipated Results - The relative costs and benefits of utilizing smaller companies will be reported. Present methods of disaggregation will also be reported and recommendations will be made concerning the methods of disaggregation.
5. Research Implementation/Cooperative Parties - The funding for this study should come from the federal government and EPRI. The success of the study will largely depend upon the cooperation of utilities, A-E firms, and contractor organizations.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: DISAGGREGATION

RESEARCH TOPIC: QUALITY ASSURANCE

1. Problem Statement - The objective of this work is to test alternative methods of achieving quality assurance objectives.
2. Importance - The practice used in quality assurance which forces workers to stop at designated "hold points" and wait until inspectors record information and give approval to proceed can be a costly and time consuming process. A study to assess alternative methods of disaggregating quality assurance responsibilities is important.
3. Research Approach - The investigators will evaluate present inspection methods including time delays due to hold points, actions taken by QA personnel, the time for these actions, and the qualifications and training of QA personnel. Alternative methods will be investigated and the costs and benefits will be assessed.
4. Anticipated Results - The study results will be fully documented and published for use by interested parties when contemplating quality assurance decisions. The report will include suggestions for quality assurance improvements and the cost/benefit analyses of alternative methods.
5. Research Implementation/Cooperative Parties - Funding for this study should come from the federal government. The success and value of the study will depend, to a great extent, upon the cooperation of utilities, contractors, and designers.

3.6 Transferability of Macro Management Methods

3.6.1 Problem Statement

Macro management methods are those management methods that are appropriate to an industry as a whole or some segment of the industry (e.g., all nuclear power plant construction projects or all valve manufacturers). Transferability refers to the application to nuclear power plant construction of those macro management methods that have proven to be successful in other industries or other segments of the construction industry.

An industry which has made many technological advances in the past two decades is the aerospace industry. One specific technology advance that has applicability in the construction industry is the computerized design system. A review of the aerospace developments should be made to identify advancements such as computerized design systems which may have applications in the construction of nuclear power plants.

A segment of the construction industry may offer some further applications to the construction of nuclear power plants. Currently in progress is a massive construction program in Saudi Arabia. Some of the management systems, methods, and controls that are being used to coordinate work activities on many large scale projects in Saudi Arabia may lend themselves to the nuclear power program here in the United States.

An organization that manages a large portion of the Saudi work is the U. S. Army Corps of Engineers. Some of the Corps management methods may be applicable to the construction of nuclear power plants. One such method is the automatic data processing system that the Corps uses to track materials from suppliers all the way to the project. An

overall investigation of the Saudi projects may identify items of applicability in the nuclear power plant construction process.

3.6.2 Importance

Throughout the course of the space program, numerous advances in technology were developed. This may be a significant source of improvements for nuclear power plant construction programs.

The management systems that were developed to manage the massive space program may be applicable to the construction industry. The computerized design systems are other examples of possible technology transfers. It is important that an investigation into the program be conducted to make the best use of these technology advancements. They may contain solutions to the problems experienced in the construction of nuclear power plants.

Experience gained from the Corps of Engineers project in Saudi Arabia deserves consideration as a possible solution to problems experienced on nuclear power plant projects. The total purchase of U. S. construction through the Corps of Engineers in the year ending October, 1977 will be \$670 million. (17:28) This represents a significant enough amount of construction management to be comparable to the nuclear projects.

The automatic data processing system, which the Corps has developed to track materials and equipment from suppliers all the way to the project is expected to be helpful in eliminating contingencies included in bids to cover delivery delays and demurrage charges for freight on board ships awaiting berth space. In addition, the system is seen as a relief to many construction headaches because it "gets the logistics off

the backs of the contractors". (17:31) Many of the problems experienced by contractors on nuclear power plant projects are logistic in nature. A transfer of technology may be helpful in solving some of these problems and reducing the amount of costly time delays.

The money spent to construct the nuclear power plants will ultimately be recovered through the rates charged to the consumer for use of the generated power. Any investigation that may lead to the lessening of the financial burden on the consumer is a desirable undertaking.

3.6.3 Research Topics

In the problem area of Transferability of Macro Management Methods, there are many research topics which might lead to a reduction in the time and cost of construction of nuclear power plants. This section will present two such research topics. These are 1) Corps of Engineers Methodology and 2) Aerospace Technologies.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: TRANSFERABILITY OF MACRO MANAGEMENT METHODS

RESEARCH TOPIC: CORPS OF ENGINEERS METHODOLOGY

1. Problem Statement - The objective of this study is to identify and facilitate the transfer of management methods developed by the U. S. Army Corps of Engineers to the construction of nuclear power plants.
2. Importance - Tax supported research and development work for the Corps of Engineers at CERL and other locations have produced computer programs and management systems which might be utilized by the nuclear construction industry.
3. Research Approach - The investigator will review management methods which have been developed by the Corps and used in such activities as the management of Saudi Arabian construction projects. The investigators will determine those methods which may be transferable and they will also determine the modes of transfer. This will include an investigation of any constraints and limitations.
4. Anticipated Results - Corps of Engineers programs and methods which might help to reduce the time and cost of nuclear power plant construction will be reported. This will include a presentation of the constraints and limitations for transfer.
5. Research Implementation/Cooperative Parties - The funding for this study should come from the federal government. The cooperation of utilities, designers, constructors, and Corps of Engineers representatives will be required for success of the study.

SUBJECT: DELAYS IN NUCLEAR POWER PLANT CONSTRUCTION

GENERIC AREA: OTHER SPECIFIC AREAS

PROBLEM AREA: TRANSFERABILITY OF MACRO MANAGEMENT METHODS

RESEARCH TOPIC: AEROSPACE TECHNOLOGIES

1. Problem Statement - The objective of this work is to identify and facilitate the transfer of management methods which have been developed by NASA and various aerospace companies to the construction industry.
2. Importance - Computerized information systems, computerized design, and other technological advancements of the aerospace industry have been developed. The transfer of these methods and systems may help to reduce the time and cost of nuclear power plant construction.
3. Research Approach - The investigators will review the management methods that have been developed by the aerospace industry. The investigators will determine those methods which may be transferable and they will also determine the modes of transfer. This will include an investigation of any constraints or limitations.
4. Anticipated Results - Aerospace programs and methods which might help to reduce the time and cost of nuclear power plant construction will be reported. This will include a presentation of the constraints and limitations for transfer.
5. Research Implementation/Cooperative Parties - The federal government should take the responsibility for funding this work. The study will require the cooperation of utilities, designers, contractors, and aerospace industry representatives.

3.7 Summary

In this chapter the specific problem areas addressed were: 1) Plant Siting; 2) Cash Flow; 3) Economies of Scale; 4) Disaggregation; and 5) Transferability of Macro Management Methods. The discussions presented the Problem Statement, the Importance, and the Research Topics.

The objective of the research topics is to eliminate or minimize the delays associated with the problem areas mentioned above.

CHAPTER 4

SUMMARY AND RECOMMENDATIONS

The work in this thesis is part of a major study of the delays in the construction of nuclear power plants. In Chapter 1, a brief description of the overall project was presented. The topics included in this thesis and the topics excluded from this thesis were also presented. In Chapter 2, a Problem Statement, an Importance statement, and the Research Topics for each of nine problem areas contained within the generic problem area of the Design/Construct Interface were given. Within each problem area, two research topics were presented. In Chapter 3, the approach was similar to that in Chapter 2 with the exception that the research topics were for Other Specific Research Areas related to nuclear power plant construction.

The author has recommendations concerning three areas. These areas are the funding of management research, the data collection in construction research, and the management of construction research.

It is clear to all parties involved in the nuclear construction process, that the time and costs of construction are excessive. Yet, the funding of management research, aimed at reducing the time and cost of construction, is virtually non-existent. For example, the Electric Power and Research Institute (EPRI) had a budget of \$180 million for 1977. Of this amount, approximately \$42 million was directed at the nuclear power segment. However, this funding is for research into hardware related areas and areas concerned with lowering the operating costs of nuclear plants. None of this money was directed toward reducing the time and cost of construction, or first costs, of

these nuclear plants. The prerequisite for significant reductions of the time and cost of construction of nuclear power plants is the flow of industry and governmental funds for this purpose. This author recommends that a high level commission be established for the purpose of generating and sustaining the flow of funds for research in the construction industry.

In the data collection and problem identification stages of research reported in this thesis, the data was collected long after the fact. This resulted in data which reflects the self interests of the respondents. Consequently, the data is biased and incomplete. It is recommended that in future research, impartial trained observers be stationed on each major project for the purpose of collection of data at the time a problem occurs. These observers should be trained to collect data for present and future research projects under the direction of educational and research institutions. These observers would be a major source of management personnel for the large projects of the future. It is recommended that this be a high level internship program designed to meet the needs of the future in the construction industry.

Another problem in the data collection and problem identification stages of studies results from the policy that a full disclosure of the sources of information be made. The concern is that important information may be withheld when sources are disclosed. In the problem identification stage it is important that a degree of confidentiality be maintained to identify the root problems. Therefore, it is recommended that neither legislative nor administrative bodies force the disclosure of information sources.

In the construction industry, research is presently being conducted primarily to satisfy the particular self interests of the funding sources but not to satisfy the overall industry needs. No management organization and no master plan for research exists in the construction industry. It is recommended that a high level coordinating commission be established to coordinate the national construction research effort.

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APPENDIX A

SITE SELECTION AND EVALUATION (5:5.15)

1. Client Requirements
 - 1.1 Steam System Operating Considerations
 - 1.2 Development of Plant Envelope
 - 1.3 Satisfaction of Community Acceptance Standards (traffic, noise, odor, appearance)
 - 1.4 Schedule Constraints on Site Availability and Development
 - 1.5 Least Cost of Acquisition and Site Development
2. Site Selection
 - 2.1 Determination of Criteria
 - 2.1.1 Engineering
 - 2.1.2 Environmental
 - 2.1.3 Institutional (legal, political, regulatory)
 - 2.1.4 Air Quality
 - 2.1.5 Transportation and Traffic
 - 2.1.6 Community Aspects (complaning (sic) related functions)
 - 2.2 Identification of Candidate Sites
 - 2.2.1 Sites Designated by Client
 - 2.2.2 Sites Designated by GAI
 - 2.3 Acquisition of Data and Information
 - 2.3.1 Collection of Available Data (climatic, air quality, plant operating parameters, traffic, existing land usage, applicable regulations)
 - 2.3.2 Acquisition of Current Data (noise level survey, local traffic count, local air quality sampling)
 - 2.3.3 Research Available Literature

APPENDIX A (Continued)

- 2.4 Evaluation and Comparison
 - 2.4.1 Tabulation of Results
 - 2.4.2 Scoring and Ranking
- 2.5 Recommendations
 - 2.5.1 Prime Site
 - 2.5.2 Alternatives
 - 2.5.3 Qualifications
- 3. Procedure for Acquisition of Property
 - 3.1 Survey and Evaluation
 - 3.2 Negotiation for Access and Option to Purchase Agreement
 - 3.3 Negotiation for Purchase or Lease with Option to Purchase
- 4. Preparation of Environmental Assessment Plan
- 5. Preparation of Community Acceptance Plan

VOLUME 1 SECTION 5

RESEARCH NEEDS
CONSTRUCTION METHODS, EQUIPMENT & MATERIAL

By

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SECTION 5 CONSTRUCTION METHODS, EQUIPMENT, AND MATERIALS

5.1 INTRODUCTION The research areas outlined here deal directly with field operations of the construction of nuclear power plants. However, some of these research areas overlap into the design functions. These outlines deal with construction methods, materials handling, job-site planning, testing procedures, QA guidelines, modularization, off-site pre-fabrication, and computer-based modelling.

For the purposes of funding, projects should be selected from the following list in the ascending order:

- Site Use Control
- Materials Handling Systems
- Modularization
- Off-Site Fabrication
- Construction Methods Survey
- Construction Methods Improvement
- Computerized Models
- Non-Destructive Testing
- Survey of Quality Assurance Standards
- Statistical Quality Control

Some of the projects such as the computer based model or the QA survey may prove to be too large for one team to handle. In those cases, it is recommended that the project be divided into three segments along the lines of civil, mechanical, and electrical systems. It would be highly desirable that all these projects be completed within 18 months of their initiation.

5.2 CONSTRUCTION METHODS SURVEY

5.2.1 PROBLEM STATEMENT To contact designers and constructors of in-construction and recently constructed nuclear plants in order to obtain details of methods used for construction or assembly of similar systems in different plants.

5.2.2 IMPORTANCE Methods employed to fabricate, construct, or erect a system are varied and generally are affected by experience of the utility, the designer, and the constructor. The choice of these methods is sometimes also affected by time or cost constraints. Not all the construction personnel are aware of all different procedural options available for a job. Therefore, it would be highly desirable to prepare a complete list of alternate methods used for each of the major construction tasks. Such a list will aid the designers and particularly constructors in selecting procedures best suited to the needs and most compatible with constraints of a specific plant.

5.2.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) contact all utilities, designers, and constructors in order to obtain the breakdown of construction activities into an appropriate number of work packages.
- b) for each of these work packages, list procedures used in recently-constructed or in-construction plants.
- c) add to the list, procedural modifications recommended by construction personnel to current practice.
- d) add to the list techniques having time and cost-saving potentials not employed yet.

5.2.4 ANTICIPATED RESULTS The product of this research will be a report dividing the construction process into appropriate work packages and for each work package listing alternate operational methods. The methods will include those that have been used, those that will be used and those that could be used to expedite the process and reduce total costs. This report should be promptly sent to all utilities, designers, and major constructors.

5.3 CONSTRUCTION METHODS IMPROVEMENT

5.3.1 PROBLEM STATEMENT To develop more rational and systematic procedures for design of construction methods.

5.3.2 IMPORTANCE The selection of procedural details and methods for various construction activities are usually based on previous experiences of the designers and constructors. Although the results are generally satisfactory, sometimes two groups may develop two entirely different sets of procedural details for the same work package. In such circumstances the time, cost, and manpower trade-offs of these two systems may not be immediately obvious. The need for trade-off analysis will be filled by rationally formalized design procedure incorporating the field experience of various constructors.

5.3.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) divide the total construction activity into appropriate number of work packages.
- b) for each work package determine general requirements of the constructed or fabricated facility.
- c) develop a design procedure that, based on above requirements, determines the type and size of equipment to use, sequence of activities, procedural details, and manpower requirements. The design should be detailed enough to allow reasonable estimates of manpower non-productive time, equipment idle, and wasted material. Possibility of using computers in some or all of these procedures should be investigated. It is highly desirable to have a system such as ICES for construction methods design.

- d) develop procedures by which the method can be optimized in terms of equipment, manpower, duration, and total cost.

5.3.4 ANTICIPATED RESULTS The design procedure developed as part of this research will be contained in a report subdivided into the major work packages. Some or all of these design procedures will be in the form of user-oriented computer programs. Utilities as well as design and construct firms should be promptly notified of the availability of the report and computer aided design procedures. Tapes of the computer program should be readily available for trial use.

5.4 MATERIALS HANDLING SYSTEM

5.4.1 PROBLEM STATEMENT To develop a system in order to facilitate storing, locating, and retrieval of parts, equipment, and materials necessary during the construction.

5.4.2 IMPORTANCE The construction of a nuclear power plant requires as much as 400,000 components. Although some of these items are large quantities of the same item, they all have to meet specific QA standards and engineering requirements for the intended system. Upon arrival on site, they must be stored for timely retrieval. A recent survey of the nuclear power plant construction industry indicates a strong demand for improved materials handling systems in order to reduce time and cost required to have materials and equipment ready for each work package.

5.4.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) conduct a survey of systems currently in-use.
- b) solicit opinions of materials handling personnel regarding desired capabilities and requirements.
- c) based on the above requirements, develop a user-oriented system that will monitor the materials availability from initial design to final installation. The system should allow for several milestones through the procurement cycle. The system should select a storage location on site and flag for retrieval at the appropriate time. The system should be interfaced with construction scheduling in order to flag possible non-availabilities well in advance. Sorting

capabilities should be built into the system such that the information can be retrieved according to different requirements.

- d) test the system on a small scale at a construction site.
- e) correct all observed deficiencies. Add desired features.

5.4.4 ANTICIPATED RESULTS The user-oriented materials handling system developed and tested under this program will be made available, together with user's manual and research report, to those utilities or constructors interested in implementing the system. Although the details of the system need not be widely distributed, a short announcement describing the system should be sent to all the utilities, designers, and constructors.

5.5 NON-DESTRUCTIVE TESTING PROCEDURES

5.5.1 PROBLEM STATEMENT To develop and evaluate non-destructive methods for determining strength and soundness of various components.

5.5.2 IMPORTANCE Assessment of strength, ductility, and soundness of concrete, welded reinforcing bars and other components are usually conducted by the traditional destructive techniques. These techniques consume a substantial amount of time for testing. Further, they delay the construction and fabrication substantially. It is highly desirable to develop methods of testing that are non-destructive and quick.

5.5.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) prepare a list of materials and components that are usually tested destructively.
- b) for each of the above, determine the specific properties that are required such as ultimate strength, extension to failure, etc.
- c) through a search of literature and innovative developmental process, identify non-destructive methods that infer those properties with an acceptable degree of accuracy. Special emphasis should be placed on compactness of machinery, ease of operation, reliability, and conciseness of records.
- d) test these methods on a construction site to document the correlation of their field results to current destructive techniques. Attempts should be made to receive inputs regarding these techniques from quality control personnel and from the NRC.

5.5.4 ANTICIPATED RESULTS The product of this research will be a report listing the non-destructive techniques that will provide, with a reasonable degree of accuracy, the results that are currently obtained through destructive testing procedures. This report should be distributed to all quality assurance departments.

5.6 MODULARIZATION OF SUBSYSTEMS

5.6.1 PROBLEM STATEMENT To develop guidelines and rationale for pre-fabricating or preassembling identifiable subsystems at vendors' locations.

5.6.2 IMPORTANCE Currently, most of the components are prepared by vendors and transported to the site for final positioning and assembly. Towards the latter part of construction activities, limitations on working space restricts the productivity of various crafts. If subsystems were assembled at the vendor's location according to owner's specifications, not only all the necessary working space can be allotted, but overall efficiency can be improved because work is done under a more controlled environment.

5.6.3 RESEARCH APPROACH In order to achieve the goals of this research, the following tasks would be performed:

- a) divide the entire plant into the logical major systems and work packages.
- b) divide each system into identifiable subsystems such that each subsystem can be built and tested at the vendor's facility. (e.g. pump with associated valves and switches, a segment of cable tray with cables, pre-wired control boxes, pre-welded pipe segments).
- c) in cooperation with a utility, incorporate this scheme into design of a proposed plant. Receive input from designers and NRC regarding merits of this scheme relative to the current scheme.
- d) incorporate the inputs into the system. Develop a manual for modularization.

5.6.4 ANTICIPATED RESULTS The product of this research will be a set of guidelines to be used by the designers who prefer modularized subsystems. Use of such a manual would lead to its refinement which would hopefully lead to standardized modules. The report and the manual should be distributed to all utilities, design firms and constructors.

5.7 OFF-SITE PREFABRICATION

5.7.1 PROBLEM STATEMENT To develop guidelines and rationale for assembling and fabricating identifiable subsystems by the constructor's forces but at a detached site near the plant.

5.7.2 IMPORTANCE Currently, most of the components are prepared by vendors and transported to the site for final positioning and assembly. Towards the latter part of construction activities, limitations on working space restricts the productivity of various crafts. If portions of each system were assembled by the contractor's forces but at a detached location, overall speed and productivity would be improved. Further, direct control can be exercised over these activities by project scheduling.

5.7.3 RESEARCH APPROACH In order to achieve the goals of this research, the following tasks would be performed:

- a) divide the entire plant into logical major systems and work packages.
- b) divide each system into identifiable and separate subsystems such that each can be pre-assembled at a detached location. Special attention should be paid to ease of final interfacing between these subsystems, overall space limitations of the site, and labor limitations.
- c) in cooperation with a utility, incorporate this scheme into design of a proposed plant. Receive input from designers, constructors and NRC regarding merits of this scheme relative to the current scheme.
- d) incorporate the inputs into the system. Develop a set of guidelines for off-site prefabrication.

5.7.4 ANTICIPATED RESULTS The product of this research will be a set of guidelines to be used by the designers and constructors who prefer decentralized construction. The report and the complete set of guidelines should be distributed to all utilities, design firms, and constructors.

5.8 SITE USE CONTROL

5.8.1 PROBLEM STATEMENT Develop a set of guidelines or a computer based system in order to design an optimum job-site plan.

5.8.2 IMPORTANCE The design of a job-site plan is normally conducted, based on previous experience and empirical guidelines. However, in order to make systematic improvements in these design procedures, a formalized design procedure must be established first. With such a procedure, not only less experienced personnel will be able to conduct the design, but improvements can be incorporated more easily and effectively.

5.8.3 In order to achieve the goals of this research, the following tasks would be performed:

- a) visit several sites to obtain details of site layout, traffic patterns, and warehousing patterns.
- b) prepare a list of all activities and space requirements for the job-site. The list would indicate time-dependent differences in requirements. Prepare a time-dependent list of proximity requirements. Prepare a materials handling network.
- c) develop a design routine or a user-oriented computer based system that considers all the above items in addition to terrain considerations in order to generate an optimized layout.
- d) present the routine or system to two utilities for use in design of a proposed site. Receive critique and suggestions from field engineers.

- e) update and refine the design routine or computer-based system in order to show the suggestions. Prepare a user's manual for the computer system.

5.8.4 ANTICIPATED RESULTS The product of this research will be a report describing the design philosophy and either a manual describing the design routine or a manual describing the use of the computer-based system together with an object tape. The reports should be distributed to all utilities and constructors. The tapes should be available on request.

5.9 COMPUTERIZED SIMULATION OF CONSTRUCTION OPERATIONS

5.9.1. PROBLEM STATEMENT To develop a computer model of the construction process in order to study interaction of men, machinery, and plan changes.

5.9.2 IMPORTANCE As the construction progresses, the schedulers and constructors continually change the sequence of activities and modify operational schemes to optimize the operations with respect to manpower, machinery, and other constraints. A computer model will be a very useful tool in aiding the responsible personnel to analyze the forthcoming events so that they can make appropriate decisions.

5.9.3 RESEARCH APPROACH In order to achieve the goals of this research, the following tasks would be performed:

- a) obtain details of execution of all work packages, activities, and work units. Such details should include machinery, working space, manpower, materials, sequence, weather, lighting requirements, QA involvement, etc.
- b) develop a model for each work unit. These models should have time-dependent features such that status of men, machinery, etc., after completion of a certain percentage of the work can be easily obtained.
- c) this model should be interfaced with the scheduling program in order to identify the concurrent work units. Then for each set of concurrent work units, the total requirements of manpower, machinery, working space, etc., would be compared with available values. Cases of conflict or deficiency should be flagged for the appropriate schedule change by the personnel.

- d) Key the model into the activities of a currently in-construction plant. Develop outputs based on the in-force schedule of the plant. Refine and debug the program. Solicit and implement suggestions of field personnel into the model.

5.9.4 ANTICIPATED RESULTS The product of this research will be the object deck or object tape of this model together with a user's manual. The availability of this system should be brought to the attention of all utilities and constructors. The program would be available on request.

5.10 A SURVEY OF QUALITY ASSURANCE STANDARDS

5.10.1 PROBLEM STATEMENT To conduct a survey of all utilities, constructors, and designers in order to obtain the quality assurance standards and determine the major differences in requirements for materials and equipment.

5.10.2 IMPORTANCE QA/QC standards are developed by utilities or constructors based on regulatory guides issued by NRC. Since the resulting standards depend partly on individual interpretations of the NRC guides, there are differences in strictness of methods devised to comply with a specific regulatory guide. Therefore, it is possible that some standards could be relaxed without violating the corresponding regulatory guide.

5.10.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) obtain QA manuals for the utilities, constructors, and designers.
- b) extract the materials, equipment, and size standards and tabulate them with the NRC guides they were intended to comply.
- c) for each requirement, obtain the rationale for the two QA standards that seem to be the most relaxed and the two that seem to be the least relaxed.
- d) develop a set of recommendations keyed to specific regulatory guides. These recommendations should outline the basic acceptable standards complying with the guide.

5.10.4 ANTICIPATED RESULTS The product of this research will be a set of interpretations keyed to the NRC guides. Using these interpretations, the utilities will be able to judge if and how far their QA standards are above

the NRC requirements. An abbreviated form of this report should be sent to all utilities indicating that full text will be available on request.

5.11 STATISTICAL QUALITY CONTROL

5.11.1 PROBLEM STATEMENT To study the feasibility of employing probabilistic techniques to determine compliance of features of materials and equipment.

5.11.2 IMPORTANCE The use of deterministic methods are more widespread than probabilistic techniques in evaluation of strength and other features of materials used in nuclear plant construction. However, deterministic methods, quite often result in unnecessary changes and materials generally are too strong for the requirements.

5.11.3 RESEARCH APPROACH In order to reach the goals of this research, the following tasks would be performed:

- a) obtain testing procedures and test results for several QC operations.
- b) using statistical routines determine how much, if any, the final value of the tested items will be above intended requirements.
- c) develop procedural guidelines for probabilistic approach to these QC operations. Indicate the savings in materials and excess strength that will be obtained using this technique.

5.11.4 ANTICIPATED RESULTS The product of this research will be a set of documented results indicating the effective overdesign using deterministic techniques. The report will also contain guidelines for implementing the probabilistic approach into QC operations. This report should be made available to all utilities, designers, and constructors.

5.12 SUMMARY AND CONCLUSIONS

The research areas outlined in this chapter are those of prime interest to utilities and constructors, although some designers may be interested in or be affected by the results of these research efforts. The Federal Government is in a very good position to provide most of the funding required by these projects. These funds will then be complemented by the state governments, utilities, trade associations, design firms, and constructors. Further interest will be demonstrated by utilities, design firms, and constructors by providing access to the site and office files, gathering information, and facilitating the conduct of research and implementation of research. Since the primary function of utilities and design/construct firms is not research, these projects can best be conducted at a university with assistance and information provided by the former. If the cost of such cooperation by utilities or design/construct firms becomes substantially large, then they should be reimbursed for parts of such costs from project funds.

These research areas deal with field operations such as construction methods, materials handling, job-site planning, modularization, and off-site pre-fabrication. Therefore, the desirable tangible benefits of the results of these projects should be felt by the cooperating utilities or design/construct firms immediately upon implementation.

VOLUME I SECTION 6

**RESEARCH NEEDS
CONSTRUCTION COORDINATION & COMMUNICATION**

By

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Senior Project Manager
Kellogg Corporation**

SECTION 6

CONSTRUCTION COORDINATION AND COMMUNICATION

6.1 INTRODUCTION

Coordination and communication presents unique problems on nuclear power plant construction as contrasted to conventional plant construction. The most obvious contrast is the time it takes to construct comparable sized plants -- approximately 3 to 4 years for a 1,000 MWe fossil plant and 7 to 8 years for a nuclear plant. This excludes initial planning, preconstruction permit review and power ascension in both instances. On nuclear plants the complexity of design becomes greater because of the emerging technology in this field. Quality control and quality assurance considerations predominate all work, and while the benefits of these programs are being extended to non-nuclear construction, implementation continues to have a dramatic effect on the level of reporting and documentation required. Changes, caused to a great extent by external factors not under the control of project management, may impact a job more than any other factors. The "moving target" of changes, which cannot be predetermined and planned for, present virtually unmanageable situations where the only controllable elements are the speed and cost effective manner in which the owner, his designers and contractors react to these changes.

Within the generic problem area of communication and coordination, specific problems have been identified where research is recommended. This research should be directed at the cause/effect relationship of the problem, its impact on the industry (time and cost) and recommended courses of action that should be pursued to eliminate or mitigate the problem. Specific areas recommended for investigation include:

- Project Organizational Structure

- Management Information Systems
- Procurement Problems — Class I Valves
- Project Scheduling
- Risk Analysis of Schedules
- Contractual Incentives Program

6.2 PROJECT ORGANIZATIONAL STRUCTURE

6.2.1 Overview.

Many management theorists define responsibilities by functions (which usually means by activity) and then assume that the desired objectives will automatically be achieved. This viewpoint is a fundamental error throughout much organizational planning today. People too often proceed in undesired directions unless objectives and the functional structures are correlated. Efforts to define a "science of organization" have frequently tended to focus on definitions of formal structures, divorced from the dynamics of people at work. These structures have frequently been unrealistic because they do not recognize that people -- not structures -- accomplish things. An organizational structure is only relevant if it establishes a vehicle for problem solving, creativity, communication flow, and decision making. Each structure must, therefore, be tailored to the type, scope and duration of the project in question. Structures that were successful for projects of one to two years duration and involving relatively few internal and external entities, cannot be presumed to be appropriate for major nuclear projects lasting nearly a decade and requiring input from hundreds of diverse individuals and agencies. Moreover, the contractual and personal relationships that exist between the parties determine to a great degree the success or failure of the project. The die is cast early in the life of the project and the outcome, in many cases, is predictable. These factors must be kept in mind when establishing and evaluating the organization of owner, designer, construction manager, contractors and suppliers for nuclear plant projects.

From a contractual standpoint, project organization is dictated by one of five basic relationships.

- The owner acts as both designer and constructor, managing all work with his own personnel.

- The owner acts as both the designer and on-site construction manager, contracting directly for construction services.
- The owner acts only in a management capacity; awarding separate contracts for design and construction services.
- The owner contracts for design and construction management services with a single firm which then contracts for construction services. (The owner may or may not sign the construction contracts, but in either case the design/construction management firm does all bid solicitation, negotiation and contract administration.)
- The owner contracts with a single firm to perform the design and construction of the entire facility, subcontracting only specialty work.

Each of these contractual forms presents different factors and problems with respect to project organization and execution, particularly as they affect problem solving, creativity, communication flow, and decision making. Furthermore, an individual owner may be constrained by corporate size, policy, structure or other reasons to one or another of the basic forms. It would be the purpose of this research area to examine each basic form of organization and determine its effectiveness in handling the following observed problem areas:

1. Concentration of Responsibility
2. Impact of Growth in Project Team Size and Duration
3. Focused Problem Solving

6.2.2 Problem Statement

6.2.2.1 Concentration of Responsibility. The concentration of responsibility for project direction is seen as one distinct area where nuclear plant design and construction can be improved. It would be beneficial to determine the various aspects of and the degree to which each of the aforementioned contracting methods could be improved in this area and to develop suggested mechanisms and procedures for accomplishing the improvement.

The essence of nuclear plant project delay can be found in the words "complexity," "long lead time" and "change." There is no doubt that these are the facts of life that have contributed to the disastrous cost and schedule overruns now being experienced. More importantly, the impact of increasing complexity, changing requirements, and time required to incorporate a change, are to a great extent beyond the control of the owner or his managers, designers and constructors. If these cost and schedule impacts can be mitigated at all, it will be through the establishment of mechanisms and procedures to concentrate responsibility for directing the entire project through all phases.

6.2.2.2 Impact of Growth in Project Team Size and Duration. Nuclear plants are inherently more cost effective in large sizes. Large size, however, leads directly to increased complexity and public exposure, which, in turn, demands greater attention to design detail and construction integrity. These all add up to greatly increased manhour requirements for both design and construction activities. In the past the typical project involved a relatively small team of designers, field engineers and construction supervisors for a maximum of two to three years. Today's nuclear plants require several hundred engineers and other non-manual workers, many of whom will be involved for as long as ten years. Knowing how projects have made the successful transition from the informal, quick-turn-around environment to the necessarily more rigid, long term efforts will be valuable information for future projects. Of particular importance would be matters of employee tenure and morale, individual career advancement, and loss of key personnel due to promotion and/or attrition.

Delays in nuclear plant construction can be avoided only if the personnel involved in its execution are satisfied with their work, can work with effective tools, and are motivated towards seeing a project successfully completed.

As projects stretch out and the teams grow larger, the individual worker may become submerged in the organization and lose the innovative ability and quick response initiative that formerly characterized the design/construction industry. The concept of a project that could consume one-third of a career may deter the best construction engineers and managers from becoming involved. Since the demanding nature of nuclear plants needs the best and most talented people, it is essential that these individuals not be lost. It is equally as important that men successful on smaller projects perform as well on the larger, more complex projects. This can be promoted by assuring that effective communications, reporting and decision making procedures suited to such projects are developed and implemented.

6.2.2.3 Focused Problem Solving. The ability to deal with problems, changes, and the unexpected is enhanced by short and direct communication and decision making channels. Having the entire design team at the construction site, however, is obviously impractical. Investigation is needed to determine the optimum engineer/planner/supervisor force required at site and the cost and time effectiveness of the alternate approaches. Audio-visual techniques could possibly substitute for actual on-site presence.

It is essential that the maximum productive use of designers, managers and supervisors be made at times when crucial decisions must be made. Assembling the required talent, communicating, and receiving direction can be as delaying as the problem itself. Successful methods for accelerating this process can be significant in improving overall project performance.

6.2.3 Research Approach.

All recent and current nuclear projects would be reviewed and categorized according to contracting approach. Schedule and cost overruns would then be analyzed to determine if one or more of the approaches was inherently superior.

During this process, the effects of various "environmental" factors unique to each project would be identified to more clearly isolate the impacts due to the decision making process. Once the general relationships and apparent effectiveness of each contracting approach becomes known, specific best and worst case projects for each approach would be identified for specific analysis. The owner of each selected project would be interviewed to determine the mechanisms, procedures, and relationships that were established initially and how they changed, or are changing, through the course of the project. Finally, the most successful mechanisms and procedures will be studied in detail to determine how they might be applied to all contracting approaches via appropriate contract terms, contract timing, team building seminars, etc.

6.2.4 Anticipated Results.

This effort should result in identifying those techniques which have proven most successful in actual practice rather than in theory. These results would then be formalized into specific recommendations for each contract approach.

6.3 MANAGEMENT INFORMATION SYSTEMS

6.3.1 Overview.

Management as an identifiable system has emerged since the turn of the century. In the last 77 years the requirements of more complex business environments and demanding performance time frames have forged the management function into a highly structured system. The system as now practiced is as much an "Art" as it is a "Science." The demands placed on the manager's role are such that a high degree of analytical capability, interpersonal skill, financial acumen, business sense, objective orientation, calculated cool, applied imagination, and creative problem solving is essential to work the system which has evolved.

Construction has always been accomplished in a performance-oriented, time-intensive work environment. Decisions and the results of their implementation occur within short time frames. In the past, this situation has produced an action oriented, reactive management philosophy. The philosophy has been as follows:

"Start right now -- go like hell -- tune the operation as you run and continually apply more push. Those things that become road-blocks or detours should be bowled over and somehow by pure drive the job will be completed on time and within budget."

This philosophy may have worked in the past using a management style of sheer personal determination, long hours, and, basically, a system of wearing the problem out. In today's environment this style is totally inadequate.

The manager's role today is exceedingly more complex, requiring a much more sophisticated form of overall management control. Most projects fail for two reasons: 1) a lack of adequate preplanning and 2) a lack of systematic control. Recognizing these failures, how can the utilities provide their managers with effective system to control time, cost and performance?

Various management information systems are presently in use today

achieving varied results. They range from fairly rudimentary manual systems, to detailed computerized reporting and monitoring systems. Some of these systems have been established by the utilities and others are provided by the designer or construction manager on the project. A few contractors employ management information systems of their own.

The following comments have been voiced by the industry:

"The system just won't work."

"The entire construction process is too complicated and changes which require backfitting cannot be accommodated in the system."

"We are supposed to be operating under a coordinated management information system, but I haven't seen any reports yet."

6.3.2 Problem Statement

What is needed is a management information system that is adaptable to all nuclear plant construction projects which encompasses the entire process -- from the very start of project feasibility through licensing, design, procurement, construction and start-up. The system must be capable of integrating all of the various disciplines throughout the process. It must be manageable, adaptable to different forms of project organizational structure, and capable of producing timely and meaningful information on which management can act. The question of how such a system can have the capacity to accept and produce information for complex projects that can span from ten to twelve years without becoming an unruly "monster" remains to be answered.

6.3.3 Research Approach

Within the confines of this study, it is impossible to list in detail the complete methodology for developing a management information system suitable to the nuclear plant construction process. Rather, this research should present a broad view of existing information systems, refine the results of input from practitioners in the field, develop a model information system,

and disseminate the research results for evaluation. The following four major tasks would be recommended for research.

1. Identify Existing and Operating Systems.
2. Define the Requirements of the System.
3. Design the System.
4. Evaluate the Acceptability and Usability of the System.

6.3.3.1 Identify Existing and Operating Systems. The nuclear power plant industry should be surveyed to determine what systems are presently in operation and the degree to which they are providing meaningful information for project management. This would include contact with utilities, designers, contractors, suppliers, and software firms. Some contact outside the nuclear field may be beneficial such as rapid transit projects, the Trans-Alaska Pipeline and other similar "super projects." These systems would then be evaluated to determine their adaptability to nuclear plant work.

6.3.3.2 Define the Requirements of the System. The requirements of a practical system should be delineated indicating the source method of information transfer, dissemination, storage and retrieval. This "model" system should recognize the needs and constraints currently experienced on nuclear projects. Some sample requirements of this system would be to facilitate management by exception, standardize procedures, provide for optimum utilization of limited resources, facilitate progress payment, cash flow analysis and capital budgeting, and, in general, provide a foundation for effective management analysis and decision making.

6.3.3.3 Design the System. The system design should incorporate the requirements outlined above and be capable of integrating all the various activities from inception to operation while defining their interdependencies. Existing software systems should be used where practicable. Consideration

should be given to the software package availability, vendor support, ease of installation and operation, technical extent, and cost of the system.

6.3.3.4 Evaluate the Acceptability and Usability of the System. The system should be verified for acceptability and usability. It should be the product of the wants, needs, and desires of the nuclear construction industry and not just the perceived ideas of those who are not intimately involved in the business of designing and building nuclear power plants. The report should summarize the work leading up to the system design, describing the system and providing information as to usefulness and cost effectiveness on nuclear power plant projects.

6.3.4 Anticipated Results.

It is anticipated that potential users of the "model system" will review the system and furnish comments which would initiate discussion within the nuclear power industry. This should lead to an upgrading of management information systems and provide a commonality of information that can be shared within the industry as both a check and incentive for better time, cost and performance control.

6.4 PROCUREMENT PROBLEMS -- CLASS 1 VALVES

6.4.1 Overview

Of major concern today is the proper scheduling and interfacing of materials and equipment deliveries with construction. The procurement effort must be organized so that needs are identified and orders placed in sufficient time to insure delivery on the job without causing delay. In order to plan procurement properly, two schedule elements must first be established.

1. The schedule need date to support design and engineering.
2. The schedule need date for construction.

In recent years there has been a general slippage in the progress of the construction work, thus pushing the "need" date downstream. At the same time, there has been an increase in the procurement time -- usually due to manufacturing delays. When the construction delay exceeds the procurement delay, there are usually no problems; when the opposite happens, however, delays to construction will almost always occur.

The one major item of equipment which has been causing delays through un-timely delivery is Class 1 valves. Even when critical or long lead valves are identified and ordered early in the job, some valves will, almost as an absolute certainty, show up late. As a category of equipment, there may be over 10,000 valves on a 1,000 MWe nuclear plant. The design and administrative functions of identifying, specifying, taking and evaluating bids, ordering, monitoring fabrication, insuring quality compliance, and scheduling delivery places heavy burdens on any organization.

6.4.2 Problem Statement

Valve delivery times are increasing at an alarming rate. At the present time there are not enough manufacturers of nuclear class valves. The number of foundries producing castings and forgings has decreased in recent

years because those plants that could not meet environmental requirements and have had to shut down. It has been stated by some that the disadvantage of manufacturing nuclear class valves outweigh the advantages. The initial time and expense of obtaining an N stamp and setting up the necessary procedures for quality control are deterrents in themselves. The cost of bidding is also higher. Nuclear valves are never stocked and the manufacturers continually complain of the fact that there is not always a clear-cut set of specifications for their manufacturer. Specifications vary from one designer to the next and even the owner's requirements may change from plant to plant. Code references may be vague or general in nature. Analytical calculations or physical testing may be required for valves subject to seismic loadings. All of these specific requirements add to manufacturers' costs or deter them from even responding to requests for bids. And, finally, the in-shop inspections, tests, and audits tend to add more negative pressures on the valve suppliers.

There is a two-fold approach to breaking the bottleneck of delays in obtaining Class 1 valves: 1) Encourage more manufacturers to produce nuclear class valves and 2) standardize on valve design.

6.4.3 Research Approach

The objectives of research in this area should be to assess the present and future capabilities of manufacturers to produce valves needed for nuclear power plants and to further assess the possibility of standardization of valve design. A survey should be conducted of the valve manufacturing industry and a catalogue of information developed including names of firms, locations, production capacities including foundries, nuclear valve production experience, sample production and delivery times, and plans to expand or discontinue production. The developed information should be presented in matrix

and tabular form for easy reference. An estimate should be made of nuclear valve needs for the next 25 years and a "capacity/need" matrix developed. A corresponding survey of manufacturers producing similar type valves, but not of nuclear quality, would complete the information gathering. Where a deficiency in capacity versus need is identified, this information should be made available to both manufacturers of nuclear and non-nuclear valves. Hopefully this would encourage new companies to begin manufacturing nuclear class valves and at the same time possibly spur expanded capacity of the present manufacturers.

A review should be made of valve specification with the view towards possible standardization. This need not be a complete and comprehensive review but should be performed in enough depth to indicate if future work in this area is warranted. Resource information for this study could be developed from owners, designers, and valve manufacturers. If standardization of valve specifications is an attainable goal, quality assurance requirements could also be standardized so that valves could be manufactured to performance standards that would be acceptable to the industry. This would then allow stocking of nuclear quality valves.

6.4.4 Anticipated Results.

A survey of valve needs and production capabilities should give an indication of the ability (and willingness) of valve manufacturers to meet future nuclear plant construction requirements. This should point to areas where increases in productive capacity would be advantageous thus shortening delivery times. Further, a competitive inventory of "off-the-shelf valves" could be developed.

6.5 PROJECT SCHEDULING

6.5.1 Overview

One of the most important elements of any construction project and the foundation of effective planning is a well-thought-out project schedule. Prior to finalizing construction methods and equipment selection, a project schedule should be formulated and agreed to:

The history of scheduling can be traced back to the time of man's initial desire to become more effective in the accomplishment of his various tasks through the proper sequential organization of his work. The process was basically one of assignment of priorities to various items of work, in order to accomplish the desired objective in an orderly fashion. As the complexity of work increased, the need for a more finite method of sequential scheduling increased. The formulation of a schedule, therefore, underwent a transition from a simple sequential tabulation of events to the use of a calibrated bar graph. This bar graph depicted the interrelationship of an item represented by the individual calibrated bar to all other items of the work. This bar graph technique remains the backbone of modern scheduling. It has been expanded and elaborated, however, to meet the demands of complex construction projects and, in particular, the nuclear construction industry. The four basic elements of modern construction scheduling are:

- Project Network Analysis
- Detailed Bar Chart
- Control Schedules for Labor and Equipment
- Short Interval Schedules

6.5.1.1 Project Network Analysis. The most commonly used method of Project Network Analysis (PNA) is the Critical Path Method (CPM). Other PNA methods, including Program Evaluation and Review Technique (PERT), are also

used to a lesser degree in the construction process. The development of PNA was prompted by the growing operational complexities in all fields of work. Better techniques had to be created to cope with and identify the interrelationship between various items of work and to isolate the most effective way to accomplish a task that might contain thousands of individual activities. The prime advantage of CPM is the identification of the critical work items. CPM also structures the interrelationship between critical and non-critical work items and the required start-finish parameters for all items. CPM is basically a finite method of network analysis which generates a tabulation of all work items together with an output of time boundaries and available float times. Computerized network analysis is virtually the only means of integrating and monitoring the thousands of work activities that must be identified and tracked in the construction of nuclear power plants. Progress reporting and monitoring, cost processing and cost and resource allocation are only a few of the options available to the user today.

6.5.1.2 Detailed Bar Chart. The information obtained from the CPM schedule can best be displayed and understood through a Detailed Bar Chart. This is an effective way to present to supervision the overall project schedule. This schedule form can visually illustrate early starts, late starts, early finishes, late finishes, and interfering and free float relationships. It should also contain quantity information by work periods. The data contained in this schedule provides the detail necessary for the formulation of the working tools -- the Control Schedule for Labor and Equipment, and the Short Interval Schedule. Bar charts are either manually or computer generated depending on the needs of the user. Today's network analysis system programs allow the generation of bar chart displays at various summary levels of detail and allows comparison of actual progress with that planned. "Look

ahead" bar chart schedules, covering the next six months planned activities have been found to be extremely helpful for those in the field charged with the responsibilities of performing the work.

6.5.1.3 Control Schedules for Labor and Equipment. Since construction is basically a labor-management process, it is essential to provide detailed schedule information relating to the proposed labor expenditure and associated equipment utilization for the project. The Control Schedule depicts quantitative information and when extended on a weekly basis it provides a "visual" of the overall labor expenditure for the life of the project. This information translates into total labor dollars expended for each period, then manhours, and, finally, a craft manpower count.

6.5.1.4 Short Interval Schedules. The Short Interval Schedule (SIS) is the one schedule tool that really gets the job done. SIS is basically a daily working schedule which must be updated and revised each week. The SIS is effective because it is always current and relevant. It does not gather dust on the wall. The primary input data for the SIS comes from the Detailed Bar Chart, the various control schedules, and the daily realities coming in from the field. SIS primarily functions as a communication tool. It provides the day-to-day schedule information to project supervision. SIS establishes the short-range goals and performance norms for all operations during the life of the project. The information contained in this schedule is best conveyed in a group supervision meeting held weekly involving all project supervision and subcontractors. The Short Interval Schedule provides the basic meeting agenda.

SIS will not be effective if it only shows the activities planned for the next week. As an absolute minimum it should show a two-week duration. Ideally, it should also contain the prime ingredients of the third and

fourth weeks. This data provides the supervisory team with adequate lead time to accomplish their planning, organizing, and implementation functions.

6.5.2 Problem Statement

While all of the elements of project scheduling are well understood, they are not always being implemented. The responsibility for project scheduling, from the inception of the project through start-up, does not always come under the direction of one authority. Design scheduling may be handled by the architect/engineer, construction scheduling jointly by the owner, construction manager and contractors, and the other elements may be relegated to a back seat priority with very little interfacing between them. For project scheduling to be effective, it must take in the entire process and come under the authority of one group that is responsible for its development, implementation and operation.

More and more owners are assuming the responsibility for the creation, implementation and operation of the total project scheduling effort. The fragmented approach of the past has created delays, confusion and frustration on the projects. There is a need to tie project scheduling systems to an overall management information system in order to give owners the tools to fully manage their projects.

6.5.3 Research Approach

This area does not in itself dictate specific research. But it does suggest that refined and sophisticated systems are in successful use in various forms on nuclear projects. Needed then is a dissemination of information. This could be in the form of case studies or experiences written by practitioners describing their systems, procedures, methods, and techniques and submitted for review and critique via professional journals and periodicals. The result will be a generation of interest in project scheduling and a corresponding

upgrading of the systems as owners, designers and contractors are made aware of successful systems used by their contemporaries.

6.6 RISK ANALYSIS OF SCHEDULES

6.6.1 Overview

Elements of risk that can affect schedules vary widely because of the unknown factors they are intended to cover. Many risks require detailed technical consideration and studies to determine the probability of occurrence and the severity of cost overruns and schedule slippage. Compounding the difficulty in defining and quantifying the effects of risks in nuclear power plant construction are the immensity of the projects themselves and the tremendous utilization of resources of men, materials, and money, and the extended time required for their completion.

Murphy's Laws (freely edited) may apply:

- Anything that can go wrong, will go wrong.
- Left to themselves, things always go from bad to worse.
- If there is a possibility of several things going wrong, the one that will go wrong is the one that will do the most damage.
- If everything seems to be going well, something has obviously been overlooked.

Scheduling risks can be considered to be comprised of three elements:

1. Hazards, being generally defined as any occurrence situation that is different than that expected or planned, whether or not it is realized that that hazard would have an adverse effect.
2. Probability of encountering that hazard, or it being unmanageable within planned resource allocations.
3. Consequence of the hazard encountered, in terms of the quantitative effect (schedule slippage), and the liable party.

When looking at risk hazards, they can be further defined as those which are "expected" and those which are "unexpected." Expected risks that would effect the schedule would include: weather, site location, geological factors, manpower availability and quality, equipment delivery, financing, etc. Examples

of unexpected risks would include: acts of God, intervenor actions, unanticipated environmental considerations, design and construction errors, materials and equipment shortages and failures, strikes and jurisdictional disputes, and backfitting.

Another way to classify risks is on the basis of when they occur, or will most likely occur; during planning and funding, design, procurement, construction or start-up?

6.6.2 Problem Statement

Prior to 1970, the average construction duration for 500 MWe nuclear plants was 47 months. In 1976 the average construction period had jumped to 94 months for 900 MWe size units. While it would be expected that there would be some time increase in building larger units, nothing of this magnitude of increase would have been expected. Projections of construction durations for plants coming on line after 1976 are somewhat less than the 94 months recently experienced, but they remain alarmingly high. Add to these figures the pre-construction period for planning, environmental hearings, permit review and approvals, plus the expected fuel loading and start-up time -- and the total time period extends to 10 to 12 years.

6.6.3 Research Approach

This research should define the types of schedule risk present in nuclear plant construction projects, evaluate the effects of these risks, and determine the alternative methods of handling these risks. Once a general definition has been determined, factual information would have to be gathered and risks quantified by severity and frequency, originating source, and site locations. Strategies for eliminating, transferring, assuming, minimizing, or sharing each risk should be developed. These strategies should then be compared against current methods being used to handle risks.

Mathematical modeling of the risks identified could be developed for empirical analysis. If this is done, the modeling should be checked against completed projects and specific risks monitored on current projects. The intent should not be to produce a major mathematical model or a laundry list of risks for detailed analysis, rather the research should define risks and present a method of analyzing the probability of occurrence and consequences as they effect nuclear plant construction schedules.

6.6.4 Anticipated Results

If risks that cause delays in the construction of nuclear power plants can be better understood, the industry will be able to anticipate and plan for their possible occurrences in such a manner that their effect on overall project schedules can be eliminated or minimized. Objectively, this would then lead to reduced construction time which, in turn, should produce lower costs to the utilities, and, ultimately, the consumer.

6.7 CONTRACTUAL INCENTIVES PROGRAM

6.7.1 Overview

Different types of incentives are being provided to firms performing the design function vs. the construction function on nuclear power plants. Design firms are usually reimbursed for their costs (direct and overhead) plus a fixed fee which would normally be considered their profit. Where design firms have agreed to a fixed fee for, say, the complete design of a 1,000 MWe plant, and the design effort has escalated from a budgeted 1,000,000 manhours to 2,000,000 manhours, their fee has effectively been eroded by 50% when measured against the resources (people and facilities) that had to be committed to the project. The owner, on the other hand, has seen his design costs double with no opportunity of transferring this cost back to his designer. Effectively, both lose in relationship to what was expected at the start of the design. While the majority of the cost overruns on the part of the designer may not be of their making, there is little incentive to minimize these overruns other than the fact that they require resources that could be utilized profitably elsewhere.

With contractors, their incentives vary even more. The lump sum or "hard money" contractor is risking his own money in an effort to maximize his profit. The "risk-reward" is greatest under this type of contract. Contractors strive to increase productivity and improve work methods. A concerted effort is made to complete the work on schedule -- thereby holding down time related overhead costs. While it is certainly to the advantage of the contractor to bring the job in at his lowest total cost, which usually means ahead of schedule, this may not necessarily be to the advantage of the owner. The contractor may attempt to substitute quality for cost and time, thereby creating

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the classic confrontation between contractor and owner over the degree of inspection and delays presumably caused by strict quality control. Changes, inevitable as they appear to be, create cost and time overruns. If the contractor believes he is not properly being compensated for the direct, indirect and, in many cases, impact of the changes, major disputes may arise. The climate is ripe for claims, which can possibly lead to litigation. An adversary relationship many times develops between the owner and his "hard money" contractors and work under these circumstances benefits no one.

The second form of contract is the "incentivised" form where the contract is usually broken down into a firm price for overhead items and a target estimated cost for labor related work. To this is added a fee which is subject to upward or downward adjustment depending on the performance of the contractor in meeting the target, labor related, costs. Monetary incentives may also be provided for meeting the work schedule. The mechanics of administering this type of contract can become somewhat complicated as the owner, in order for the incentive contract to work, must recognize changes that increase the amount of work to be performed and/or delay performance of the work. The risk, however, of major labor cost overruns is now assumed by the owner and this of itself is an incentive to the contractors.

The cost-plus-a-fixed-fee form of contract is being used to a considerable extent in the construction of the power block areas for many nuclear plants. This form of contract seems to be one of the easiest to administer when it comes to handling changes. Once the required change has been identified and the necessary design completed, the construction effort can proceed without delay as there are no contractual restraints to hinder cost-plus work. Cost effective construction is lacking, however, as it is difficult to provide incentives that spur the contractors on to increased productivity and timely performance.

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A final form of contractual incentives is that being used by utilities who perform all of their design and construction with in-house personnel. The obvious "incentive" here lies entirely with the owner as his effectiveness in design and construction determine the timeliness and total cost of the project. Only those utilities that have numerous plants scheduled over a period of years can afford to gear-up for this type of operation.

6.7.2 Problem Statement

The form of contract and manner of providing incentives for design services is fairly well established and does not present the unique problems of the construction contracts. Construction contracts, however, pose the double question: what form is the most cost effective and what form is the most time effective? How incentives are provided to decrease cost and improve schedules should be the subject of this study. The fact that so many forms of contracts are being used today, providing differing incentives to the utilities and their contractors, indicates that there is little consensus of opinion on the best use of incentives.

6.7.3 Research Approach

This research should identify the incentives for both owner and contractor, determining if and how incentives can be provided to decrease cost, eliminate or minimize delays and improve schedules. A survey of on-going nuclear power plant construction should be made to examine the many types of contractual relationships to determine the basis and reasoning for the particular type of incentives being used. The incentives and how they effect each party to the contract should be classified and rank ordered as to importance. For the owners this would include: total cost, timeliness of completion, quality of work, ease of administration, manpower drain on the company's personnel, etc. For the contractors, incentives would include: potential for

profit enhancement, decreasing of risk (usually in labor cost overruns), payment terms, escalation allowances, bonuses, opportunity for repeat business, and so on. The key element would be to find those incentives that benefit both the owner and his contractors.

An assessment of where and how incentives are being used and their effect on cost and schedule should be made. A quantitative analysis could be developed through examining productivity manhours for similar operations under different forms of contract as well as the total time and cost to accomplish these operations. While it may not be possible to determine a definite cause/effect relationship for the various incentives used, a general relationship should be obtainable.

A "model" contractual arrangement could be developed incorporating the various incentives identified from the different forms of contract between owners and contractors. This model could then be tested for practicability and potential by reviewing it with selected owners and their contractors.

6.7.4 Anticipated Results

It is anticipated that this study would result in a better understanding of incentives, the promotion of awareness of the effect of incentives on cost, time and delays, and possible new or suggested revisions of present contractual arrangements which would include newly identified incentives. Through a weighing of the advantages and disadvantages of different incentives, least cost decisions can be arrived at for projects being constructed under varying conditions and owner needs.

VOLUME I SECTION 7

**RESEARCH NEEDS
MANPOWER AND PRODUCTIVITY**

By

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SECTION 7
MANPOWER AND PRODUCTIVITY

by
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Introduction

The 1974 AIF Survey of Causes of Nuclear Power Plant Delays listed shortages or immobility of craft labor, and inadequate labor productivity as two of five leading causes of delay on plants for which construction permits have been issued. The Penn State Power Plant Education and Research Needs Meeting on May 10 and 11, 1977 identified the area of productivity studies as extremely important and one which merited extensive investigation over the entire spectrum of construction activities. The initial effort of newly organized Edison Electric Institute Construction Committee was to develop a list of power plant construction problems. Responses of utility executives identified labor relations, training of construction personnel and others. However, the topic identified as most important was construction productivity, and its improvement was the first problem undertaken by the Construction Committee Task Force. Finally, the interview survey reported in Section 2, Vol. II, to determine the Barriers to Shortening Construction Schedules identified manpower shortage and productivity as a current or potential problem on all the projects in the University of Texas Subcontract Area.

Typical nuclear project craft levels are shown in Figure 1.¹ Employment, training, and adequate supervision of such numbers of skilled craftsmen is an extremely important and difficult task. Also, there is a need to find ways to motivate the workforce. Earl Bourque, Vice President of Construction, Ebasco Services Incorporated emphasized the decrease in pride in workmanship, the lack of interest in the project, and lack of dedication to the employer.² A previous study by the writer of motivation on large

^{1, 2} C.B. Tatum, "Management of Nuclear Power Plant Construction Projects, Tasks, Practices, Improve Techniques", M.S. Thesis, New York University, 1976.

Figure 1

CONSTRUCTION CRAFT REQUIREMENTS FOR TWO UNIT PROJECT

SOURCE: AN ANALYSIS OF THE SOCIOECONOMIC IMPACTS OF WNP-3 AND WNP-5, WASHINGTON PUBLIC POWER SUPPLY SYSTEM, RICHLAND, WASHINGTON, SEPTEMBER 17, 1975, P. 12

projects indicated 41 out of 69 workmen did not care if the company was making money.³

The following research needs topics under manpower and productivity study problems, their importance, possible research approaches, and anticipated results. There is considerable interrelationship between topics, but an effort was made not to repeat information that may be applicable to more than one topic. For example, Motivation and Morale and Absenteeism and Turnover are two topics which appear to be related to one another. On the other hand, the high degree of interrelationship between labor availability prediction, open shop versus union, and project agreements for labor management is not apparent. In other words, it isn't obvious that the effective availability of skilled craftsmen is dependent upon union labor agreements on crew sizes, work practices, foremen to journeyman ratios, standby labor, etc. Finally, the topics will be grouped according to these interrelationships, but there is still considerable overlap.

³ Bernard Kendall, "Survey of Perspectives Related to Worker Performance on Large Construction Projects", M.S. Thesis, University of Texas, 1976.

METHODS OF MEASURING PRODUCTIVITY

Problem Statement.

According to a recent survey in power plant construction, labor productivity has become one of the major causes of delays in this industry.¹ It is generally believed that the average worker on a construction project is willing to perform a reasonable day's work. Therefore, the problem lies in planning his work in advance and giving him better instructions. Last August at an ASCE's Construction Productivity Conference, a study was revealed that showed "only 32% of the 8 hours a day supposedly spent working was direct work." Even more interesting was the fact that 29% was for "waiting" and then 13% for "traveling."² It becomes obvious that steps must be taken to diminish the waiting and traveling times on these large jobs in order to improve productivity. What is needed then are techniques by which steps can be evaluated and the reasons for adopting one step rather than another justified by fact rather than by hunch or intuition. The idea is to first develop methods of measuring productivity which will enable one to judge the overall effectiveness of a particular procedure, and then improve on this effectiveness such that increased productivity will become a by-product. In this manner one has not demanded more of a worker but merely to use him more efficiently. To coin a phrase, "work smarter, not harder."

Importance

When one speaks of measuring productivity one must first be able to define it in units of output. Generally productivity has been expressed on a quantitative basis as the ratio of a unit rate of construction output to a corresponding rate of labor input. The most widely accepted rate is the output per man-hour or man day although expressions of output per dollar value of the total labor unit are often used where various input skills are required.

¹"Power for Millions", National Electrical Contractors Association.

²"Productivity on the Construction Site", ASCE, January, 1977, pp. 74-79.

Time and money are synonymous factors in the success of any job and therefore are the prime tools in measuring productivity. Cost reports are generally the limit in the analysis of the production of certain processes, but they are frequently inadequate and too late to take action to improve an operation. Time on the other hand is much more adaptable to changing wages in various locales. Time studies of working processes such as work sampling, five minute ratings, crew balance and time lapse photography provide valuable information in the construction industry. Of all of these, the time lapse photography has the greatest potential. This system enables one individual to set up a camera and film an entire day's work and yet not be present. By condensing this time span to 15 minutes by time lapse, procedures can be evaluated and tested from a broader spectrum as compared to a short interval critique with each visit. From these films, inefficient uses of men and equipment can be uncovered and corrected. Many believe that such techniques can only be applied to very repetitive work, but this is not true. A process which will be repeated as many as three or more times (as is usually the case on power projects) or even on future jobs becomes prime material for the time lapse analysis. Future use of a method from a time lapse analysis not only serves as a pre-planning tool but also as an excellent means of estimating costs.

Research Approaches

1. A comparison of time lapse photography measurements to those of 5-minute ratings and work sampling studies of the entire site.
2. Develop a "Bogie Book" of time for each type of work in which operations are broken down into man hour targets for field comparison.
3. Determine the possibilities of creating a national library of time lapse films that would be available to all contractors as guidelines for either estimating or as an indoctrination of procedures for different levels of management and personnel.
4. Use of time lapse as a tool in preplanning (or influence in).
5. Compare, by use of time lapse, productive time of various nuclear plants to the 32% figure of ASCE.
6. Determine the effects of time lapse on the safety of the job.
7. Determine the use of time lapse as a documentation tool for as built files.

8. Comparison of union and non-union production rates.

Anticipated Results

Viewing time lapse would produce a more accurate means for measuring specific items of work and enable one to effectively evaluate other techniques for improving productivity of manpower. Further job satisfaction would be increased through better preplanning and coordination as a result of viewing time lapse films before initiating work. Allowing men to view time lapse of an operation they are about to perform rather than having the foreman explain it would allow less supervision over the men during construction.

As a result of all the time lapse films a "Bogie Book" of all operation including time, men and approach to construction could be implemented. This book would include the estimated manhours to complete work items that are broken down into sufficient detail to be applicable to nuclear sites throughout the country.

MOTIVATION AND PRODUCTIVITY

Problem Statement

Project managers on nuclear power plant construction projects most often face the reality of managing less motivated foremen and workmen than their counterparts on smaller jobs. Motivation has a major influence on productivity as emphasized by behavioral scientist Rensis Libert's comment "the roof of productivity is the motivation of the individual."

Previous productivity studies by the author has isolated four motivational problems peculiar to large construction projects: (1) little identification with the work or project; (2) lack of participative decision-making as a result of deep hierarchies and bureaucratic procedures; (3) inadequate communication and coordination such that crews are waiting as lower level supervisors frantically search the site for answers; (4) detrimental changes in the work, supervision, and manpower requires previous work to be torn-out and results in a reduction in learning curve efficiency improvement. The overall impact is a deterioration of motivation and a feeling that craftsmen and foremen have no control over their work or what they produce.

The problem with nuclear power plants in relation to motivation and productivity is that organizations ruin good, hard-working, and conscientious craftsmen and foremen. For example, the craftsman and foreman is unable to set goals for himself, realistic or otherwise, because they are often incompatible with the schedule. In other words, craftsmen, and especially foremen, prefer a little discretion in how work is to be accomplished. If they could use their experience and imagination to do a job better or faster they usually want to and receive ego satisfaction from their contemporaries. However, these desires are often suppressed by rigid schedules and exacting QA/QC requirements such that the need to think, innovate, and plan is removed from the workplace. Skilled and innovative people drawn to nuclear power plant sites are not allowed to use their skills, and they are even reprimanded for being innovative because innovation screws up the plan.

The objective of a research study would be to list, describe, and implement motivational techniques and organizational changes that project

managers could employ when faced with any one of a combination of reasons why foremen and workmen are less productive on a nuclear power plant project.

Importance

There is an overall concern in the utility industry for major improvement in the construction of power plants as illustrated by electrical utility executives who ranked their concerns: (1) productivity; (2) manual labor; (3) overall improvement cost and schedule; (4) restrictive work rules, featherbedding, and standby; (5) management, engineering and technical personnel; (6) overtime and shift practices and rules. This Edison Electric Institute survey overwhelmingly identified productivity and the improvement thereof as the first problem to be researched by their newly organized Task Force to examine generating plant construction. In the recent Penn State workshop on Power Plant Construction Education and Research Needs, Saxon Palmetor, Manager of Construction GPU Service Corporation, Roy Miller, Manager-Project Control Services, Virginia Electric and Power Company, Earl Bourque, Vice-President - Construction, Ebasco Services, Incorporated, Alexander Schmidt, Vice-President of Construction for Riley Stoker Corporation, and John E. Martin, Manager of Engineering, Public Service Company of Colorado emphasized the importance of productivity research. Finally, the Atomic Industrial Forum's Survey of Construction Delays and the recently sponsored ERDA Ohio State study of Barriers to Reducing Construction Schedules indicated the significant impact of labor productivity on project time and costs.

From all the previous indications, labor productivity improvement should rank as a significant nuclear power plant problem that would benefit from research. Although productivity improvement is much more than getting manual labor to work harder, behavioral science research findings indicate a strong relationship between productivity and the motivation of the individual. Furthermore, behavioral findings explain how people become apathetic, dissatisfied and even work in direct opposition to goals if the organization is unable to fulfill individual needs so that the only reward is eight hours pay.

There are many other reasons, in addition to motivation, that contribute to productivity of 30%-40% or 3 hours per day. However, improvements in decision-making, communication and coordination plus a reduction in

changes, turnover and absenteeism would have a significant effect on morale as well as improve productivity. For example, reduction of the average waiting time of nuclear plants per day by lowering the level of decision-making would not only increase productivity, but also improve motivation.

Research Approaches

1. Select two union and two non-union nuclear power plant sites under construction and conduct a random survey of each hierarchical level to determine the attitudes of managers, supervisors, and craftsmen. Isolate all the problems that relate to motivation and productivity irregardless of how remote they may be.
2. Using time lapse analysis, work sampling, five minute ratings, or crew balance studies, plus the monthly cost reports, evaluate productivity levels and determine the most frequent productivity problems.
3. Determine the most significant motivational/productivity problems that could be researched.
4. Review behavioral research findings, and modify their techniques of improving motivation and productivity for the four sites.
5. Review organizational development studies in construction to develop similar, or different, motivational strategies.
6. Implement techniques for improving motivation and reducing demotivation by initially using the least expensive and time consuming motivators.
7. Evaluate the results using work sampling, five-minute ratings and crew balance productivity studies.
8. Determine if turnover or absenteeism has been reduced.
9. Use a second questionnaire survey to determine if attitude to the work has changed as a result of the first level motivation program.
10. Initiate second level motivators, then evaluate, and proceed to the third and highest level motivators with intermittent productivity and job satisfaction evaluation.
11. Calculate the cost of introducing each level of motivation and compare it with the savings generated. Also, evaluate intangible benefits such as a happier work force, less absenteeism and turnover decreases the significance of craft shortages, and the long range effect of transferring more enthusiastic personnel to another nuclear construction site.
12. Determine the most successful motivators and show how they can be modified, if necessary to meet requirements of other nuclear plants under construction. Hopefully, the study of two open shop and two union sites will cover many of the same problems faced by nuclear power plant contractors throughout the country. Publish the findings and prepare appropriate reports showing how a rather modest or extensive motivational program would improve productivity and job satisfaction plus reduce absenteeism and turnover.

Anticipated Results

This study would explain in detail the procedure, cost, and results of a motivational program to improve productivity. Questionnaires will be created to evaluate attitudes before and after each phase of the study. Only slight modifications will be required in each set of questionnaires in order that they may be applicable to other nuclear plants under construction. Secondly, the means of measuring productivity plus the percentage improvement that took place on each project would be published for the motivational phase that was undertaken. This information would be confirmed by percent reductions in the cost or schedule reports.

Attitude change results will be published by studying questionnaire trends and evaluating open ended comments. Hopefully, job satisfaction will be reflected in less comments like the following summaries of conversation with nuclear power plant foremen.

"Power house work is hard to get interested in -- you are only a small cog in a large wheel."

"On big jobs like this, you don't really know why you are doing something."

"You want to accomplish something, but you become frustrated, and crews become frustrated as they wait for information."

These comments are even reported in the newspaper, so contractors may be willing to undertake motivational programs to change what their craftsmen and foremen say to the many newsmen that are frequently quoting workmen that the company is inefficiently managing the project and indirectly increasing utility rates.

Turnover and absenteeism percent reduction, or even the actual before and after figures could be published. A change in these figures is the initial sign that morale is improving and the motivational techniques are influencing the behavior of construction personnel. A company constructing a large petrochemical complex employed the writer's first level motivators and they experienced a 100% reduction in absenteeism when compared to the same period of time a year before. Likewise, there was an indication of less turnover, but the motivational program was initiated in the final one-third of the project, so there was a natural reduction of manpower.

Although the research will concentrate on the previous results, there will be supplemental benefits such as improved quality if there is greater job satisfaction and knowledge as a result of the motivation program. There should be improved communication between each level of the hierarchy. Since people are not just working for eight hours pay, there will be a greater tendency to give a little extra and make things happen even though the communication will probably never be as efficient as information flow on less complex construction projects with fewer hierarchical levels.

REDUCING ABSENTEEISM AND TURNOVER TO INCREASE LEARNING CURVE EFFICIENCY

Problem Statement

Absenteeism and employee turnover traditionally have been major problems unique to the construction industry. In nuclear power plant construction, the problems of absenteeism and turnover have been extremely critical and have had a greater impact on work schedules than absenteeism and turnover on conventional construction work. Both absenteeism and turnover rates have been considerably higher on nuclear work than commercial or industrial projects. One nuclear project in the southwest reported an average of 20% absenteeism during winter months and as high as 50% on certain days. In another project in Florida, turnover rates were reported as being 300% for carpenters, 400% for electricians, 400% for pipefitters, and 250% for ironworkers. These high rates of absenteeism and turnover must be accounted for and reduced if nuclear projects are to get back on schedule. Research will be directed towards finding out why absenteeism and work turnover are unusually high on nuclear projects and what can be done to decrease absenteeism and turnover.

There are several factors believed to be responsible for high absenteeism rates. Among the most important are bad weather conditions, location of construction site, and worker attitude towards the job. The first of these, bad weather conditions, is not a new problem to the construction industry. It is, however, one of the most serious. Workers simply do not like to work in cold or wet weather. Unseasonably cold weather is responsible for a major portion of the absenteeism problem. Also, most nuclear power projects are not located near urban centers. This causes a commuting problem for most workers. One worker interviewed commented that it would not be worth driving to the site to pick up two hours "show up" pay if it looked like rain because he would spend more money on gasoline driving to the site and back home. Many workers cannot identify with their job. With thousands of people on the jobsite at any given time and several operations going on simultaneously, a craftsman may feel he is unimportant and makes no real contribution to the progress of work. For this reason, he may stay at home, feeling he will not even be missed.

Turnover problems are very critical in the nuclear construction industry. High turnover rates can be explained by job dissatisfaction, lack of training, poor job site locations, and by so called "boomers." Since nuclear work is relatively new to most craftsmen, they know little about the job as a whole, and don't understand certain things such as why an extraordinarily stringent QA/QC requirement must be imposed. Confusion and frustration result from not being familiar with nuclear work and job dissatisfaction results from not being allowed any input into job planning and scheduling. Craftsmen and supervisors alike are given little responsibility and generally must wait for upper level management decisions before continuing their work. "Boomers," people who work on jobs in order to earn a certain amount of money and then move on are also a major reason for turnover. On one project it was reported that these people made up about 40% of the work force. Also, many craftsmen can usually find better or just as good jobs closer to where they live, so many are leaving nuclear jobs just on the basis of their location.

Importance

Absenteeism and turnover have triggered many problems adverse to schedule and cost. The manpower shortages resulting from absenteeism and turnover have a tremendous effect on learning curve utilization and productivity. Competent craftsmen have been in short supply, and jobs have been delayed substantially because these men were not available. The demand is so great that the contractor is not able to be selective about whom he hires and must hire low producing workers as well as productive ones. Craftsmen know that labor is in short supply, and sometimes their productivity level will drop because they feel their job is secure and they have no one to compete with for work.

The field manager for one project in the deep-south stated that the shortages were so bad that he had, during the life of the job, hired approximately 3,000 pipefitters to keep a competent force of 450 of these men working. New workmen are constantly being hired and introduced to nuclear work. Those who are not used to this type of construction must reorient themselves before they begin to feel confident in their work and can find their way around the job. Learning curve utilization suffers drastically and productivity levels drop.

Also, the constant changing of the workforce disrupts momentum and continuity in the daily activities. The daily schedules must be replanned and arranged so that new employees can be used.

Research Approaches

1. Exit interviews among craftsmen who are leaving their job should be conducted to find out precise reasons for leaving and problems they encountered during work. Also, managers and supervisors attitudes should be determined concerning the reasons for turnover and absenteeism.
2. Implementation of training programs and group sessions to educate craftsmen and create motivation about nuclear work.
3. Develop incentive programs for craftsmen to stay with the company. Introduction of financial incentive for workers who stay with the company for a certain number of years. Also, financial incentive for good attendance records.
4. Questionnaires before and after the implementation of training and incentive programs to determine changes in attitude among craftsmen.
5. Daily absenteeism records should be kept and craftsmen should be clearly informed about absenteeism policies. Make employees aware of the fact that they are needed and will be missed if absent.
6. Absenteeism and turnover rates should be measured before and after the implementation of training and incentive programs to see if there has been a significant reduction in these rates.
7. Evaluate long range benefits of learning curve utilization from future projects built by better skilled and more highly motivated craftsmen.

Anticipated Results

The study should produce some valuable information concerning reasons for high absenteeism and turnover rates among construction crafts on large projects. Questionnaires will produce information useful to management in determining what kind of programs should be implemented to decrease absenteeism and turnover rates. Craftsmen should experience increased job satisfaction through better training and more reward from the job than just eight hours pay. Training programs will allow craftsmen to make more decisions and have input into the daily activities, therefore taking these problems away from management and allowing them to concentrate on more important problems. Motivation and increased productivity will be experienced, and better quality work will result. With less turnover,

workers will become more familiar with the work and should experience increased interest in the job, thus utilization of the learning curve will result and will be beneficial to future projects. Hopefully, absenteeism and turnover rates will drop significantly, and the shortages of the key trades will have less impact on construction schedules than before. The results mentioned will be beneficial to the nuclear industry as a whole and prove valuable to other construction industries as well.

PERSONNEL TRAINING AND DEVELOPMENT

Problem Statement

There is a lack of understanding of the lower hierarchical levels of what nuclear power plant construction is all about. For example, most craftsmen and foremen feel that nuclear containment is to hold the explosive and radiation effects of the bomb if there was an accident.

There is even less understanding of the interface between systems and areas of the project. This may be the major reason for not lowering decision making on nuclear sites, even though it is an accepted practice on conventional construction projects. Therefore, educational programs need to improve a foreman's knowledge of overlapping areas on the entire project.

Supervisory training should encourage management to initiate lower level decision making authority so less crews will be waiting for foremen who frantically go from office to office to get an answer.

In relation to productivity and training, research should be initiated to improve the effectiveness of a field supervisor to plan, schedule and control the work force. Frequently, interviewees commented how the foreman and general foremen were the key to labor productivity and that there were not enough foremen and general foremen with nuclear construction experience. Likewise, individuals are often quickly promoted as a result of an expanding work force, yet they may lack the capability and confidence to supervise nuclear work. Therefore, research findings that develop the method of training that could reduce the on the job experience requirements necessary to productively manage crews would have a significant impact on reducing nuclear power plant costs and schedules.

Importance

The exacting QA/QC requirements and the importance of understanding the interaction of systems or areas of a nuclear plant are two major reasons why lower level supervisors have had their decision making authority usurped by management. This has had an adverse effect on the morale of foremen and general foremen, plus crews frequently must wait for answers. Therefore, it isn't unusual for work sampling studies to indicate craftsmen waiting as much as working on nuclear sites. The following comments from foremen on nuclear sites emphasize the importance of providing the training

that gives both supervisors and management confidence to allow greater participation in decision making.

"When there is a minor problem, you are not given the authority to correct it; you must find the right individual who can okay it."

"I'm used to working on a job where I make a lot of day-to-day decisions. But it isn't like that on a big job like this. All I really do is order my crew to do this and that. There's no room for responsibility."

"On big jobs like this, you don't really know why you do something. So if you come to a problem, you have to wait until someone tells you what to do."

The previous comments seem to indicate that field supervisors have little control over their work and merely follow orders. However, interviews with project managers and area supervisors stressed the importance of the first-level of supervision to overall project productivity. The foreman is charged with the responsibility of executing the work in the most effective and expeditious manner. Thus, management should have established procedures to select the most effective foremen and general foremen. Secondly, there is a need for supervisory training programs for foremen and general foremen to enhance their effectiveness as supervisors, and to provide opportunities for craftsmen to advance to foremen and higher level positions.

Finally, it is important to conduct research in determining what training programs to institute at the craftsman and foremen level. Many craft apprenticeship programs are antiquated and should be revised in the interest of speeding up the development of skills.¹ An efficient program to develop skills quickly and be attractive to craftsmen, management, owners, and unions is of utmost importance to the nuclear construction industry.

Research Approaches

1. Evaluate strong supervisory training programs and offer suggestions to improve their effectiveness for nuclear power plant construction.

¹ Earl Boroque "Keynote Address" at the Penn State Power Plant Construction Education and Research Needs Meeting, May 10 and 11, 1977

For example, the National Electrical Contractors Association has Foremanship and Field Manager's short courses to improve supervisory capabilities. The Associated General Contractors is developing a comprehensive supervisory training class. Finally, companies such as Brown and Root and Daniel International have in-house training for their current supervisors and individuals who are seeking higher level supervisory positions. The advantage of an in-house program given at the site is that the education modules can all be directed toward the unique characteristics of nuclear power plant work.

2. Evaluate the competence and effectiveness of construction supervision to determine how education could accelerate the capabilities of foremen.

Work sampling, crew balance, five minute ratings, and especially time lapse analysis should provide an accurate measure of productivity of crews. Teaching these techniques of work improvement may be the initial supervisory training class on nuclear sites.

3. Determine what are the most important factors that influence productivity, quality, job satisfaction, absenteeism, and turnover. This information could be used in problem-solving discussion sessions in supervisory training classes. The objective would be to get first level supervisors to determine their own solutions to problems that delay the project, adversely affect morale, and cause skilled craftsmen to remain at home or leave the project.

A different approach employed by Ontario Hydro in a "Productivity Study Bruce G.S. 'A'," obtained similar information as the above. There were 106 problems that were identified by foremen which could potentially reduce productivity on a nuclear construction site in Bruce, Canada. This survey information became the basis of a four day training course for the supervisory staff on Bruce "A" and "B".

4. In regard to craftsman training, it may be necessary to take a completely novel approach for nuclear power plant construction. Research should examine how utilities, contractors and unions can develop nuclear power plant craftsman-technicians. This may require the evaluation of training programs outside construction; such as the aerospace industry. Aerospace contractors must work to exacting tolerances and QA/QC requirements. Therefore, instead of simply improving existing construction training programs, or starting from the bottom, it would be worthwhile research to determine if aerospace educational programs could be adapted to nuclear power plant construction.
5. Research is needed to forecast manpower requirement data to implement the preceding training program as well as to attract and recruit individuals into nuclear power plant construction. The subsection on labor availability prediction examines how this research could be performed in order to recruit and train enough skilled craftsmen to meet future manpower needs.

6. Research into establishing the training requirements should continue by examining what would be the most effective educational techniques for craftsman, and particularly, young supervisors with little nuclear or management experience.
 - a. How should the material be presented?
 - b. Who should be responsible for the training? (union, company, etc.)
 - c. How should individuals be selected?
 - d. Should training be mandatory for supervisors irregardless of their previous experience?
 - e. How can educational modules be designed to be transferrable to other nuclear power plant sites?

These previous questions should be answered by researchers who have evaluated what nuclear construction training that is currently available and determined how strict specification tolerance educational programs were instituted in other industries.

Anticipated Results

1. The survey of training programs should indicate the amount of available information that could be readily provided to craftsmen and foremen through contact with specific associations and companies. In particular, educational modules that are designed for nuclear construction should be evaluated and possibly, the government could encourage companies and associations to include this information in their training programs.
2. Work improvement techniques could become an integral part of supervisory training. This is a very effective technique for foremen to quickly evaluate their methods and determine how direct work percentages could be increased above the present 35% average.
3. This research on training needs, plus other studies, should identify the factors influencing productivity, job satisfaction, quality, absenteeism and turnover that could be addressed in the classroom. Some problems will be peculiar to a site while others will be common on most nuclear construction projects. A survey questionnaire or interview format will be designed to quickly get this information so it could be discussed during training sessions.
4. Finally, teaching techniques from previous nuclear construction training programs, the aerospace industry, and this research would provide the educational modules which would be transferrable to nuclear sites during various phases of construction. The overall outcome could be more productive craftsman and foremen by accelerated nuclear construction education as well as on the job experience.

PRODUCTIVITY IMPROVEMENT THROUGH QA/QC TIME LAPSE FILM RECORDINGS

Problem Statement

Productivity on nuclear power plant construction projects is generally lower than that on conventional construction projects. This lower level of productivity can be attributed to several factors, among them is the problem of construction delays caused by QA/QC requirements, inspections, and documentations. Much productive time is lost on the job while crews are waiting for inspectors to come by and check to see that certain QA/QC requirements have been met. Also, documentation requirements for QA/QC on construction procedures and materials has been a major source of construction delays. For example, the painting of one bolt for the reactor required seven pages of documentation. It was reported that the painting subcontractor's supervisor spent 75% of his time providing proper documentation on the job as compared to about 10% on a non-nuclear project. Therefore, the objective of the proposed research is to find ways of increasing productivity by using time lapse photography for QA/QC inspections and documentation.

Importance

Poor labor productivity is a major problem facing the nuclear industry. As productivity levels decrease, projects are stretched out and costs skyrocket. Through time lapse inspection and documentation of QA/QC requirements, higher productivity rates can be reached. Motivation is adversely affected when QC inspectors delay approvals after supervisors and workmen make an extraordinary effort to complete an item to meet the schedule. Supervisors experience difficulty in obtaining a similar effort when craftsmen consider that the work didn't really need to be rushed.

Also, many areas of work are probably being completed with little or no inspection because personal inspection is of a "spot check" nature. Time lapse filming offers complete inspection of an activity without having an inspector present. It also enables management to provide visual proof of the quality in covered up items of work.

Equally important is the fact that costly delays are caused by extensive documentation requirements for materials. This requires a considerable amount of time be spent on these non-productive jobs.

Research Approaches

1. Time lapse photography equipment would be set up on the job site so that critical activities could be viewed closely enough for QA/QC inspectors to determine if the required quality had been achieved. Some difficulty may result in not being able to view the entire scope of the activity. Two cameras on one activity may be required in this case.
2. Materials being installed will be documented on film as permanent visual proof of quality and assurance that these specified materials were actually used.
3. Inspectors will view time lapse films and determine if the required quality and procedures were employed on that particular activity.
4. The results of the analysis performed on time lapse films will be compared to those obtained by personal visual inspections.
5. Time lapse results, based on time required to analyze, quality of data, and extent of data, will be evaluated to determine the feasibility of using time lapse photography for QA/QC controls and material documentation.

Anticipated Results

The study should produce some key methods of increasing productivity. Fewer inspectors will be required on the project because time lapse photography offers a rapid and convenient method for inspecting, thus crew delays caused by inspections will be minimized. The films will provide extensive inspection coverage as compared to a "spot check" type of inspection. They will also show documentary proof of procedures and materials used in installation.

Also, time lapse film employed by crews could better utilize the learning curve and thus improve productivity. Craftsmen and supervisors could use films as training aids and references for construction methods. NRC personnel could be trained in writing and preparation of QA/QC guidelines by reviewing construction processes on film. If craftsmen, supervisors, and inspectors use these films as training aids, and can refer back to them when needed, the industry will experience better qualified personnel in each of these positions.

SHORT INTERVAL SCHEDULING

Problem Statement

Large scale projects, such as nuclear power plants, require a great amount of travel time and have very little repetitive work. These conditions breakdown into a rather complex scheduling process by management, and cause workers to have little identification with their work. Workers, therefore are unaware of why they are doing a task, since no ultimate goal can be foreseen. Furthermore, workers become frustrated and unsure of their work as the projects become larger and less repetitive. These factors contribute to productivity of 30% to 40% or 3 hours of actual work per day.

Importance

Improved productivity and worker satisfaction in this area becomes a key byproduct of improved work scheduling. On most large projects workers seem to work in opposition to the primary task at hand when they are given a large task to perform. Further, men are unable to visualize an end to their task and are unable to set any goals. Therefore, any innovative techniques by the men are suppressed.

It is from this premise that short interval scheduling becomes an excellent device for such projects. From this technique large unending tasks are broken down into shorter jobs with a viable end. Each time the men are given a work order they are able to use all their past experience to attain a clearly visible end and job satisfaction and productivity increase.

Research

1. Study the work order techniques of Procter and Gamble and Daniel International.
2. Develop a short interval scheduling technique that could be implemented on nuclear power plant projects.
3. Investigate worker morale and production before and after short interval scheduling is introduced by use of time lapse photography.
4. Investigate the production level developed by short interval schedules by use of cost reports, crew balance studies and five minute ratings.
5. Using a questionnaire determine the attitudes and motivation of workers before and after short interval scheduling is introduced.

6. Determine any change in absenteeism and turnover due to short interval scheduling.

Anticipated Results

This study will produce greater job satisfaction and morale in the workers. Turnover and absenteeism reports should reinforce the value of short interval scheduling. With these aspects being improved a definite rate of increased productivity should be recorded by time lapse photography. Plus, the evaluation of productivity will be more accurate if the short interval schedule is also employed in controlling the project.

PRODUCTIVITY UNION VS OPEN SHOP

Problem Statement

Recent advancement of the Open Shop movement has produced a perpetual battle of verbiage between Union and Open Shop constituents. Claims and counter claims by both has caused an uneasiness as to which is truly a more productive means of contracting.

On one hand, unionists claim superior quality work, as they have better trained personnel; plus the lack of financial incentives and competition has created a safer job for all concerned.

On the other hand, Open Shop advocates accuse unionist intervention of featherbedding, work restrictions, and opposition to labor saving devices as deterrents to productivity. Further they feel that competition and work incentives create happy and productive workers and not an unsafe job.

Importance

Then, to determine and define any differences between Union and Open Shop construction would be extremely valuable to this industry. With this information a client could determine their preference as to the manner of construction they prefer. The basis being in all cases, is to save the utility money and time.

Research Approaches

1. Evaluate a Time Lapse Study of similar construction techniques from both Union and Open Shop.
2. Analyze the costs of similar jobs.
3. Compare turnover and absenteeism of Union versus Open Shop projects.
4. Perform an indepth comparison of the role of foremen in Union and Open Shop construction.
5. Compare the effects of prefabrication in Open Shop to in house work on a Union job.

Anticipated Results

From this research, a better understanding of the pressures a foreman is experiencing and further how a company can deal with his situation. A worker's ability to produce would likely be very similar in Union and Open Shop with the differences being in union restrictions and bargaining power.

PROJECT AGREEMENT AND LABOR MANAGEMENT'S EFFECT ON PRODUCTIVITY

Problem Statement

Productivity on nuclear power plants, as on all large projects, is being constantly threatened by union intervention over various disagreements. Jurisdictional disputes, restrictive work practices and objections to labor saving devices create problems for management and delays in schedules. Furthermore management's right to manage is being threatened by union control of supervisors and foremen.

Therefore, the primary purpose of the project agreement in today's market is to supplement local agreements and remove some of the obviously restrictive working conditions in local agreements. By doing this, management has more time to plan the project rather than battle with the union. In a recent interview of a nuclear power plant superintendent, he noted that although they had had very little trouble with strikes, he still spent much of each day settling petty quarrels and disputes over jurisdiction disputes or wordings in recent contracts.

Importance

This type of agreement is not new as it was used during WWII and more recently on the Alaskan Pipe Line. Both of these met national needs, and now electricity has become very important. This type of agreement would eliminate jurisdictional disputes and in most cases allow craftsmen to cross trades in order to complete a task. Even more important would be the absence of work stoppages or slowdowns.

Standardization of nuclear plants is of great interest to many at the present, and a labor agreement would allow prefab work and time saving devices which are otherwise forbidden by union rules.

Research Approaches

1. Compare similar union projects by means of cost and delays in which one has an agreement and the other does not.
2. Investigate areas and document those which benefit or breakdown contract agreements.

3. Determine the effectiveness of craftsmen that are able to perform several trades rather than just one.
4. Investigate the influence or changes (pressures from peers) in a foreman after a negotiated national agreement.

Anticipated Results

Productivity should show increases due to less delays, strikes and slowdowns. Savings in construction processes will be witnessed due to the avoidance of jurisdictional disputes, the use of labor saving devices, and prefab construction.

LABOR AVAILABILITY PREDICTION AND MANPOWER SHORTAGES

Problem Statement

Nuclear power plant construction schedules require from 2000-4000 craftsmen for a one or two unit project. However, there is frequently a shortage of one or more crafts during periods of peak manpower requirements on a nuclear site. Therefore, if labor availability prediction could alert project managers of the potential craftsmen that are seeking work, then construction schedules could be adjusted to absorb the manpower.

It would be a reasonably simple research project to predict the labor demand of nuclear sites and surrounding industrial projects. However, labor availability prediction requires a complex analysis of: (1) full-time versus part time craftsman (i.e., craftsman that performs construction in one season and farms in another season); (2) seriousness of the workforce (i.e., "boomers" may work enough to take long periods off to hunt and fish); (3) ability to recruit trainees or apprentices; (5) skill development; (6) union restriction on number of apprentices and the time to advance to journeyman status.

The other aspect of the craftsman availability problem is the necessity to conduct research which would minimize the peak manpower demands. Frequently, companies purposely space construction of twin nuclear units years apart because of the shortage of labor and this peaking of skilled trades. Manpower leveling and allocation computer programs could be developed or current ones could be improved to reduce peak demand and allow two unit projects to follow close behind one another.

Even with specially instituted training programs, skilled welders capable of meeting nuclear quality standards are usually in short supply in most areas. Furthermore, electricians and pipefitters are often in demand and their overall productivity could be improved.¹ Therefore, developing additional training programs and instituting work improvement techniques such as time lapse analysis could increase the number of craftsmen and improve their individual productivity.

¹ AIF 1973-74 Survey of Causes of Delays on Nuclear Power Plants

Importance

There has been insufficient research in plant location in regard to predicting labor availability, and what utilities should do if there is a shortage of manpower. In other words, projects are often isolated from major metropolitan areas, so the driving time may be 1 1/2 to 2 hours or more; and frequently, there are inadequate highways for craftsmen to commute to the site. Labor availability should be a consideration in siting plants, for the longer commuting time has an adverse effect on the number of craftsmen that can be recruited plus long distances encourages turnover and absenteeism.

Even though craftsman availability prediction studies have been attempted by some groups, few have been properly completed. It is important to develop a procedure that utilities could follow to predict manpower needs and indicate ways to obtain qualified craftsmen. Thus, how should the utility and constructor plan and arrange for labor availability in advance of the initiation of construction?

Although research into predicting manpower requirements, considering commuting distances in plant siting, improved recruiting and training, plus productivity improvement may not seem as urgent do to recent plant postponement and cancellation, these concerns over labor availability may intensify if nuclear power receives additional support from the government. Thus, construction manpower could definitely be one of the limiting factors in the country's ability to construct nuclear power plants during the next ten years.

Research Approach

1. Review the labor demand and supply studies being conducted by Mr. William Rahn, U.S. Labor Department, to determine how ERDA could supplement their research.
2. Develop a computer program, check list, and formula, or other method that utilities would gather data, plug-in, and predict labor availability during the siting process, and more accurately, prior to construction. This latter information would then be used in a well-developed manpower leveling and allocation computer program. If cash flow wasn't the major constraint, then manpower availability would more than likely be the most important factor in the development of the project schedule. Float time in the schedule is manipulated by the resource allocation and leveling program to reduce peak demands, but current programs, and

even the development of a more advanced one,² is necessary to take full advantage of this technique.

3. An impartial university study should be conducted to determine if, and how, union practices that aggravate the demand for skilled craftsmen could be eliminated by nuclear power plant agreements. For example, open shop contractors are able to maximize the use of their skilled craftsmen, because there are none of the following restrictions:
 - a. No pre-established crew size (time lapse analysis frequently shows overmanning of construction activities).
 - b. No foreman to journeyman ratios
 - c. No standby labor
 - d. No featherbedding and make work practices
 - e. No restrictive work practices such as the use of automatic welding equipment
 - f. No restrictions on innovative materials or design
 - g. No journeyman employed to do unskilled work
 - h. The work week can be varied to makeup time due to bad weather
 - i. There is less turnover
 - j. Shift work is at reasonable premiums and overtime is at time-and-a-half.

Furthermore, the study would evaluate apprenticeship training to determine how the union programs could meet the skill and manpower requirements for future nuclear power plant work.

4. Another more radical, but necessary, research study would be to determine where, to what degree, and how to import skilled craftsmen to an area. This would necessitate developing a means to transfer fringe benefits funds from local to local. At times the demand may be so great that utilities could consider recruiting skilled craftsmen from Canada and Europe. The previous research should consider importing contingencies as well as cooperating with unions and other heavy industrial construction employers drawing from the same labor craft pool to establish area wide labor requirement forecasts.
5. Research that would determine how NRC backfitting changes could be minimized would improve both manpower availability and the accurate prediction of the required number of craftsmen for nuclear projects. These

²Calin Popescu, "How to Use CPM in Practice-Resources", University of Texas, 1976.

NRC requirements place additional workload on construction labor, aggregate skilled labor shortages, and adversely affect morale and productivity. For example, 25%-30% more manhours per KW were required for 1979 plants as compared to those completed in 1972-73.

Before NRC could issue a blanket retrofitting requirement, impartial university researchers would conduct a cost-benefit analysis to insure that it would improve the safety and reliability of the plant. Similar research would tackle the need for extensive documentations in which thousands of skilled manhours are devoted to QA/QC requirements. If time lapse films could record work procedure and other QA/QC data, less documentation is necessary. The objective of the study would be to reduce the 75% of the time some field supervisors devote to documentation as compared to only 10% on a non-nuclear project.

6. Considerable research should be devoted to improving productivity to reduce the impact of inadequate labor availability. The initial step would be to create productivity indicators and controls. This would be followed by methods improvement studies, and time lapse film analysis to insure crews are not overmanned.

Anticipated Results

1. Availability projections of short and long term requirements for construction manpower would have accurate data accumulated by major industry segments (power plant, refinery, process chemical, etc.), regions of the country, and skilled trades. This would improve construction scheduling, manpower allocations, and utilization of skilled labor.
2. Labor agreements which reduce restrictions will alleviate the unnecessary demand for skilled labor and allow more work to be performed by semi-skilled or unskilled workmen.
3. Recruiting, transferring, and training research could reduce the low productivity on nuclear sites as a result of insufficient numbers of competent supervisors and skilled craftsmen. This is absolutely necessary to reverse the long range trend of an increasing manpower shortage.
4. Research outside the field of labor availability prediction that improves the overall performance of skilled craftsmen will reduce the detrimental effects of insufficient manpower. In particular, if quantities of materials to be installed could remain the same, rather than continually increasing as a result of NRC changes, less manpower would be required to build future projects and they could be completed in a shorter period of time.

SHIFT SCHEDULING

Problem Statement

There are nuclear power plant construction projects that would reduce costs and time through double or triple shift scheduling of critical path work. However, there are both problems and opportunities that could benefit from research aimed at improving the productivity on each shift.

Unions have considerable control over the arrangements for shift work. For example, lack of uniform starting and quitting times for all crafts on large projects reduces the likelihood of effective manpower utilization when shift schedules are instituted. Furthermore, there is even a lack of suitable union arrangements for shift work, particularly for manning small second shifts on critical activities. It was reported that in some localities, there were crafts which declined to work shifts or work shifts at various non-uniform rates up to double time.¹ Thus, shift work would be almost as uneconomical as continuous overtime, plus create inequities and dissatisfaction among craftsmen.

On the other hand, a project in this subcontractor's area indicated less problems and greater productivity on their night shift than during the regular day shift. The comments of the area supervisors, general foremen, and foremen indicated the following advantages of working on the second shift:

- (1) There was not as much interference from upper level supervisors and QA/QC inspectors because a majority of these people went home at 5:00 p.m.
- (2) The union halls were closed during this time so that the business agents did not become involved with the workmen who would have the prerogative to call them during the day.² Thus, foremen had slightly greater control over the craftsmen.
- (3) The second shift did not normally have to find new work as it was largely employed to finish work begun during the day shift.

¹ AIF 1973-74 Survey of the Causes of Nuclear Power Plant Delays

² Reference is made to Saxon Palmeter's Keynote Address at the Penn State Power Plant Construction Education and Research Needs Meeting (5-10&11-77) for discussion on a foreman's dual loyalty to union and company.

- (4) Craftsmen on the night shift appeared to be more serious about their work. Many of these workmen heard about the job after the hiring had been completed for the regular shift, but they wanted work badly enough to take a night position rather than wait for an opening in the regular shift.
- (5) There are fewer men in the night shift so there was more room to work.
- (6) Foremen have been able to motivate the second shift by arousing their competitive spirit against the day shift. The second shift tended to think of itself as the "second team" in the work force and jumped at the chance to make the day shift look bad.

Importance

There are nuclear power plant projects that are scheduled on a double shift in order to meet the utility's future power requirements. Secondly, if only critical activities are continued on a second shift by a small work force, then both float and project times are reduced at the minimum cost.

Double shifts take better advantage of equipment on the project. The rather compact working area of a nuclear site can be well-lighted for night work. Furthermore, second shift scheduling reduces the detrimental effects of over-manning a crowded site or employing costly overtime.

By creating the conditions which initiate the competitive spirit in most members of the work force, shift work offers exceptional motivational opportunities. Management could provide feedback and recognition based upon short interval schedules to crews performing similar work on the day and night shift. Hopefully, interest in the work will be greater, there will be less absenteeism and turnover, and productivity would be increased.

Research Approval

1. Research may have little effect on the union constraints on shift work. However, it may be possible to indicate to unions how shift work could be a deciding factor in a utility selecting a union or open shop contractor. This topic should definitely be included in any national project agreement.
2. Research which would examine how shift work could increase productivity would be very beneficial to utilities.
 - a. A national survey by written questionnaire and/or personal interviews should be conducted to verify the previously listed findings on the productivity advantages of the second shift.

- b. A critical review should be undertaken of the types of interference of upper level supervisors and QA/QC inspectors during regular shifts. Are these individuals really needed on the project, or perhaps they may interfere to justify their position? If QA/QC is so important during the daily hours, why isn't the same number of inspectors on the night shift if the number in the work force is essentially the same?
3. Shift work scheduling and the interrelationship between material logistics and equipment availability could be examined by studying projects employing one shift versus other projects working a double or even triple shift. A list of detrimental effects of overcrowding by continually adding craftsmen, versus the time a double shift should be initiated to assist construction managers and utilities which must make this decision.
4. A unique study could be developed to examine competition between first and second shifts. This would be of a friendly nature and quality would be evaluated, as well as productivity to determine the most effective work group. Motivation of a rather apathetic nuclear power plant craftsman could be improved considerably if a competitive spirit was created on the project. Various methods of measuring and visually displaying regular versus second shift productivity by crews should be researched.
 - a. The study would require before and after measurement of productivity, plus continual feedback of the attitude of the work force.
 - b. Perhaps, representatives of crews could establish the method of evaluation and nominal rewards that would recognize effort.
 - c. Researchers would study turnover and absenteeism figures, for they should drop if the work force enjoys the competition.
 - d. All crews should receive feedback from management at significant milestones of the project.

Anticipated Results

1. The study would clearly indicate the necessity for unions to make arrangements for shift work when overcrowding occurs on a project.
2. Research findings would also provide key factors which indicates when the utility and contractor should institute a second or even third shift.
3. The overall procedure for creating competition, evaluating results, providing feedback, and recognizing achievement between first and second shifts has a tremendous motivational value to a nuclear power plant site. Attitude, turnover, absenteeism, productivity, and even quality measurement would provide valuable information to future construction projects irregardless of whether they will employ double shifts.

RESEARCH IMPLEMENTATION/COOPERATIVE PARTIES

Implementation

The order the subsections were arranged would be the recommended progression of manpower and productivity research. The initial study would measure productivity and determine the most significant factors that influence the effectiveness of construction manpower.

Previous studies have indicated motivation, absenteeism, and turnover as universal problems on nuclear sites. A research program should be aimed at improving motivation, and thus, reducing absenteeism and turnover. If productivity indicators were developed in the initial study, this could provide excellent before/after feedback on the value of the motivational program. Also, just eliminating the factors isolated in the previous study that prevent the workforce from developing feelings of high productivity is a motivator for all levels. That is, if a sense of accomplishment can be developed on the nuclear site, this may be the prime motivator.

The capability of the time lapse camera that would be employed in the initial measurement study, craftsman and supervisory training, and QA/QC productivity improvement could become a significant management tool on a nuclear site. The analysis may improve activity planning and encourage short interval scheduling of definable work packages. More effective planning improves motivation by developing feelings of high productivity, and this is usually the most important factor for increasing job satisfaction of construction manpower.

The final research studies are somewhat controversial, so a good track record on the previous projects would be beneficial to the researcher. Although everyone supports a study evaluating union versus open shop productivity, it would be difficult to find participants, eliminate bias, and report results. On the other hand, research to evaluate projects under the present labor agreements, and possibly, providing input for John Dunlop's national nuclear power plant labor agreement would be a more worthwhile project.

Predicting labor availability, and possibly, reducing manpower shortages involves a comprehensive evaluation of the supply and demand of skilled craftsmen resources. The U.S. Labor Department has initiated availability studies, but the work restrictions, lack of adequate training, and other

factors aggravating manpower shortages would again involve controversial studies.

Finally, shift scheduling should be researched to determine if competition between shifts could be encouraged, and also, to verify if second shifts have less productivity hinderances than regular shifts.

Cooperative Parties

One of the most difficult problems the researcher must face is how to handle proprietary productivity data. It may be sufficient for the researcher to report productivity increases as a result of programs to improve motivation and reduce absenteeism and turnover. Or, if enough sites are examined, actual before and after productivity figures could be reported, but not associated to a project or company.

Researchers will have to obtain nuclear contractor and utility approval of methodological instruments (questionnaires, interview surveys, work sampling studies, and time lapse film analysis). All information would be confidential, so comments are not associated to names. Finally, the contractor and utility should have the authority to edit the reports.

Sufficient site investigations should be conducted to determine productivity differences due to types of contract, union versus open shop, method of organization, area of the country, etc. However, considerable front-end work must be completed by researchers before utilities and contractors would agree to the analysis of factors influencing productivity. Even more effort is required to convince utilities and contractors to make the changes necessary to demonstrate results. The best approach to developing this close working relationship is to receive ERDA, EPRI, EEI, Contractor Association, and Labor Union endorsement of the study.

The researcher is in an even better position if a utility or contractor brings a universal productivity problem to the researcher and requests assistance. If this situation does occur, the researcher could gather data, develop techniques to assist the contractor and utility, and report positive or even negative results. Only a small percentage of the information would be too confidential to share with other utilities and contractors.

In summary, how will the desperately needed productivity research be accomplished? ERDA and NSF could sponsor utility-A/E-Constructor-University teams which conduct long term and extensive productivity studies over the

entire spectrum of construction activities. Utility, EPRI and EEI funds that are earmarked for research should begin to include short or long term management related research. Utilities and contractors could sponsor manpower and productivity studies to solve a problem that may be prevalent on many sites. If the utility-contractor-researcher team is able to save time or money, perhaps a continuous research group would result, and they could consider other problems plaguing nuclear power plant construction.

SUMMARY AND CONCLUSIONS

The problem of poor productivity on nuclear power plant construction projects has been verified by numerous studies such as GPU Service Corp's evaluation of an average craftsman's working time of 35%, or less than 3 hours per day, on six projects in Florida, Colorado, Pennsylvania, and Connecticut. These figures are similar to 30%-40% average working time reported at the Civil Engineering Productivity Conference in August 1976.

Mr. Alexander Schmidt, Vice-President of Construction, Riley Stoker Corporation indicates another adverse trend; whereby erecting equipment costs have risen to 40%-45% of the delivered and erected price. Only a few years ago this activity cost 20%-25% of the total. Mr. Stoker concludes that productivity of labor is an area of study that cries out for help.

Productivity is related to skill of the craftsmen, so additional training by the nuclear industry, would supplement the efforts of craft apprenticeship program. Likewise, supervision must be improved to tackle the increasingly complex nuclear plants with strict specification and dimensional tolerances requirements and the never-ending design changes. Furthermore, foremen and general foremen will be called upon to motivate the craftsmen by helping him feel achievement, assume responsibility, and accept challenges.

Both the availability of construction manpower and labor productivity will be limiting factors in our ability to construct nuclear plants during the next ten years. Research work in the challenging topics previously described could make a substantial contribution to reducing or eliminating manpower or productivity as a barrier to completing nuclear plants on time and within cost.

VOLUME I SECTION 8

OTHER RESEARCH NEEDS

By

**Dr. John D. Borcharding
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**Dr. Richard E. Larew
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**Note: This section in the final report will contain information from
all contract parties and be organized by the principal investigator.**

**The following pages of this draft include the input from
Dr. Borcharding. The input from Dr. Larew is included in
Chapter 3 of Section 4 of this volume.**

Section 8
Other Research Areas
Intervenors

J.D. Borcharding, University of Texas

Problem Statement

Due to the controversial nature of nuclear power plants, public intervenors have caused many pre-construction delays on projects located in various areas of the country. In particular, the Waterford 3 project was plagued by only a few intervenors. The Seabrook demonstrations and imprisonment is a more graphic example of organized intervention.

Frequently, intervenors file injunctions or use delaying tactics to postpone public hearings. There is absolutely no damages if the intervenor's charges are not proven, so they have nothing to lose by delaying projects.

Importance

Pre-construction delays are costly to utilities, and frequently, the environmentalists' objections and sympathetic court rulings discourage the project in question as well as future nuclear power plant construction.

Research Approach

Data should be gathered from past projects to determine what effect intervenors have had on cost and schedule. Court proceedings would be examined to determine what problems have led to the granting of an injunction or postponing of a hearing. The results of the investigations and decisions should provide tabular data that could be used by courts to evaluate similar situations.

A formula of damages should be developed; whereby, intervenors will bear some liability for halting a project. This formula will depend upon the relative schedule position for the project and projected cost increases. Thus, the intervenor would have the opportunity to present well-substantiated concerns, but petty delaying items may end in a judgement awarding damages to the utilities.

The courts could warn the intervenors by examining the tabulated outcome at previous projects and indicating that they have little chance of

proving their points, plus they could wind up paying damages of \$1000 per day. Furthermore, weak cases could be automatically disregarded by courts with an understanding of previous decisions.

Anticipated Results

If new policies were instituted by courts, then months of needless delay and cost increases could be saved. The number of petty nonlogical delaying tactics would be reduced as a result of the court awarding damages to utilities.

Section 8
Other Research Areas
Cash Flow
J.D. Borcharding, University of Texas

Problem Statement

Utilities are facing the challenge of building \$1 billion, 1200-1300 Mega Watt nuclear generating units with limited cash. In some areas of the country this problem becomes acute when construction costs are not added to rate base. For example, the utility must borrow the money from lending institutions rather than passing the costs to the consumers as construction progresses.

Increases in interest rates and length of time for financing plus inflationary increases in material, equipment, and labor costs make it difficult to estimate the final construction cost. The illustration of Waterford 3 estimates of \$230,000,000 in September 1970 to \$815,000,000 in July, 1976 or the San Onofre 1970 budget of \$450,000,000 jumping to \$2,075 billion in 1975 are the rule, rather than an exception, in nuclear power plant construction. It comes as an unpleasant shock to a utility that expects a \$10-15 million per month cash flow to end up paying \$15-25 million per month to meet the projected schedule. Therefore, the only alternative to a limited cash situation of \$10-15 million per month is to lengthen the schedule. On the other hand, if costs are reduced when labor effectiveness is increased such that you perform the same work with a smaller labor force, then a utility can maintain the schedule and the overall project cost will be less. For example, a nuclear project was forced to cut back manpower from 2000 to 1200 workmen at the first of the year due to cash flow problems. The utility agreed to extend the completion from June 1 to September 1 and accept a 3-month delay. However, the management of 1200 people was so much more effective than 2000 craftsmen that the June 1 date was met.

Importance

Cash flow limitations is potentially the most detrimental barrier to reducing construction schedules on many projects under construction at this time. In the University of Texas Subcontract Area, one nuclear power plant has been postponed four years due to a recently enacted state referendum that

prevents utilities from passing construction costs to the consumers in the rate structure. Another utility is in an extremely weak cash position as a result of a commitment to continue their nuclear plant on schedule. A third utility is facing severe cash flow problems, and this will probably be the determining factor in scheduling the work. A final utility has lengthened its schedule a year to meet projected cash flow requirements.

The cash flow problem experienced in the Southwest is also prevalent in the West, Midwest and East. The Southeast is the only area of the country that may not be feeling the effects of limited cash and ever increasing construction costs.

Research Approach

EPRI, EEI, and ERDA should support manpower and productivity studies that reduce labor costs, 30%-35% of the direct capital cost for construction. In particular, this would include the studies proposed in Section 7, but research in Sections 4-6 would have a similar cost benefit if scheduled time is reduced. If manpower is accomplishing more work with less people then cash flow constraints are not as great and there is also less need to go to costly overtime to attract craft labor when there is a shortage.

A second approach beyond the Section 7 studies is to concentrate on planning activities under a cash flow constraint. Computer allocation and leveling programs could assist project management to determine the proper mix of supervision and manpower to prevent crowding. Likewise computer program time-cost trade-off research that allowed non-critical activities to be lengthened could reduce costs and not affect the overall project duration. In both instances, time lapse filming of crews could provide invaluable planning information such as too many men being assigned to a crew or men waiting an unusually long time for the material.

Research should also be undertaken when utilities add manpower or go to overtime as a result of schedule delays or inadequate productivity. The utilities cash flow is severely strained because less experienced or fatigued manpower are not as productive, there is overcrowding, and frequently, inadequate supervision.

A completely different approach would have universities work with utilities to determine innovative financing technique. How is financing being accomplished? How have other capital intensive industries financed

their projects? Could different financial methods be developed to benefit the user, as well as the utility, in order to prevent the situation that occurred in Missouri in which voters rejected the passing of construction costs for utility projects in the rate structure.

Anticipated Results

The first three research approaches to the cash flow problem provide a means for utilities to get more work for less money. For example, time lapse analysis consistently shows too many men in crews, and a reduction of one or more workmen will not increase the time required to complete the activity, but it does reduce costs. Therefore, productivity studies that illustrate techniques for contractors to "WORK SMARTER, NOT HARDER" should have an extremely beneficial effect on labor cash requirements.

An unbiased study of alternative financing that gives the rate payer and utility fair consideration would be an important factor in meeting the cash demands to maintain generating capacity. Also, this will keep the nuclear power generation alternative alive, for the ever increasing costs and delays on nuclear power plants has almost priced them out of consideration.

VOLUME I SECTION 9

SUMMARY AND CONCLUSIONS

By

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Note: This section will be written for inclusion in the final report
based on the author's review of the draft report.

VOLUME I APPENDIX A

SELECTED BIBLIOGRAPHY

Note: The bibliographies currently included by section will be combined and organized herein prior to issuance of the final report.

VOLUME II

VOLUME II SECTION 1

BARRIERS TO SHORTENING CONSTRUCTION SCHEDULES
SUBCONTRACTORS REPORTS

By

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Mr. Sid R. Okes
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Barriers to Reducing Construction Schedules
On Nuclear Power Plants

by

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University of Texas at Austin

Subcontract' to Ohio State Research Foundation

Introduction

The first section of this report will discuss the most significant barriers to reducing construction schedules on nuclear power plants, and the second part examines possible research studies that can eliminate or minimize construction delays.

In-depth interviews with utility executives, engineer-designers, construction managers, constructors and subcontractors associated with nuclear power plants under construction in this subcontractor's area provided the information on delays and potential research. Additional data was furnished by individuals from the Atomic Industrial Forum, National Electrical Contractors Association, Power Plant Acceleration Task Force, Federal Energy Administration, Energy Research and Development Administration, Consolidated Edison of NYC, GPU Service Corporation, and Stanford University Workshop participants. Appendix A lists the names, titles, affiliations, and projects, if applicable, of the individuals that were interviewed. Appendix B is the revised interview survey that was developed from the author's original survey and the Ohio State Matrix. Although the interview usually followed the survey format, individuals were encouraged to discuss possible research projects as they examined various factors that have delayed their projects.

Pre-construction Delays

One of the projects, Riverbend 1 & 2, in the subcontract area has a Limited Work Authorization (LWA) due to a major construction delay -- Licensing. The project was within a week of receiving a construction permit in August 1976, but the Vermont Yankee Ruling stopped Licensing and has caused a nine month delay.

A second project, Waterford 3, experienced licensing delays, and for two years it was held up for anti-trust hearings. Also, environmentalists (intervenors) and the associated court rulings delayed the project. The fifty-one months of pre-construction delays has increased cost estimates from \$230,000,000 in September, 1970, commercial operation, January, 1977, to \$815,000,000 in July, 1976 for commercial operation in Spring, 1981.

At this time, the most difficult problem encountered in licensing is alternative site selections. The siting requirement prevented issuances of a construction permit to a Florida utility until it made a more thorough investigation of an alternative site. The PSAR, Environmental Impact Statement, alternative siting requirements, anti-trust hearings, the possibility of intervenors and associated court hearings have forced utilities to allow four to seven years of planning before issuance of a construction permit. This long lead time plus the construction and start-up time has increased nuclear plant project schedules to ten to fifteen years.

Even though pre-construction is not considered a major part of this research, possible research studies in standardization and the economic impact of each aspect of licensing delays will be discussed in the second part of this report.

Engineering and Construction Delays

Changes

Although a subsequent section shows that cash flow is potentially the most detrimental barrier to reducing construction schedules, changes due to NRC, Utility, Engineer/Contractor and Vendors, have the most impact on day to day field operations. One project in this subcontract area reported that 40% of the changes are due to regulatory requirements; 35% by utilities; 10% engineering initiated; 10% contractor request; 5% by vendors. This particular project lengthened the schedule one year due to the lost time from regulatory and utility changes. A structural concrete subcontractor explained how changes were the major barrier to meeting schedules and they had an intangible effect of destroying momentum and morale.

In relation to change delays, there is the necessity to provide design lead time for construction so that the field project engineers conduct constructibility reviews of the drawings to plan methods and detect interferences. Consider the project engineer's position when he establishes the methods to employ, and as the work begins there is another revision. One project that was 20% complete had thirteen revisions to the excavation drawings and 24 revisions to the flow diagrams.

Finally, changes, as well as everything else on a nuclear power plant construction project, must be thoroughly documented. Thus, minor field modifications cannot be accomplished when the crew is performing the work, and lower level supervisors must wait on upper level approvals and the proper documentation.

Manpower

The productivity of labor on nuclear power plant construction sites is usually much lower than on commercial or even industrial

construction projects in the area. Often low productivity is blamed on union restrictions, featherbedding, type of contract (cost plus vs fixed price), skill levels, QA/QC requirements, design changes, and timely information, material and equipment deliveries, weather and plant arrangement and accessibility. However, the most significant productivity problem is due to unqualified field supervisors with little or no nuclear power plant construction experience. This lack of nuclear experience, plus QA/QC requirements has forced management to assume much of the decision-making authority and responsibility that is normally delegated to general or crew foremen. The foremen are no longer planners, for any innovation they implement would probably adversely affect the planner's well laid-out schedule. When an obstacle is met, the foreman must find the planner and the crew usually waits. This is one reason why studies on nuclear power plant projects indicate that the average journeyman spends only 30% of his day on productive work.

Another manpower problem that is peculiar to large industrial projects is the high turnover and absenteeism. One project in Florida reported turnover of 300% for carpenters, 400% for pipefitters, 350%-400% for electricians, and 250%-300% for iron workers. Therefore, the learning curve, familiarity with the site, and knowledge of procedures is lost. Also, in the subcontractor's area, one project reported an average daily absenteeism of 20% and absenteeism as high as 50% in cold or wet weather.

Regardless of whether the project was union or open shop, utilities, contractors and subcontractors were concerned about the

effect of low productivity on the project schedule. Many of the subsequent research study recommendations will be directed toward improving the productivity of manpower.

If this goal is accomplished, not only costs and time would be reduced, but the effect of shortages of craftsmen (welders, pipefitters and electricians) which frequently occurs on nuclear power plant projects would be minimized.

Other research recommendations such as plant standardization, concerning the physical material content, greater design-construct leadtime, and less NRC back fitting would also improve productivity and the effectiveness of construction manpower.

Quality Assurance/Quality Control

The stringent QA/QC requirements necessitate numerous inspections be carried out before construction can progress. Furthermore, specifications must be adhered to in minute detail, and strict tolerance requirements make it necessary to redo work that is slightly in error but is normal construction practice. For example, a slab was replaced because slump requirements were not met; even though it may have met the required strength. There have been so many QA/QC guidelines and the variation of interpretation by individual inspectors has made it difficult for management and supervisors to know what is required. Some guidelines concern components which have already been completed and they must be taken out and redone.

Redoing work also has an adverse effect on the morale of workmen, so loss of interest could result in less quality regardless of QA/QC. Workmen are frequently asked to work within strict

tolerances even though there isn't a reason -- just the requirement. ACI Code 315 allows rebar shear tolerance of 1", while ACI Code 318 requires 1/2" shear tolerance. With the number of cadwelds and the length of 1" and less bars, it is almost impossible to meet ACI 318. Which code should govern? In nuclear construction, one always takes the most conservative number.

Motivation is adversely affected when QC inspectors delay approvals after supervisors and workmen make an extraordinary effort to complete an item to meet the schedule. Supervisors have difficulty obtaining a similar effort when craftsmen consider that the work didn't really need to be rushed.

Finally, the stringent QA/QC has taken the challenge of innovation and participation in method planning away from the craftsman, for he is told what to do in minute detail.

There were complaints from contractor personnel that NRC federal guidelines are written by engineers with little construction experience. Likewise, QA/QC inspectors have little practical experience in working with materials on a construction site. For this reason they are over cautious and tend to be inflexible and too stringent when interpreting specifications or guidelines.

The documentation requirements for QA/QC is a final source of construction delay. This is particularly true for many materials delivered to the site. For example, the painting of one bolt for the reactor required seven pages of documentation. The painting subcontractor's supervisor said he spent 75% of his time providing proper documentation while this may amount to 10% on a non-nuclear project.

Material Supply

Material supply is a potentially difficult barrier to overcome on a nuclear power plant construction site. Part of the reason is the QA/QC documentation requirement, and secondly, the ever increasing amounts of materials to be installed.

Manufacturers do not carry a surplus of even the ordinary items used in all nuclear power plants, because they are afraid of an NRC change which will make them obsolete. The supplies must be nuclear certified, and many manufacturers aren't interested in pursuing this stamp due to documentation requirements. For example, the limited number of certified valve manufacturers and the closing of casting and forging companies has led to shortages across the country.

Manufacturers are only marginally interested in nuclear work, so they frequently place other orders for non-nuclear certified (undocumented) equipment ahead in the production schedule. Therefore, any missing items must be blocked out as the construction work is being accomplished, and crews must return to the area at a later date to finish the work.

The amount of material required for construction continues to grow as a result of NRC regulations, seismic requirements in particular. Duct work for Unit 2 of the Arkansas Nuclear One project went from 100,000 lbs. (Unit 1) to 130,000 lbs. while supports were changed from 3" X 3" to 6" X 6" angles and the weight went from 130,000 lbs. to 250,000 lbs. Concrete, steel, piping, electrical conduit and wire, and other materials continue to increase as additional safety (redundant) systems are added to each new

nuclear power plant project.

Cash Flow

Cash flow will probably be the most detrimental barrier for utilities to overcome on the plants under construction at this time. One power plant in the subcontractor's area has been postponed four years due to a state referendum that prevents utilities from passing construction costs to the consumers in the rate structure. Another utility is in an extremely weak cash position as a result of a commitment to continue their nuclear plant on schedule. A third utility is facing severe cash flow problems, and this will probably be the determining factor in scheduling the work. A final utility has lengthened its schedule a year to meet projected cash flow requirements.

Of the five previously discussed schedule barriers, cash flow may be the most difficult to research. Other than a study to determine the best method of scheduling with limited cash flows, this would be a particularly difficult area of research. However, costs can be reduced when labor effectiveness is increased as a result of successful manpower research studies.

Pre-Construction Research

The preceding section on pre-construction barriers to nuclear power plant reduction was considered beyond the scope of this study. However, the time required for siting, plant safety licensing, environmental impact studies, anti-trust hearings and satisfying intervenor injunctions is threatening the economic feasibility of the nuclear power plant alternative to power generation. Therefore, if the current administration favors reduction in this period of time, ERDA could undertake a study to determine the most time consuming delays during pre-construction, evaluate causes for such delays, and propose alternatives to minimizing them.

A second case study will be concerned with the cost and delays that have occurred when intervenors file injunctions to delay a project. Data will be gathered from past projects that show the cost and schedule delays brought about by intervenors. If possible, some fraction of this cost could be assessed against an intervenor when the court determines that the work stoppage was without significant cause.

Standardization will be mentioned in the following section as a potentially effective method of building nuclear power plants in a shorter period of time. This is equally true for the pre-construction, and ERDA should do a study of the pre-construction time requirements if utilities would adopt additional SNUFF plants.

Each of the proposed studies should have a major impact on governmental agencies, and hopefully, improve the overall nuclear

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construction changes.

Finally, there could be considerable research into changing code and standard requirements that add to the schedule and cost of construction without any benefit to plant safety, operation and maintainability. For example, a series of research studies on concrete ACI codes for slump, temperature, and rebar tolerances to determine reasonable requirements that do not affect strength could improve schedules and decrease costs. The changes in slump could make it easier to pump, have less trucks rejected, and possibly eliminate the removal of placed concrete that may meet designed strength but it wasn't placed within the narrow slump requirements. Likewise, the temperature restrictions make it necessary to cool aggregates and add ice rather than water to the mix to place concrete in the Louisiana summer. Tests which show minimal strength reduction even though the concrete is placed at a higher temperature would be beneficial to Southern contractors.

The most detrimental change that is affecting the installation of new projects and will require retrofitting of operating plants, is the greater seismic requirements. A thorough study of seismic requirements should be undertaken, and perhaps, ERDA could even sponsor earthquake prediction research that would allow sufficient time to shut down a plant.

Manpower

The detrimental effect of changes on the project schedule, also has an adverse impact on construction manpower. Therefore,

a reduction of NRC, Utility, Engineer, Constructor, and Manufacturer changes will help maintain project momentum. Standardization would help to maintain this momentum and also it could lead to improvements in the learning curve. For example, the momentum of Arkansas Nuclear One (Unit 1) was not maintained on Unit 2 due to the frequent changes. Plus, workmen were continually being told that the work must be done differently on Unit 2 due to NRC and QA/QC requirements.

Research into accelerating the learning curve impact on the construction manpower would improve productivity on the site. This would entail developing significant construction operation slides and time lapse film presentations.

A whole new outlook toward training is necessary on nuclear power plants. Research with unions, contractors, and utilities should concentrate on development of nuclear power plant craftsmen-technicians. Perhaps studying the training programs in the aerospace industry, and modifying them for construction would be better preparation for the tolerance and QA/QC requirements than simply improving existing construction programs.

In relation to productivity and training, research should be initiated at improving the supervisor-field manager's capabilities. Frequently, interviewers commented that the supervisors were the key to labor productivity and there were not enough foremen and general foremen with nuclear construction experience. Therefore, research into the type and method of nuclear construction supervision training for supervisors should be a beneficial technique

for reducing the experience requirements while improving productivity, and thus, reducing costs and schedules.

Better trained supervisors can also teach craftsmen, and a more productive crew could reduce the detrimental effects of manpower shortages that are frequently experienced on nuclear construction sites. A second alternative for becoming more productive with fewer craftsmen is the implementation of work improvement techniques. A research study employing time lapse film analysis and work improvement can illustrate this most effective method of placing materials, establishing crew sizes, and structuring the work flow for repetitive activities.

The manpower shortage is compounded by high turnover and absenteeism on nuclear power plant construction sites. Therefore, research that gives recommendations to reducing turnover and absenteeism would be beneficial. For example, incentive systems based on longevity at the site and weekly attendance could be structured for power plant sites.

An entire series of studies to improve job satisfaction by video tape introduction, newsletters, family tours, and other motivators could further reduce turnover and absenteeism. However, productivity improvement is possible through research into higher level motivators such as lowering the level of decision making, involving crews in method improvement studies, and developing competition among crews.

Motivation and job satisfaction may also be improved by short interval scheduling that gives crews work goals. A work

order, short-interval schedule should be investigated not only as an approach to avoiding delays, interruptions and changes, but also as a motivational device to challenge crews with small segments of the work to develop greater identity with the project.

This short interval scheduling research could be extended to define and measure construction productivity on power plants. Currently, manpower and unions have received much of the criticism, so there may be significant union support for research to establish improved productivity measurement, and a thorough evaluation of the factors influencing it.

Additional studies with union cooperation could explore four-ten hour day work week, selection of foremen, provisions for shift work, and turnover and absenteeism reduction. Unions could be the focal point for educating foremen and workmen on nuclear tolerance and QA/QC requirements. Instead of attacking unions, research would focus on determining a list of demotivators such as why materials are not available, why inadequate tools and equipment are used, why drawings are incomplete, and why the work place is congested. Innovative approaches to eliminating demotivators, which relate to planning, scheduling, control, changes, and others will have a beneficial effect on job satisfaction, but more important, productivity will also be improved and schedules and costs can be reduced.

Quality Assurance/Quality Control

The delays associated with the stringent quality assurance and quality control program may be reduced by research into improved training of manpower, supervisors, and especially QA/QC inspectors. QA/QC knowledge and judgment is necessary to make timely decisions to allow the work to continue. How to prepare inspectors to make these decisions would be the major subject of study.

The considerable documentation and approvals that are required to place concrete should be investigated to determine steps for reducing these requirements. Penn State's research is an initial approach to investigating concrete quality requirements to determine methods for reducing costs. QA/QC red tape severely hampers construction and it seems to exist for its own sake rather than a rational approach to support construction schedule as well as guarantee quality.

Frequently, utilities over commit themselves to unrealistic QA/QC requirements in order to get a construction permit. A study of these QA/QC commitments, and a determination of which ones could be relaxed without an effect on the overall safety of the project could be researched. This is also true for overcommitment to a NRC specification that is rather indefinite so the utility and engineer continually take the most conservative approach.

In addition to overcommitment to QA/QC, there has been a tendency to add back-up system upon back-up system, so the project

may be unsafe due to greater plant complexity. Before a tolerance is tightened or a new back-up system is added, there should be a research study to evaluate the cost to benefit. Likewise, there may be considerable merit in investigating strict tolerances and back-up systems currently being required to determine if the cost to benefit would indicate some relaxation. Either type study could hold nuclear safety as the utmost in importance, but why spend time and money meeting a requirement that is not necessary? For example, strict concrete slump requirements were previously mentioned under changes as a possible research topic to investigate. A relaxation in the tolerances would more than likely save time and money, if statistical research would indicate little, if any, effect on final strength. Another example is the length of time for concrete set-up before forms are stripped. Could the two to three days in warm weather and seven to ten days in the winter be reduced?

In summary, over specifying may cost the project 10% - 40% increase in labor cost and time, so cost-benefit analysis and the appropriate research studies could have a major impact on reducing schedule. Thus the first research study should concentrate on identifying specifications, codes, guidelines, etc. that are impractical, and then outline how they could be changed.

Materials Supply

Many of the problems from materials delays is a result of QA/QC requirements at the manufacturers plants. Therefore, the

previous comments on realistic specifications, reduction in documentation, less time for approvals, reassessing the value of redundant safeguards could apply to potential research of components for nuclear power plants.

Also, some unrealistic material quality requirements necessitate ever increasing quantities. Cost and schedule reduction could be accomplished if quantities could be established for a standardized plant, and perhaps, research studies could investigate a reduction in materials quantity without a determinable effect on safety. Seismic requirements need to be thoroughly evaluated to determine safe design levels, for this has added considerable quantities and has contributed to greater obstructions.

Less material delays would be encountered if documentation could be reduced to make it economically feasible for more manufacturers to get into the nuclear power plant component business. For example, manufacturers frequently say it isn't profitable to supply 5 - 10 pages of paper for a specific item such as a bolt. Consequently, only a few companies produce this particular bolt and at times, contractors must wait for delivery. The research would answer "what documentation is absolutely necessary to insure the plant safety rather than continually asking for more paper that doesn't contribute to the project."

Again, standardization would have a beneficial impact on manufacturers for they could afford to have some surplus components and equipment. The possibility of prefabricated modules and field assembly of components would also appeal to manufacturers. A study showing the material availability advantages

of standardization or modularization would provide an even more convincing argument to move in this direction. Also, this would encourage more manufacturers to enter this business because there would be less NRC changes that adversely affect production.

Time lapse filming research to examine material flow on a site would improve productivity and possibly, reduce damage. This research could be initiated at the offsite pipe spool fabrication facility. The improvement in fabrication time would have a direct impact on construction schedules, for more productive piping would be done in a factory environment.

In summary, research should be aimed at reducing QA/QC delays associated with the lead time for materials and equipment. The nuclear documentation requirement has resulted in many manufacturers delaying or disregarding orders because they aren't profitable. This has been expensive (5 to 10 times the cost of a similar, but a non-nuclear approved component) and time consuming, but there is no indication of an increase in the quality of the product.

Cash Flows

The most serious barrier to reducing construction schedules may be the most difficult to solve by research. However, universities and utilities may want to investigate alternative financing methods.

Research should be undertaken into managing construction schedules under the influence of cash flow constraints. For

example, a nuclear project was forced to cut back manpower from 2000 to 1200 workmen at the first of the year due to cash flow problems. The utility agreed to extend the completion from June 1 to September 1 and accept a 3-month delay. However, the management of 1200 people was so much more effective than 2000 craftsmen that the June 1 date was met.

The research proposed under manpower would hopefully improve cash flow, because less manpower would be accomplishing more work. Time lapse films frequently reveal that too many men are assigned to a crew, so these studies would assist constructors planning work.

Computer program time-cost trade-off research on which non-critical activities are lengthened could reduce costs and not affect the overall project duration. Likewise, developing computer allocation and leveling models could prevent the crowding of too many workmen on the site and inadequate supervision. Frequently, the opposite situation is experienced on nuclear plants; whereby, schedule delays and low productivity is counteracted by adding more manpower or going to overtime. Thus, the utilities cash flow is severely strained because less experienced manpower is not immediately productive, and they may be under supervised or over crowded.

Conclusion

The first section of this report illustrated pre-construction and construction barriers to improving construction schedules. Since changes, manpower, quality assurance/quality control, material supply, and cash flows have such a major influence on construction costs and schedules, a series of research studies were suggested to minimize and solve problems in these areas. Many of the proposed studies overlap more than one area, and include problems that weren't discussed such as research studies related to reducing the effect of weather on construction schedules.

The proposed studies must be better developed before this research could be considered. However, the evaluation of schedule barriers indicate that successful implementation of research in these areas would be beneficial to utilities, engineer-constructors, and the public.

CONSTRUCTION DELAYS
ON
NUCLEAR POWER PROJECTS

DRAFT INTERIM REPORT

Submitted to:

OHIO STATE UNIVERSITY RESEARCH FOUNDATION

and

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

by

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Section 2.3

INTRODUCTION

To identify major delays that were occurring in the construction of nuclear power plants, five power utility companies were contacted in the western and mid-western sectors of the country. They were requested to set up interviews with representatives involved in the initial planning of their nuclear power projects, the design effort, on-site construction management, and contractors presently working at the jobsite. The following utility companies and nuclear power projects were visited:

Arizona Public Service Company (APS)
Palo Verde 1

Northern States Power Company (NSP)
(office visit only)

Pacific Gas and Electric Company (PG&E)
Diablo Canyon 1
Diablo Canyon 2

Southern California Edison Company (SCE)
San Onofre 2
San Onofre 3

Washington Public Power Supply System (WPPSS)
WNP-2
WNP-1
WNP-4

On the APS and SCE projects, Bechtel Power Corporation is acting as both architect/engineer and on-site construction manager with the responsibility for the major construction effort at both sites. Representatives of both design and on-site construction were interviewed. Representatives of NSP were interviewed and, while they presently have no nuclear plants under construction, the problems encountered during construction of their three operating plants and their licensing delays on their proposed Tyrone Plant were

discussed. PGE acted as its own designer and construction manager. Both of their units are now at the state of completion where very little construction work is being carried on and it was not deemed productive to interview any of the present contractors on the project. On the WPPSS Project, in addition to representatives from the owner, on-site design and construction management representatives from Burns and Roe, Inc. and United Engineers and Constructors, Inc. were interviewed. At the request of WPPSS, none of the present contractors on the job were interviewed.

The interviews were conducted in such a manner that a general discussion was elicited from the questions posed in the Interview Form (see Appendix A). These comments and answers were then categorized into major delay types. A severity ranking, based on an increasing scale of 0 to 10, was computed from all the responses and is shown in Figure 1. Also shown is the source of delays listed by the organization that would be responsible for the various delay types.

The author would like to express his appreciation for the information and candid replies given by all those interviewed, and to acknowledge the valuable time they gave to this effort. A list of those interviewed is included in Appendix B.

Barriers To Shortening Construction Schedules

Delay Matrix

Delay Types	Severity Ranking*	Principals	Owner/Utility	Arch./Engineer	Construction Manager	Source of Delays	Owner	Arch./Engineer	Construction Manager	Contractors	Subcontractors	Suppliers	Labor Unions	Federal Regulations	State Regulations	Intervenor	Others
Design Quality	4 3 2																
Design Complexity	6 0 5																
Design Variability	3 3 0																
Design-Construction Leadtime	10 10 10																
Changes	9 10 10																
Manpower Availability	5 0 2																
Manpower Turnover	0 3 3																
Manpower Quality	1 0 1																
Productivity	1 10 0																
Labor Relations	8 10 8																
Supervision	3 3 4																
Material (Timely Availability)	0 0 2																
Equipment (Timely Availability)	1 3 2																
Material/Equipment Quality	2 0 3																
Financing	3 0 2																
Information Communication	3 0 0																
Coordination	5 3 7																
Construction Quality	2 5 2																
Construction Methods	7 5 5																
Weather	1 0 0																
Geological Factors	4 5 7																
Site Location	4 5 3																

*Severity Ranking
0 - No Problem
10 - Major Problem

Figure 1.

DISCUSSION OF DELAY TYPES

The following discussion pertains to the major delay types that were identified through our interview. While the number of companies interviewed (five) is relatively small, a total of 23 in-depth interviews were held which should provide sufficient base for a comparative analysis and understanding of the various delays in nuclear construction as perceived by those engaged in the industry.

2.3.1 Design Quality. The quality of the design continues to improve and this is due, in part, to the following:

- Less design changes required due to the issuance of fewer regulatory guides, codes and standards after 1975.
- Standardized designs being adopted, especially by NSSS manufacturers.
- A better understanding of what is, and is not, acceptable for nuclear plant construction.

What may be happening, however, is a sort of self-imposed internal ratcheting effect whereby designs are being up-graded to the point of no possibility of questioning their adequacy. This is happening where seismic considerations have required tremendous amounts of reinforcing steel for plants located in areas of severe predicted earthquakes and this design then carries over to plants located in areas of much lower predicted earthquake activity. It appears that a "state-of-the-art" plateau is being reached and the learning experiences (most very expensive and time consuming) are now in the past.

While there may have been some delaying impact due to the quality of designs in the past, this is not considered a major factor at the present.

2.3.2 Design Complexity. Nuclear power plant construction is, by its

nature, a complex operation. If contractors take on nuclear plant construction without an appreciation of this fact, they will run headlong into delays and work more costly than anticipated. Architect/engineers also are finding the complexity of design an ever increasing problem requiring a greater manhour effort in the design stage. Design manhours have increased in recent years from under one million manhours to between three and four million manhours for a single, 1,000 MWe plant. When taken as a whole, the increased complexity of these plants has had a marked impact on the design and construction time frames. One utility reported construction delays of approximately five months overall due to the increased complexity of design.

Some obvious examples of this increased complexity is the more than doubling of electrical cable in recent years, rebar densities of up to 950 pounds per cubic yard of concrete with half the total tonnage No. 18 bars (2-1/4" diameter), thicker concrete slabs and walls, and the general crowding in of systems due to the fact that the size of the power block buildings are continually being held down in an effort to economize on the cost of the buildings themselves.

In the design stages, computerized spacial interference programs have been developed to identify conflicts before they become construction interferences in the field. Zones for various systems have been set for the various electrical, HVAC and piping systems within a floor level.

Probably the most successful method to date for reducing interferences is the use of models which are now being built and used during the design phase. A large scale is used (3/4" = 1'-0") and virtually everything that goes into the plant is shown -- down to 1" diameter pipe runs. The cost of building these models is in the range of \$500,000. Changing and updating the models as revisions to the drawings are made must also be performed. Once

plant construction is begun, the models can be moved to the job site and used throughout construction to assist the contractors in planning, sequencing, and performing their work.

All of the efforts to eliminate interferences and reduce the complexity of design leads directly to the matter of constructibility analysis. Is it performed, and if so, when and by whom?

In most of our contacts with A/E firms, they reported that they were performing constructibility analysis in the early design stages of the project. In the case of the plants being designed and built by Bechtel, they were bringing their construction people into the design phase of the project 18 months prior to the start of construction. This enabled them to get the benefit of construction-oriented people providing input to the design. Scheduling, sequencing of operations, equipment selection, and craft man-loading are some of the elements that would go into the constructibility analysis. In the case of A/E's who had design, but no construction responsibilities, constructibility was performed by the designers for various disciplines. It was the feeling of all that once the design was completed, constructibility changes could no longer be made without disrupting the project schedule and thus making whatever change might benefit the construction process, impractical from a cost/time standpoint.

2.3.3 Design Variability. "Pride of authorship" seems to prevail to a great extent when considering the design variability from one A/E to another. Each A/E has its own preferences and procedures and, without question, incorporates them into their designs. Owners, too, have their particular preferences; even where a duplicate plant is being designed numerous changes are introduced to suit the owner's particular needs and desires. Site specific conditions to a great extent determine the major design differences in what

could be termed "sister plants." The obvious disadvantages in non-standard designs are increased licensing time necessary for complete review, increased design costs, and loss of some economies in construction which could have been gained from the learning curve in building identical plants.

Where site specific conditions (seismic, flooding, environmental, etc.) do not preclude duplication of plants within a particular project site or geographical area, standardization of plant design offers considerable savings in design costs, an estimated 10% construction cost savings on successive units, material and equipment savings through multiple unit purchasing, and probably most importantly time saved in the licensing of the project, now taking four to six years.

Standardization should be applied to two or more units being constructed successively on the same site or to the SNUPP (Standardized Nuclear Unit Power Plant System) concept where numerous plants of identical design are being constructed by utilities in geographically separated areas. It should be pointed out that under the SNUPPS Program design must be based on the most limiting environmental conditions. Therefore, sites in the western part of the United States would not be at all compatible with those in the midwest, at least from the standpoint of seismic considerations..

Standardized plants, usually consisting of the power block only, could conceivably produce "off the shelf" designs which should, in turn, produce substantial cost savings for the industry. Deterrents to standardization are the earlier discussed preferences of owners and A/E's, changes required due to the continuing evolution of NRC guidelines, improvements and changes made by NSSS and other suppliers, and the incorporation of general improvements that come with experience and time.

2.3.4 Design Construction Leadtime. There was virtual agreement among

the utilities, A/E's and on-site construction managers that the power block design should be at least 50% complete before the first Class 1 concrete is placed. Interestingly, though, most acknowledged that construction actually started at about 30-35% of design completion. Two reasons are given for this inconsistency: 1) the design was thought to be more complete than it actually was, and 2) the design had fallen behind and construction had to begin if more time was not to be lost. It appears that designs started five years ago were uniformly underestimated in terms of the time and manhours required for the design effort. As a general statement it can be said that once construction started the design never caught up. Experience and the shift towards more standardized designs will, in the future, reduce the delays now caused by a design not complete enough for construction to proceed in an orderly fashion.

2.3.5 Changes. The major contributing factor to the stretch-out in design and construction time and the tremendous increase in manhours for design was the proliferation of new nuclear application standards during the years 1973 through 1975. During this period, one utility identified some 1450 additional nuclear standards, of which 800 applied to civil-structural work. (See Figure 2) These changes are a result of on-going safety, environmental, and site suitability analysis during the PSAR (preliminary safety analysis report) review period and as a result of standards identified at other plants which would apply to a unit under construction. When new standards require major changes to the design, and the project is in the construction stages, expensive and time-consuming backfitting is required. Examples of major changes which caused delays prior to and during construction are as follows:

- Plant relocation due to environmental or site suitability objections -- 12 month delay.

Identified Nuclear Application Standards

Figure 2

- Review of seismic requirements for increased ground accelerations due to predicted earthquakes -- 12 month to 24 month delay.
- Change from "on-stream" to "off-stream" cooling -- 6 month delay.
- Backfitting of pipe whip restraints for postulated breaks in major piping systems -- 6 month to 12 month delay.
- Modifications of cooling water systems due to new state and federal water quality standards for "on-stream" cooling -- 6 month delay.
- Major modifications and additions to equipment and systems -- 6 month delay.

The manner in which changes are implemented in the field can have serious implications. Obviously, it is to everyone's benefit to complete the changes in the most expeditious and least-costly manner. However, some utility company policies inhibit the orderly processing of these changes. Where contractors are working under "hard money" or competitively bid contracts, and the change is not covered by previously identified unit price or similar lump sum work, the change process can become very involved and create delays. Usually, an extra to the contract must be negotiated prior to the work starting. If this is not possible (the parties cannot agree on a price or the scope of work cannot adequately be defined) the contractor is usually directed to proceed with the changed work and he will later be reimbursed on the basis of force account work or a negotiated amount. At WPPSS where, in the past, most contracts have been of the lump sum type, the execution of a change order from the time it is first identified by engineering to its incorporation in the work and resolution of payment with the contractor can take up to four months. Recognizing this delaying effect, WPPSS has now started awarding contracts on the basis of an "incentivised" unit price contract with target manhours. When changes are needed, they will now be expeditiously accomplished within

the structure of their contracts.

During the construction of their two nuclear plants at Diablo Canyon, PC&E used a combination of negotiated and competitively bid forms of contracts. Where changes in the work were required on negotiated contracts, the direct costs were automatically reimbursable under the contract and the fixed fee usually remained the same unless the scope of the work was increased substantially. In a few instances, hard money contracts were converted to negotiated contracts where the impact of many changes became a major factor.

On the construction of the San Onofre and Palo Verde Plants, Bechtel Power Corporation is acting as both architect/engineer and general contractor. Here, field changes are effected without delay as Bechtel is operating basically under a cost-plus, fixed-fee type of contract.

NSP is designing their new Tyrone unit under the SNUPPS method and since theirs is one of the last to be constructed, they expect few design changes during the construction phase of the work. It is, therefore, their intention to act as their own construction manager and contract the work out on the basis of competitively bid work packages.

The effect of changes on the construction process breaks down into the following categories:

<u>Type</u>	<u>Effect</u>
Change during design phase	Possible design delay
Change during construction phase	Possible design delay, possible construction delay, possible contractual delay

Changes, at whatever stage of the project, have a demoralizing effect on all concerned -- from the designer to the tradesman making the change. While changes need not be accepted as inevitable, they will occur with a certain degree of certainty and must be approached as challenges. Different

solutions are being utilized by each company with various degrees of success. It can be stated that changes required, from whatever source, are expensive and create a major delay impact in the construction of nuclear power plants.

2.3.6 Manpower. The availability of manpower affects the owner, architect/engineer, jobsite management and contractors. The rapid build-up of supervisory nuclear construction personnel at WPPSS from about 30 people in the early 70's to approximately 300 engineering and administrative personnel at the present has presented unique growth problems. The other utility companies interviewed have had the advantage of many more years in the design and construction of power generating facilities with a larger resource of personnel that could be moved into the nuclear field. The architect/engineers interviewed indicated only minor problems in obtaining qualified design engineers. The manual craft labor was, generally, in sufficient supply and of adequate skill level with the exception of pipefitters. The more exotic welding requirements in nuclear piping has created a shortage of qualified welders at all sites visited and either jobsite or union training schools for welders have been established. Manpower projections show manual labor peaks of 1,900 men needed on a single, 1,000 MWe unit, and close to 3,000 men for two units being built with a one to two year lag between them. Attempts are being made to level manpower requirements and this effort is especially adaptable to duplicate units under construction. However, computer based manpower leveling was not being performed to a degree that would be expected on projects of this magnitude.

The effects of manpower availability, turnover, and quality did not appear to present any measurable delaying impact on the projects visited.

2.3.7 Productivity. The productivity of the work force was rated as high at all of the job sites visited. There was not, however, a clear or

uniform definition from those interviewed as to what "Productivity" means. If the workmen were engaged in productive effort versus non-productive effort (waiting, transporting, break, travel, instructions and planning) they were considered to be productive. Based on this analysis, productive time of the manual work force varied between 30 and 50 percent of the time on the job. But what was accomplished in this productive time varied even more. As an example, the manpower effort required to install reinforcing steel for the containment vessel varied from 16 to 35 manhours per ton. No easy conclusions can be drawn from this except to state that productive accomplishment and productive time spent on performing a particular activity are not the same thing. Many other factors have a marked effect on the productive accomplishment of the tradesmen. These would include design complexity, degree of inspection, equipment selection and utilization, material availability, work plan methods, and general working conditions at the site.

At all projects there was very little non-scheduled overtime and virtually no scheduled overtime. Second and third shifts are being worked on a routine basis at San Onofre and to a lesser degree on the other projects. Neither the overtime or shift work has had any measurable effect on productivity.

Monitoring of manpower productivity was being maintained in various forms on all projects. Comparisons were made between estimated manhours and actual manhours for various tasks performed -- with differing levels of detail. Few studies of productivity through "point in time" analysis or time lapse photography are being performed.

2.3.8 Labor Relations. All of the projects visited are being built with union labor. Listed below is a tabulation of strikes or shutdowns at the various plants compared to the number of months each plant has been under

construction through June of 1977.

Plant	Strike or Shutdown Delay-Months	Months Under Construction	Percent Construction Complete
WPPSS -- #2	6	52	41
WPPSS -- #1	0	19	3
WPPSS -- #4	0	19	2
Diablo Canyon #1	5	63	99
Diablo Canyon #2	5	74	90
San Onofre #2	2	40	35
San Onofre #3	2	33	35
Palo Verde #1	0	13	3

Only the APS projects are operating with a project agreement, which includes a "no-strike, no-lockout" clause for the duration of the job. Wages and fringe benefits are, in the case of the APS job, paid retroactively to the date of the contract agreement expiration, once they are agreed to by the local bargaining groups. The pros and cons of project agreements will not be discussed here, however, the majority of the utility representatives felt that project labor agreements would have been beneficial to their projects.

2.3.9 Supervision. Top supervision of Owners, A/E's, CM's, and Contractors was rated as excellent. On-site construction management, however, seemed to lack experienced personnel in the middle management levels. Contractors, in some cases, were weak at the general foreman and foreman levels -- probably due to a lack of nuclear plant construction experience. One very interesting comment was that on large, long-term projects, people have a tendency to lose their identity and there is a need to rotate people in and out

to keep up their moral and sense of involvement.

2.3.10 Materials and Equipment. Material and equipment deliveries as a delaying factor were rated very low by most everyone interviewed. Reasons for this are:

- A general slippage in construction allowed what would be late material and equipment deliveries to catch up.
- An awareness on the part of owners and A/E's of critical items so that orders could be placed well in advance of "need" dates.
- An organized expediting effort to monitor the status and track fabrication in the vendor's shops.
- As materials or equipment did not arrive as scheduled, work-arounds or out-of-sequence construction would be performed.

Delays in delivery of Class 1 pipe valves was the only concern expressed by more than one utility company.

Some delays were identified with the vendor's quality assurance and quality control program. Most utilities pre-qualified their suppliers; however, on occasion it would be necessary to send a team of engineers in to assist in setting up a QA/QC program. The more plant inspections conducted by the owners, or their engineers, the higher the quality of the item being purchased and the less chance of rejection on the jobsite. A definite side benefit to plant inspections is the ability to closely monitor fabrication and insure timely delivery to the project.

Some problems identified with Class 1 equipment deliveries were the requirements of analytical calculations or physical tests to meet seismic requirements and the more exotic paint requirements for high temperatures.

As a general practice, delivery "need" dates are established listing critical items based on updated construction schedules. Ideally, delivery dates are usually set two months in advance of the "need" dates.

2.3.11 Information Communication: Delays experienced in this area included those during the licensing stage of the project prior to obtaining a Construction Permit (CP); owners reported that it was now taking up to four years to complete and the myraid of agencies and bureaucracies involved was escalating. Also, there were many overlapping jurisdictions between federal, state and local agencies which compounded the problems. Managing the licensing phase of a nuclear project today, and trying to tie the process down to a meaningful schedule, is becoming ever more difficult. Delays at this stage may contribute as much to the overall slippage in bringing a plant on line as any other factor.

In our study we limited analysis of delays to the construction process (design, procurement and construction) and for this reason "information communication," as a delaying factor, was rated quite low. During the construction process information appeared to flow in a rather normal manner and, except for the heavy burdens of paperwork (which of necessity required a large number of people) this was not a delaying factor. As an example of the documentation required, one manager reported that they were, on the average, involved in one and one-half audits per day and the time involved for each amounted to 150 manhours.

2.3.12 Financing. None of the projects visited were directly affected by cash flow constraints. During periods of peak cash demands or high interest rates, various methods were used by the utilities to keep the projects going. These included:

- Freeze on the addition of design engineering personnel for non-critical design work.
- Curtailment of other projects originally in the utility's construction budget.
- Deferral or rescheduling of non-critical construction work on the projects.

- Continual cash-flow analysis to assist in financial planning for the raising of additional capital through the bond or equity markets.

Considering the tremendous overruns in original total cost budgets, it is remarkable that utility companies have been able to keep their projects going. Over the past 10 years it is not uncommon to see original total cost budgets soar over 300% with interest expense amounting to from 10% to 15% of the total project costs.

2.3.13 Coordination. Depending upon the type of contract, the various lines of authority will vary. Where the owner acts as his own designer and construction manager, the matter of coordination within his own organization and with the contractors performing the work is the simplest and the most direct. This was the style adopted by PG&E on their Diablo Canyon plants. The next level of complexity, from a coordination standpoint, is the relationship employed by SCE and APS where Bechtel is both the architect/engineer and general contractor. The most difficult coordination relationships appear on the WPPSS Projects where the architect/engineer acts as designer and construction manager with the work being contracted out by the owner, but administered by his A/E. The more "cooks in the kitchen" the greater the chance for coordination problems.

Coordination problems which are causing delay manifest themselves in three broad areas: 1) Owner to Architect/Engineer, 2) Owner to Vendors (with possible A/E involvement) and 3) Owner to Contractor (again with possible A/E involvement). Various methods are being utilized to improve coordination between all parties involved in an effort to recognize possible delays in advance of their occurrence and to eliminate or mitigate their potential impacts on the project. This is accomplished through scheduled meetings where action is taken to eliminate or work around these potential delays. Computerized

project scheduling and progress monitoring is now being used on most of the projects as the "early warning" system. One computer-based system is being used to schedule and monitor the work based on "activity packages" where construction areas are defined and engineering design and procurement is then integrated into the schedule and keyed to these activity packages. As construction proceeds, six-month "look ahead" schedules are generated as are three week "rolling" schedules. These latter two schedules may be manually generated from the computer based information. Project trend analysis is also performed to monitor actual vs. planned manpower utilization at various summary and task levels.

In spite of the various sophisticated systems being used to plan, schedule and monitor these projects, coordinating the interfaces between designer, procurement, and construction continues to be one of the major barriers to timely completion of these nuclear power plants.

2.3.14 Construction Quality. It was unanimous with those interviewed that the construction quality of the nuclear plants met or exceeded all reasonable requirements. One contract manager commented that where non Class 1 work was being performed, the quality of the work continued equal to that for Class 1 work. A utility representative stated that the experience they had gained with quality control on nuclear plant construction was being utilized on their fossil plant construction, where they now are finding shorter start-up times and increased plant reliability. Insuring high quality through well-administered QA/QC programs has very little delaying effect on the projects. Where operations do have to be shut down to meet quality requirements, corrective action is taken almost immediately and the deficiencies do not require correction later in the construction process where significant delays could occur. As more contractors and vendors enter the nuclear construction arena,

problems and minor delays do arise -- usually in their establishing a QA/QC program. The cost, however, of administering a QA/QC program is not minimal. At the first level of responsibility, contractors on a single unit of the WPPSS projects are manning the job with approximately 100 personnel engaged in QA/QC. At the second level, the on-site engineer or construction manager will have a team of between 20 and 40 people engaged in this effort. An audit team of about 5 completes the owner's responsibility for third level QA.

2.3.15 Construction Methods. In the case of construction contracts being awarded on a negotiated or hard money contract basis, the construction methods are left up to the successful bidder. By the time bid packages go out to the contractors, the design and sequence of construction is frozen. This is not always the ideal situation. The advantages that could be gained from contractor's input for alternative construction methods, changes to the sequence of work, and possible design changes, generally cannot be made at this point in time.

There is also the problem of shared equipment and facilities on a job being built under multiple contracts. Coordination and communication problems also increase as more and more contractors are simultaneously working in tight areas. The alternate solution of "locked step" construction, where each contractor completes his work before the next starts, is entirely impractical from both a time and cost standpoint.

The general consensus of those interviewed was that for the power block work, construction contracts should be awarded (or negotiated) in sufficient advance of construction so that the contractor's representatives can provide input to the design in the area of constructibility, scheduling, sequence of operations, equipment selection, and manpower requirements.

Outside the power block where the work is of a more conventional nature,

less congested and subject to fewer design changes, lump sum contracts are preferred. Here also, the construction methods employed are more straight forward and have a minimal impact on others working in the general area.

2.3.16 Weather. Climatic conditions at the four project sites visited were ideal. The only adverse comment about the climate was at Palo Verde where, during the summer months, it gets very hot (temperatures rise to over 100° F) and provisions for concrete cooling are necessary. Some drop-off in labor productivity is expected during the summer.

2.3.17 Geological Factors. The present seismic reanalysis being performed by PGE for their Diablo Canyon plants is a result of the discovery, in 1973, of the Hasgri fault approximately six miles off shore. This reanalysis for a predicted 0.75g ground acceleration at the site has already delayed fuel loading for Unit #1 by 16 months and the total delay period is not known at this time. Seismic considerations at the San Onofre plant caused a one year delay; design was suspended and a reanalysis increased the predicted ground acceleration from 0.5g to 0.67g. It was estimated that these design changes, needed to meet the higher seismic loadings, added one year to the construction program. The APS and WPPSS plants are in geographical areas of low predicted earthquake activity and these plants are being designed for a 0.20g to 0.26g ground acceleration. Obviously, geological factors play an important part in both plant site selection and design. When higher than anticipated earthquake effects must be incorporated into the design of the plant after the original design is complete, delay and increased costs will be the inevitable results.

2.3.18 Site Location. Aside from climatic and geologic considerations and their effect on design, the siting of the plant becomes very important when

evaluating environmental consequences, the plants proximity to water and avenues of transportation, and the availability of a highly skilled and sufficiently large labor market. In the case of all the plants visisted, one or more of the above listed "siting" factors was acting as a delaying factor in the construction of these plants. The siting must be viewed as a trade-off when considering alternative locations. It is, therefore, doubtful that the "ideal" site could be obtained for nuclear plant construction as there will always be site deterring factors wherever the plants are located.

SUMMARY

The results of interviews and job site visits point out that a number of delay types were common to all projects visited and considered by those interviewed to have a high delaying impact on their construction operations. These major delay types are, in order of decreasing severity:

- Design Construction Leadtime
- Changes
- Labor Relations
- Construction Methods
- Geological Factors
- Coordination

These delay types are controllable; and major efforts are being put forth to eliminate or mitigate their effect. The success of these efforts, and the corrective measures used remain to be seen; but through a better appreciation and understanding of delays, improvements in the schedules and the attendant cost benefits can be made.

APPENDIX A

INTERVIEW FORM

DELAYS IN THE CONSTRUCTION OF NUCLEAR POWER PLANTS

INTRODUCTION:

Kellogg Corporation is conducting this interview as one element of a research project sponsored by the Energy Research and Development Agency to identify specific problems that are causing delays in the design and construction of nuclear power plants. To encourage open and candid responses, individual comments will be kept anonymous.

We would appreciate your completing the PERSONNEL DATA and GENERAL INFORMATION sections prior to the interview. Also, please look over the INTERVIEW SURVEY and be prepared to discuss it at the time of our interview.

PERSONNEL DATA (Interviewee):

Name _____

Title _____

Address _____

Phone _____

Education _____

Experience:

Years in Industry _____

Years with Company _____

Years in Nuclear _____

GENERAL INFORMATION

PROJECT DATA:

Owner _____ Plant _____

Size - MW _____ Type _____ Reactor _____

Designer _____ Const. Mgr. _____

Prime Contractor(s) _____

Major Subs. _____

Major Suppliers _____

Milestone Dates:

Feasibility _____ Planning _____ Temp. Const. Permit _____
Const. Permit _____ Fuel Loading _____ Comm. Oper. _____

Design Time, Planned _____ Mo. Const. Time, Planned _____ Mo.

Design Time, Actual _____ Mo. Const. Time, Actual _____ Mo.

Design Cost, Estimated _____ Const. Cost, Estimated _____

Design Cost, Actual _____ Const. Cost, Actual _____

Type of Contract:

Design _____ Construction _____

Current Status of the Project: _____ % physical completion.

Labor Status for Construction:

Union _____ Open Shop _____

INTERVIEW SURVEY

1. Which of the following changes are responsible for delaying construction of nuclear power plants? (Explain their impact on the overall project schedule.)
 - a. Changes that were necessary to allow construction.
 - b. Changes requested by the Owner.
 - c. Changes imposed by modifications in licensing and regulatory requirements due to: (a) safety, (b) environment, (c) permits, (d) quality assurance, or (e) others.
2. How did design affect the schedule for?
 - a. Timely completion of the design.

b. Design complexity.

c. Design constructability.

d. Design standardization.

e. Performance of risk analysis.

f. Other.

INTERVIEW SURVEY
Page Three

3. How has manpower affected the progress of the work when considering availability, quality and productivity for ?

a. Engineer and technical support personnel availability.

b. Diversion of technical personnel time to regulatory matters.

c. Craft labor.

d. Manpower turnover.

INTERVIEW SURVEY
Page Four

e. Skill level of craft labor.

f. Productivity of the work force.

g. Capability of supervisors.

h. Flucuations in level of labor force.

INTERVIEW SURVEY

Page Five

4. Have labor disputes and strikes been a problem on the construction site?
If so, how many days were lost per year?

5. How has the availability and quality of material and equipment affected project progress?

a. Materials availability

b. Equipment availability

c. Material and equipment quality.

INTERVIEW SURVEY

Page Six

6. What affect has (a) weather, (b) geological or geographical factors, or (c) site location had on project delays?

a. Weather.

b. Geological or geographical factors.

c. Site location.

INTERVIEW SURVEY

Page Seven

7. Have QA/QC requirements delayed the project? To what extent?
8. Have coordination and communication difficulties between the Owner, A/E Firm, NSSS, or Contractor been a problem that may have delayed construction? If so, to what extent could this problem be alleviated in the future?
9. What affect, if any, has the Owner's cash flow had upon the construction schedule?
10. Are there any causes of delays that may be more significant in one area of the country?

INTERVIEW SURVEY

Page Eight

11. Did the type of construction contracts entered into have any affect on the schedule?

12. Was an incentive type bonus paid for?

a. Meeting schedules.

b. Meeting cost (or manhour estimates).

13. Identify the most significant delays that had the greatest adverse effect on the project:

a. During design.

INTERVIEW SURVEY

Page Nine

b. During construction.

14. What would you do to eliminate or mitigate the delays identified above?

a. During design.

b. During construction.

15. In reviewing delays on the project, what type of research should be undertaken by ERDA to solve the problems created by these delays?

INTERVIEW SURVEY

Page Ten

16. What are the major factors that contributed the most to maintaining satisfactory progress on the project?

17. What are the major factors that hindered the success of the project?

18. What general suggestions would you have regarding more effective design and construction of nuclear power plants?

APPENDIX B

INTERVIEWEES

Arizona Public Service Company

William M. Petro
Site Construction Manager

Roger L. Robb
Assistant Project Director

Bechtel Power Corporation

Peter Dragolovich
Project Manager, Design
San Onofre Project

B. R. McCullough
Field Construction Manager
San Onofre Project

J. A. Packard
Field Construction Manager
Palo Verde Project

Burns and Roe, Inc.

Kenneth Fox
Resident Project Engineer
WNP-2 Project

John D. Wilson
Director, Construction
WNP-2 Project

Northern States Power Company

Arthur V. Dienhart
Vice President
Plant Engineering and Construction

Roth S. Leddick
Manager
Nuclear Plant Projects

Pacific Gas and Electric Company

Richard S. Bain
Manager
Station Construction Dept.

G. S. Bates
Superintendent
Station Construction Dept.

James O. Schuyler
Nuclear Projects Engineer
Engineering Department

Michael R. Tresler
Project Superintendent
Station Construction Dept.

Southern California Edison Company

L. D. Hamlin
Project Manager

Robert R. Hart
Construction Superintendent

United Engineers & Construction, Inc.

S. B. Barnes
Project Manager
WNP-1&4

M. P. Dechter
Manager, Liason Engineering
WNP 1&4

Washington Public Power Supply System

A. D. Kohler, Jr.
Project Division Manager
Nuclear Project No. 2

C. B. Organ
Project Engineering Manager
Nuclear Project No. 2

Ralph H. Rockwood
Construction Superintendent
Nuclear Projects Nos. 1&4

Lindy S. Sandlin
Manager of Project Planning
and Measurements

John P. Thomas
Project Manager
Nuclear Projects Nos. 1&4

M. E. Witherspoon
Project Engineering Manager
Nuclear Projects Nos. 1&4

CONSTRUCTION DELAYS
ON
NUCLEAR POWER PROJECTS
IN THE SOUTHEAST

Draft Interim Report

Submitted to
Ohio State University Research Foundation
and
U.S. Energy Research and Development Administration

by

Parviz F. Rad
Associate Professor
Department of Civil Engineering
Clemson University
Clemson, South Carolina

May 15, 1977

Draft
Construction Delays
on
Nuclear Power Plant Projects
In the Southeast

ABSTRACT

Interviews were conducted with 50 design and construction staff of five organizations during 15 separate interviews. During these interviews areas of high impact requiring meticulous and careful handling were identified.

The results indicated that the most important items in the design-construction cycle of a nuclear power plant are coordination, equipment availability, design-construct lead-time, and handling of design changes. Coordination encompasses activities necessary to handle all the other high impact delay cases.

Coordinating tasks are more effective when they are conducted by departments of an identifiable group so that there are neither duplications nor gray areas. Use of computerized systems facilitates storing, handling and sorting of the data for the many different tasks of the coordinating teams.

INTRODUCTION

Most of the effort during this phase of the work was directed towards interviewing as many officials or owners, designers, and constructors as possible. The principal investigator met with officials of Duke Power Company, TVA, Georgia Power Company, and South Carolina Gas and Electric Company. The principal investigator interviewed design personnel of the Tennessee Valley Authority and the Duke Power Company and the construction staff of Duke, TVA, Daniel, and Georgia Power. The principal investigator visited McGuire, Catawba, Hatch, Summer, and Watts Bar Nuclear Power Plants to receive input from the individuals involved in construction of plants. All told, as of this writing, a total of 15 office or site interviews were conducted with ⁵⁰~~30~~ respondents. Since most of the individuals interviewed have a relatively strong background in nuclear power plants, the experiences of other plants such as Oconee, Browns Ferri, Cherokee, Farley, and Callaway were also shared during these interviews with the principal investigator.

The principal investigator was privileged to receive very courteous and open cooperation from all the respondents. The investigator was impressed with the desirable mix of more experienced personnel and the recent graduates representing extensive field savvy and new technology. It is important to note that an average plant built in the Southeastern region will take less time and will require less money than plants in any of the other regions.

Early in the interviews, it became apparent that collection of detailed history of any or all of the plants may not provide the type of input required by this contract. Therefore, in most of the interviews, general discussions were held and the respondents were asked to highlight the high impact areas regardless of whether or not they had delayed construction of

a given plant. Part of the reason for this change of procedure was that if a cause of delay persists for a significant amount of time, through reorganization, change of procedures or other appropriate modifications, the problem is normally remedied by the owner, designer, or the constructor. Therefore, what may have been a cause of delay in one or two plants will no longer occur in the future activities of the organization involved.

Therefore, the emphasis of the interviews were placed on identifying areas with high impact and requiring meticulous and careful handling. These areas are either those that have actually caused delays in design and construction or those that have been controlled by selecting appropriate procedures.

A summary of the interviews is given in table 1. The items ranked high are the high impact areas that might cause delays if not handled appropriately. The areas ranked low are those that would cause delays if they are allowed to become inordinately excessive. However, under normal circumstances, the impact of the latter on the overall construction duration is considered negligible.

An attempt has been made to refer to all the pertinent inputs provided by all the respondents. However, care has been taken to ensure that the comments represent those of a group (design, construction, scheduling, etc.) and not an individual within a group. By copies of this report, the principal investigator is requesting the responding organizations to provide further inputs to clarify and amplify the comments reported here.

RESULTS OF THE INTERVIEWS

During the course of the interviews, the principal investigator met with representatives of licensing, design, construction, and project control groups. The discussions were centered on the factors contributing to delays in design and in construction of nuclear power plants. The following format suggested by Ohio State University was used for reporting the results in order to allow an orderly compilation of data from the Southeastern, Northeastern, Southwestern and Northwestern regions.

Owner/ utility	Arch./ Engr.	Interior construction manager	Supplier	Prime Contractor	Sub- Contractor	Labor	Principal Players	Discussion- Areas
1	1	1	1	1				Design Quality
1	1	3	3	3				Design Complexity
2	2	2	2	2				Design Variability
9	9	9	9	9				Design - Construct Leadtime
10	10	10	10	10				Changes
3	3	3	3	3				Manpower Availability
3	3	3	3	3				Manpower Turnover
3	4	3	3	3				Manpower Quality
4	4	4	4	4				Productivity
-	-	-	-	-				Labor Relations
1	1	1	1	1				Supervision
5	5	5	5	5				Material (timely availability)
3	3	3	3	3				Material Quality
9	9	9	9	9				Equipment (timely availability)
7	7	7	7	7				Financing
8	8	8	8	8				Information Communication
10	10	10	10	10				Coordination
1	1	1	1	1				Construction Quality
3	3	3	3	3				Construction Methods

DESIGN QUALITY

Design procedures are based on codes established by AISC, ACI, ASME, and IEEE, ^{etc.} Design Manuals are developed by each design office to define details of design procedures complying with a given requirement. The design of a system for a nuclear power plant will first involve interpretation of appropriate guides established by the Nuclear Regulatory Commission. Once these guides are translated into specific engineering performance requirements, the in-house design manuals are used to compute sizes, quantities and other specific data.

Since the design process is based on professionally approved codes, it is accepted by all the design and construction personnel. However, some feel that there exists cases of overdesign in sizes and capacity of components. These cases of overdesign may be in the form of too thick a wall, too large a pipe, etc. In any event, the quality of design and the guide interpretations are believed to have negligible impact on cost and duration of the construction.

In the past, occasionally, the constructors were given blueprints in which either the same space was utilized by two different disciplines or the interface of two pieces was not correctly determined. Regular staff meetings in design office have been instrumental in minimizing these interferences. Further, construction of detailed small scale of a plant has been proven to be an additional tool in eliminating the interferences. The model can further be used for training of personnel, study of constructibility and numerous other constructive purposes.

DESIGN COMPLEXITY

Design complexity is interpreted as difficulty of on-site execution of the blueprints. Although every effort is made in the design offices to design the systems and components as constructible as possible, field personnel believe that constructibility of items has a modest effect on the speed of progress and hence on possible delays. In order to remedy severe cases of design complexity, in a few instances formal and informal communication channels have been established to convey the field experience back to the design office. The use of this feedback as well as the inclusion of experienced construction engineers in the design team further enhances the constructibility of successive designs.

Such feedback and constructor-participation schemes are much easier to implement in cases where both the design and construction teams are under the same corporate management. Otherwise, specific management and implementation schemes must be developed by the owner to encourage maximum utilization of previous field experience.

DESIGN VARIABILITY

By virtue of differences in design experience, guideline interpretations, and professional judgments, each design office has a particular way of handling the design process. Hence substantial differences can be observed between nuclear units built at different localities. Even design offices which use the same basic concept repeatedly seem to produce modified designs continuously because of the evolution of NRC guidelines through the design process and from one plant to the next.

However, such variability seems to have a low impact since details of the construction process are carried out from blueprints and not necessarily from memories of specifics of previous activities of several years before. Further, differences in site conditions, labor conditions, and equipment availability seem to overshadow design variability.

DESIGN-CONSTRUCT LEAD TIME

It is a consensus among field personnel that a lead time of at least three months is necessary in order to make final arrangements for logistics of materials, equipments and labor.

In some cases, shop drawings need to be developed on-site before fabrication can begin. In cases where all designs for critical work package are not on-site with sufficient lead time, contingent plans must be developed for work in areas for which complete blueprints are available. Such redirection of efforts will result in immediately quantifiable delays caused by delaying the execution of the critical path.

Some unmeasurable delays may also result by mobilizing for a non-critical activity, when critical blueprints arrive, and remobilizing for the critical activity. In such cases, one might observe relatively low values of productivity due to frequent direction changes.

CHANGES

Almost all nuclear power plants are constructed under a phased or fast-track scheme. A fast-track scheme normally optimizes handling of field-originated and regulatory-based changes. However, in some cases, the speed and phasing of design lend themselves to re-evaluation of completed blueprints which may be under execution on-site. A typical plant may receive ⁵⁰⁰ office generated changes. When changes arrive on-site, a certain amount of unmeasurable redirection causing delays and using unplanned manpower is necessary to implement the changes. Handling ^{the} changes becomes a little more complicated when either the designer or the contractor are part of a different organization from the owner. This in some extreme cases involves disassembling or removing already completed units. If the modified blueprint requires new or modified pieces of equipment, an additional delay will be experienced equivalent to the length of procurement cycle necessary to deliver the desired piece of equipment to the site. Further, in such cases, observed productivity may be acceptable in first assembly, disassembly, and second assembly. However, the performance factor for that activity may prove to be significantly lower than other similar activities. Recognizing the impact of changes on the overall time and cost of a plant, many Southeastern plants have developed management tools compatible with their corporate structures and operational procedures in order to minimize cost and delays involved in handling changes.

MANPOWER AVAILABILITY

At the peak of manpower utilization, a nuclear power plant construction site employs 2000-3000. There have been occasions in the past when the field supervisors have not been able to fill all the vacant positions in the labor and craft categories. However, at the present time, there is a satisfactory pool of manpower for employment by the plant construction. The availability of manpower is related to the national state of economy, season of the year, and operation of other industries in the Southeast region. All told, shortages of manpower can modestly affect the construction progress.

MANPOWER TURNOVER

In the Southeast region, during the construction of a power plant about 5000-6000 laborers and craft personnel may be hired to fill a peak of 2000-3000. Because of this significant turnover, the plants have ongoing initiation and training programs that familiarize incoming workers to the operations of that site. Since the rate of turnover is not uniform, at times of high turnover, the training staff may be enlarged to meet the situation. Manpower turnover has a modest impact on the progress of the construction because, in addition to the training costs and time, the hands-on experience gained by workers is continually eroded by turnover.

MANPOWER QUALITY

Manpower quality is directly tied in to availability and turnover. During the times of low availability or high turnover, the project supervisors may have to begin hiring less qualified workers to fill the vacant positions. Inclusion of such workers into the work force will probably not affect the productivity but it might lower the performance factors of the construction operations, thus contributing to delays. It is believed that during severe shortages of manpower and significant reductions in manpower quality, the construction speed is significantly affected.

PRODUCTIVITY

Productivity, by definition, is the percentage of a day's time available for direct work. Productivity is affected by personal motivation and skill, as well as logistics of work area, availability of tools, readiness of materials, and congestion of the working space. Another indicator of worker's effectiveness which is used in estimating costs and durations is ^{the} performance factor which is the number of ~~man-hrs~~ ^{man-hrs} workers required to finish one unit of work. One major difference is that productivity can be compared directly among different crafts whereas performance factor, unless normalized, can only be compared with the same activity in another location.

The productivity in nuclear power plants generally varies between 20-50% but, since productivity is affected by many factors, it cannot immediately identify a problem area. However, productivity can be taken as a broad measure of general well being of the construction activity. If after long periods of high productivity, a low productivity period is observed, a careful analysis of all contributing factors must be made to remedy the problem.

During the past several years, project control groups have evolved on the job site in order to monitor progress of activities, performance of workers, availability of parts, and to inform appropriate organizations of observed anomalies. One of the duties of the project control group is to continually monitor the performance ~~face~~ factors and update the projected cost and duration of the plant.

One other task performed by this group is periodic work sampling. Each work sampling is conducted by several observers over a course of a couple of weeks. For the purposes of this sampling, the work force is categorized

into 10-15 identifiable crafts. During the course of sampling, percentages of the following items are determined for each craft: direct work, waiting, travel, transport, tools/materials, planning/instruction, break, personnel, late start/early finish. If productivity or work performance factor are lower than normal, the project control group identifies the source of the problem and recommends a plan of action to the appropriate level of management. Since about one-third of the cost of a nuclear power plant is attributed to manpower, an improvement of even a few percentile units will have substantial impact on the overall cost and duration.

It was the consensus among all the respondents that productivity and performance factor are extremely useful management monitoring tools. Most of the Southeastern plants have ongoing work sampling programs in order to measure the general well being of the construction activity and to trigger management action if productivity drops to an unacceptably low level. It is commonly agreed that significant and sustained low productivity will result in substantial delays and cost increases.

LABOR RELATIONS AND SUPERVISION

Most of the construction sites in the Southeast enjoy an open shop atmosphere. The relation of the constructors with the labor at-large is good and it is believed by the Southeastern constructors, and supported by constructors of other regions, that open shop activities offer many management advantages which would help time and cost of the plants. As for the supervision, all respondents expressed satisfaction with the level and quality of supervision exercised in construction of nuclear power plants.

TIMELY AVAILABILITY OF MATERIALS

Prefabricated parts, equipment, and machinery are ordered by the engineering design department and administered through the procurement department. However, raw materials such as cement, sand, gravel are purchased by the site personnel. Each site has various stockpiles of these materials to be used as a buffer between arrival of successive purchases. The rate of depletion of these stockpiles is dependent upon the kind and size of activities in progress. However, the rate of arrival of new shipments depends on the lead time allowed for the activity as well as general market supply of that raw material. On occasions during the past 3 years, portland cement was difficult to obtain on short notice and in satisfactory quantities. If material availability problem becomes severe, significant delays and cost increases will result. Many of the construction activities have developed computerized systems or management routines to monitor and replenish the supply of raw materials to meet the demands of current activities. These systems and routines will predict the occurrence of shortages and minimize their impact.

Material Quality

In compliance with Nuclear Regulatory Commission's guidelines and in accordance with quality assurance programs of each constructor, ample documentation must be generated to insure a high quality for all safety related materials and components. All construction sites have permanent quality control staff that examine all materials in the light of already established procedures and document their findings. Most respondents indicated that, notwithstanding NRC guidelines, they would maintain a quality assurance program in order to fulfill their desire to build a safe and operable power plant. Therefore, the attitude of quality assurance, but not necessarily the paperwork, is applied to even the non-safety materials used on a nuclear site. To some extent, this attitude is carried over to hydroelectric or fossil fuel plants that the same organization may be involved in.

Almost all raw materials delivered to the site meet the quality assurance standards set forth in the appropriate agreements. However, quite often the documentation necessary to prove the compliance does not arrive with the materials. Therefore, there is some delay until the material is cleared for use. The suppliers are gradually becoming aware of the importance of proper documentation that the construction supervisors require. As a result of this awareness, occurrence of non-documented or low quality materials is being decreased.

TIMELY AVAILABILITY OF EQUIPMENT

On a typical nuclear power plant some 2000-4000 pieces of hardware must be purchased. Some of these are standard off-the-shelf items but mostly they are specially-designed-and-fabricated items. These items are normally ordered through the engineering design departments and administered through the procurement group. On most of these items conceptual designs and detailed blueprints of all parts must be provided to the plant design groups so that appropriate support and interface arrangements can be made. The fabrication process is conducted in accordance with the client's quality assurance program but scheduling of various components, casting and machinery is usually at the discretion of the vendor with the understanding that the vendor will meet the contractual delivery date. However, in most plants, almost all the vendors have been late in delivery from a few days to a few years. However, if the plant's construction is slower than anticipated, the contractually late items may seem to be on time for construction.

Typically, when a required and critical piece of equipment does not arrive on time, work is redirected elsewhere until work can be resumed at that location. Unmeasurable delays will result from planning such a redirection and a mobilize-demobilize-mobilize effort. An illustrative example is that of valves and pipe hangers in short supply these days. One solution implemented was to install pipes with temporary hangers and spool pieces. Then later disassemble all the temporary hangers and spool pieces, and finally install the permanent hangers and spool pieces.

In some instances expediting groups have evolved. The mission of an expeditor is to monitor the progress of a vendor through a predetermined chain of milestones and then either attempt to speed up the fabrication

process or notify the design and construction staff of updated delivery dates. Many respondents indicated that in today's environment of vendor-client relations, on time equipment is possible only with a formalized and active expediting team having quality control duties as well.

An interesting technique tried on occasions is that of establishing with the vendor several milestones and activities for the fabrication process. These milestones and activities will then be monitored and updated through the use of a CPM/PERT scheduling routine. The projected delays in final delivery will be interfaced with the routine monitoring the plant construction. This computerized system will be used by the expediting team in their conversations with the vendor and in their status reports to the utility management.

One factor that complicates the procurement process is the introduction of plant changes that involve changes in equipment size or quantity. These changes will require vendor's replanning, work redirection, and remobilization; all of which are costly in terms of time and money. Other factors affecting vendor's performance are demand on all its lines of products, cash flow, and documentation specifically required by nuclear safety related items.

Vendor deliveries amount to about one-third of the cost of a nuclear power plant and their prompt delivery affects manpower efficiency. Management routines and computerized systems are being developed or implemented by many organizations to minimize the equipment related delays.

FINANCING

A nuclear power plant may cost between \$0.2-1.0 billion to be spent over a course of about seven years. This money is provided partly through the utilities' development funds but mostly must be borrowed from financial institutions at rates averaging about 13%. At the peak of construction activity several million dollars per month may be required to sustain all operations. On occasions, as a result of tight money market or revised demand forecasts, the utilities may not be able to allocate all necessary funds for construction and therefore either the project is continued on a slower-than-projected rate or ^{is} completely stopped. Cash flow has direct and severe impacts on the construction duration of a plant. The occurrence of low cash flow at ^{best} ~~least~~ can be projected and interfaced with construction activities and cannot be prevented through project control schemes.

INFORMATION COMMUNICATION

At a first glance, a power plant is financed by the utility, designed either by the utility or by a consulting firm, and constructed either by the utility or a construction firm. However, due to the licensing requirements, fast-track nature of the design and construction operations, and general complexity of the project, specific tasks are performed by separate departments within different organizations sometimes totaling 30 departments in all. A typed listing of these departments are:

1. Licensing	12. Civil Construction
2. Civil Design	13. Mechanical Installation
3. Mechanical Design	14. Electrical Installation
4. Electrical Design	15. Quality Control
5. Design Scheduling	16. Quality Assurance
6. Cost Estimating	17. Model Building
7. Expediting	18. Warehousing
8. Procurement	19. Construction Scheduling
9. Manpower Estimating	20. Procurement Scheduling
10. Cash Flow	21. Start-Up Scheduling
11. Document Control	

If all of the activities are performed by the utility, the information communication involves simply generation of the appropriate summary and forwarding it to all affected departments. However, if the above activities are performed within corporate structures of several organizations, a specific chain of command must be followed for transmittal of this information.

The problem becomes further complex if part of the design or construction is subcontracted by the design or construction prime-contractor.

If the information is communicated only occasionally, it may lose some of its effectiveness. Further, if a specific guideline has not been established for the type of information, some important information may be withheld inadvertently. Therefore, a specific frequency and content should be established for the information communication. The routing of this information is also important. Care must be taken that all affected parties have access to the information.

One very important facet of information communication is that if recipients are not expected to or authorized to act on that information, they may begin to ignore the information; the attitude being that if it is important, appropriate decisions will emanate from the top.

Recognizing the importance of up-to-date information on all facets of the construction, the utilities have established computerized systems or management routines to refine and summarize the data and further distribute them by mail or at regular meetings to representatives of various groups. During the past five years, the scheduling groups have been established and enlarged to handle or monitor such details as cash flow, manpower efficiency, preplanning, and materials availability.

COORDINATION

A wishful ideal situation would be the case where the engineering design of a nuclear power plant, including all the construction details, are prepared and all materials and equipment are on-site before construction begins.

In such a case very little coordination and hardly any real-time decisions need to be made during this relatively speedy construction. However, for a multitude of reasons, the design and construction are normally conducted on a fast-track basis. Therefore, design; construction; procurement; financing; and manpower planning all proceed concurrently. The rate of progress in each of these activities affects the nature of other activities. Thus, with the numerous inevitable field, office, and regulatory-based changes, information communication and coordination of activities has been recognized as one of the most important items in the construction of a nuclear power plant. Active coordination can minimize, predict, and remedy problems caused by design-construct lead-time, materials availability, manpower, and equipment availability. It can also minimize problems with design complexity, constructibility, productivity, and construction methods.

Generally, the information needed for coordination is generated by various groups that are expansions or spin-offs of planning, scheduling, cost control, and data processing groups. Therefore, in addition to those involved in actual design and construction, there are groups that deal with management and control of the project. In one instance, they are actually part of identifiable major groups called project control. Although the project control groups do not make the decisions, they are responsible for monitoring all important activities, noting their speed of progress and their

effect on the project, and reporting the status of the project to the appropriate levels of management. Quite often, the status report includes outlines of appropriate management actions. Project control groups usually use computers extensively for bookkeeping and sorting of the data. Considering that there are at least 3000 activities involved in design and at least 10,000 in construction, the scheduling and progress updating becomes a relatively complicated task. Further, handling procurement and storage of at least 2500 items, payroll of 2000 workers, and periodic work sampling and quality control activities add a new dimension of difficulty into ~~the~~^{it} job.

Recognizing the importance of coordination and project control, the utilities have developed or implemented management routines or computer systems that perform various monitoring and managerial tasks including the following typical examples:

1. Monitor the three disciplines of design and update overall schedule.
2. Monitor the construction activities and update overall schedule based on performance factor and equipment availability.
3. Monitor the entire procurement process and predict the late equipment deliveries.
4. Monitor the on-site availability of materials for use with current or near-future activities.
5. Monitor construction and flag start-up testing.
6. Handle cost estimating, cash flow, and payroll.

By virtue of their actions and their comments, the respondents have indicated that coordination is extremely important. Probably the single most important ⁱⁿ ~~B~~ construction of a plant, particularly, if design and construction contractors and subcontractors are involved.

CONSTRUCTION QUALITY

The construction supervision and management normally represents a substantial amount of professional experience and technical knowledge. It was agreed unanimously among the respondents that the quality of construction is very satisfactory partly because of the quality of supervision and partly because of the rigid quality assurance program that is followed throughout the project. There is, and justifiably so, a sense of pride among everyone involved about the quality and reliability of nuclear power plants.

CONSTRUCTION METHODS

Although many of the logistics of the execution of the design blueprints are at the discretion of field staff, sometimes specific procedures are outlined in order to achieve the end result. If design and construction teams are divisions of different organizational activities, enough feedback may not be developed between the two teams. In such a case, delays specifically related to methods of construction may arise. Although in the past there may have been cases where such delays have occurred, such delays are likely to occur far less as a result of project control and coordination schemes under development at various utilities.

SUMMARY

The results of the interviews conducted in the Southeastern region indicate that the most important items in the design-construction cycle of a nuclear power plant are coordination, equipment availability, design-construct lead time, and handling of design changes. Coordination, in the broadest sense of the word, encompasses ~~all~~ items necessary to handle all the other items. Coordination can be conducted by a new team called project control, construction management or any appropriate corporate title. However, it seems important that all fractions of this team be integrated fully so that there are no overlaps in duties and duplication of efforts, but more importantly, so that there are no gray areas that receive no attention. It probably makes little difference whether the utility or the designer or the contractor provide the project control service so long as the duties and responsibilities are clearly defined.

There is a multitude of management routines and computerized systems dealing with various facets of coordination being developed either by the utilities or for the utilities by outside firms. Not all the utilities have all the systems but at the same time, due to differences in organizational and corporate structures of utilities, a system cannot be transplanted from one utility into another without major modification.

A useful feature that could be built into a coordinating system is incorporation of past experience into the new designs either by formalized reports of a previous job or by presence of a responsible construction person in the design office.

Considering the size of data that needs to be handled by the project control group, it becomes imperative that most of the bookkeeping and sorting of the data be handled by a digital computer. An ideal case would

be where the data are transferred between various programs automatically
as soon as status of various items change.

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VOLUME II SECTION 2

PARTICIPATING INDIVIDUALS
ORGANIZED BY COMPANY

By

Note: Complete listing unavailable for inclusion in draft report.

VOLUME II SECTION 3

REFERENCE BIBLIOGRAPHY

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