Positive Experience in Designing and Constructing Nuclear Power Plants

Prepared by

Special Task Group
of
AIF Committee on Power Plant
Design, Construction and Operation

January 1983

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I. INTRODUCTION

The Nuclear Industry has received much criticism for major cost increases, schedule extensions and quality assurance concerns in recent years. The projects bearing the brunt of such criticisms have generally been plants experiencing delays caused by financing difficulties, load growth questions, regulatory changes, and various interventions or legal actions against them. While the entire nuclear industry is being challenged, the focus of criticism has usually been on the plants exposed to these problems. Generally overlooked are the many specific project designs and construction activities that have progressed on schedule and achieved excellent results. Little public attention has been drawn to specific innovative designs, methods and techniques used successfully on various plants to improve constructibility, schedule, cost, quality, and/or licensing acceptance.

This report identifies some specific examples of design and construction activities which demonstrate that excellent results have been achieved in the areas of cost, schedule and quality. The report stresses examples of innovation and development that would be particularly applicable to future work either for new plants or for plants not yet completed. In addition, the report discusses briefly the current experience in foreign countries where nuclear plants have been built on short schedules with good results. In many cases, U.S. experience and development have been implemented on foreign projects of later design vintage than our own plants.

It should be noted that the U.S. Light Water Reactor design and project planning base is rapidly becoming old. No new plants have been conceived and developed since the early to mid '70's due to the lack of new orders and the "work-off" of the large number of earlier orders. Despite this hiatus in new plant orders, many of the plants conceived in the early to mid '70's offer excellent ideas and innovations based on the industry's substantial past experience. This report will show that if the best currently available innovations and developments in both design and construction methods were to be incorporated into new orders, there would be a substantial improvement in cost, schedule and quality. Also, if the newer construction techniques and methods could be applied to existing designs, significant improvements could be made.

It is important to keep in mind that design and construction activities on a nuclear power plant cannot be decoupled from the governing regulatory licensing process. The current licensing framework must be improved to allow for the future nurturing of the types of improvements discussed in this report. Corrective measures such as a single-stage licensing process, use of preapproved standardized designs and sites, a streamlined hearing process, a workable and "safety-conscious" backfit rule, and promulgation of a realistic source term would act vitally to serve this purpose.

To enable the reader to place the following examples of good design and construction experience in context a chart of a typical mid 1980's (completion) construction project schedule and sequence of events is provided opposite. A description of the schedule is attached in Appendix A.

II. EXAMPLES OF GOOD SPECIFIC EXPERIENCE

A. Engineering and Design

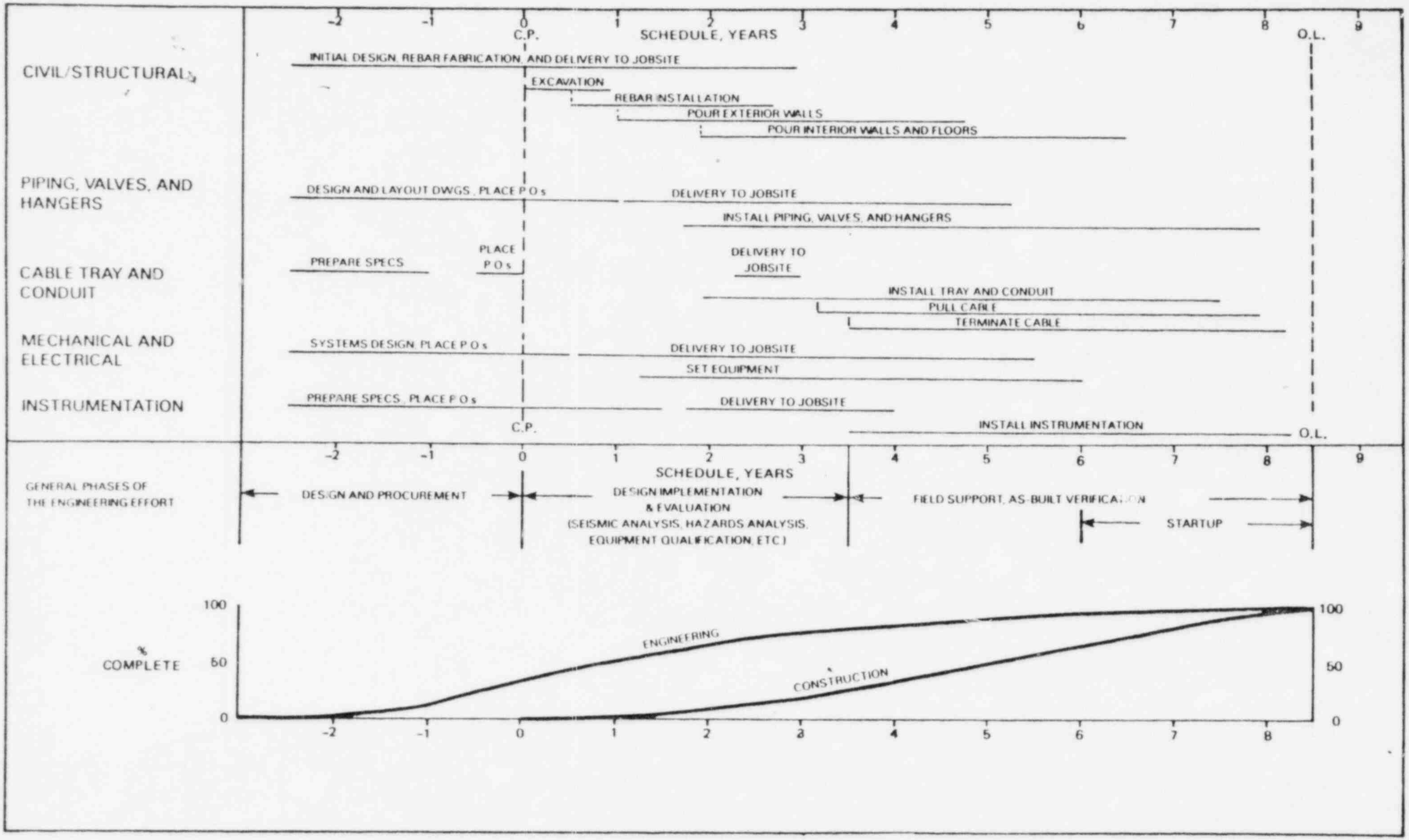
(1) *Design Models*

Today virtually all large engineering and construction companies use the design-modeling technique. A model can produce significant savings in total plant cost. Most of the savings come from interference problems that are recognized and solved at the design stage. Design models have proven highly beneficial in:

- Developing operable, maintainable and buildable plant arrangements.
- Eliminating much of the normally additive space requirement margins. This results in a plant with minimum volume yet buildable and maintainable.
- Utilizing of the "Modularization Concept." The design model is a must in establishing the maximum size and construction of a module that can be prefabricated, transported, lifted and set in place.
- Routing field-run bulk small piping, instrument tubing, raceway, supports, etc. This requires early shipment of the design model to the field.
- Encouraging "Design Freezes" by seeing a completed system on a design model.

A three dimensional composite design model of a mid-western nuclear power plant under construction has significantly reduced total plant cost by streamlining the physical design and reducing costly field interferences. The model incorporates

SCHEDULE FOR NUCLEAR POWER PLANT DESIGN AND CONSTRUCTION PROCESS FOR MID-1980s COMPLETION OF LWR PLANT



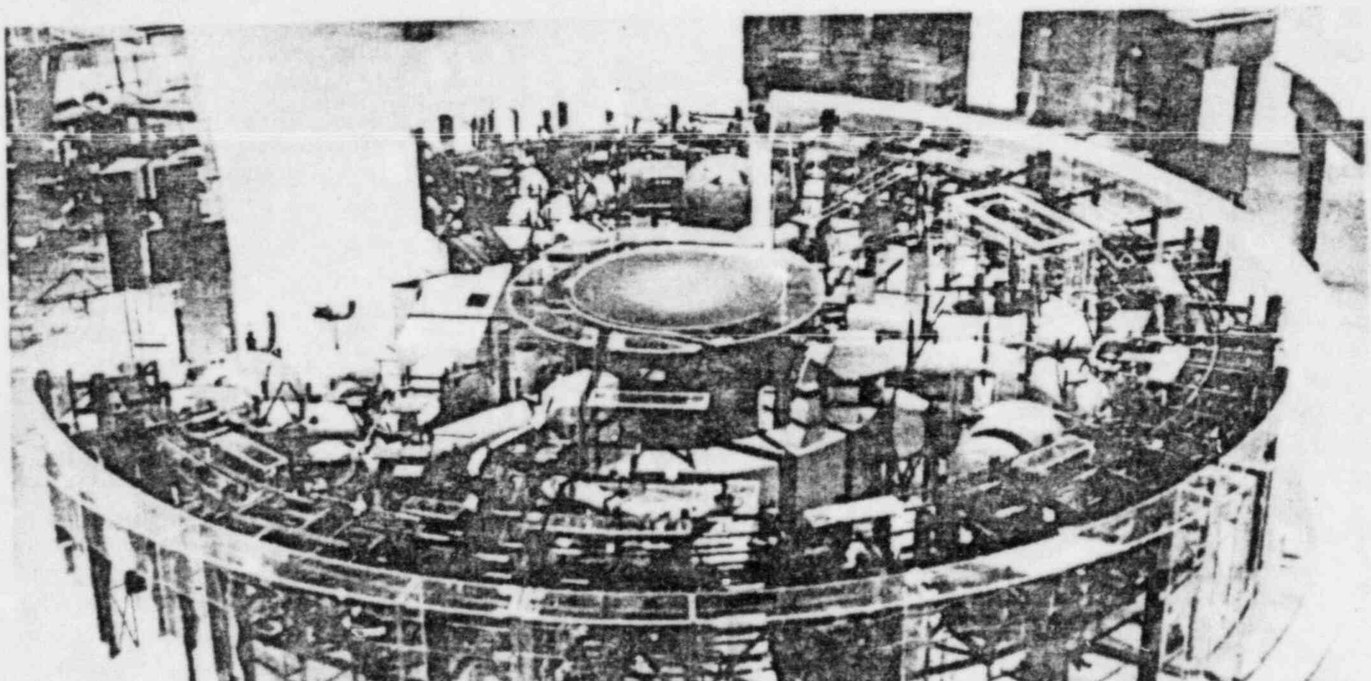
details of all structures, components, equipment, conduit, pipe, HVAC ductwork, instrument lines, gauges and transmitters, turbine generator, and piping 1/2" diameter and larger. It has been estimated that the use of this detailed model has resulted in the elimination of over 1,000 physical interference problems. Millions of dollars in construction costs as well as significant construction schedule time have been saved by elimination of these problems during the design phase.

In addition to its benefit as a design and design verification tool, a detailed model of this type is of significant benefit in planning the most efficient method of construction, such as; establishing the order of assembly; providing the precise definition of the scope and complexity to the various subcontractors; performing access studies to assure adequate space for maintenance; familiarizing the plant operating and maintenance staff with the final plant design; reviewing the design for OSHA compliance, and other related activities.

(2) ***Application of Computers in Design and Analysis***

Computers were initially seen by engineers as powerful calculating machines. The development of computers meant that calculations which were once beyond practical ability became routine. With the ability to perform extended calculations came the ability to place engineering design criteria on a more rational basis. For example, until 1971 all power plant piping was designed according to American National Standard Institute (ANSI) standard B31.1. This code placed a limit on pressure stress and thermal stress range. Starting in 1971 with ANSI standard B31.7 and later with American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code section III, limits were placed instead on primary and secondary stresses considering all loadings (pressure, thermal, weight, seismic, etc.) that produce such stresses. Calculating stresses on the new basis required the use of computers. Another related factor requiring the use of computers was refinement of seismic calculations. Similar requirements for computer power were imposed by seismic design requirements for mechanical equipment and structures.

Architect-engineers coped with these requirements by installing powerful computing systems in-house and by developing in-house staffs to



NUCLEAR ISLAND MODEL

ensure their continuous operation. Without the in-house capability, it would have been virtually impossible to perform all the required calculations and yet maintain a reasonable plant schedule.

Initially, access to the computer was gained through punched cards. Now the engineers and technicians also can access the computer directly through video display terminals. This procedure supplies more direct and faster access. While calculations may not be performed by the computer immediately, when they are performed the engineer can view the results at the terminal and make changes in the input as necessary to obtain a satisfactory result.

The use of video display terminals has permitted engineers to perform calculations at the job site using data stored in the home office computer. This procedure facilitates changes required to fit field conditions. A changed configuration can be calculated quickly, instead of waiting several days for home office evaluation.

Another broad area of good experience with computers is graphics. A number of organizations use computer aided design (CAD) systems. Use of a mainframe for this application means that an enormous memory is available with all drawings for a nuclear project available at any terminal in the system. This feature facilitates production of drawings by calling up other drawings as background and facilitates checking by overlaying drawings. It also permits calling up a large inventory of standard details.

Originally, CAD systems were thought of as a drafting tool. In that role, they were very successful for producing drawings and for coordinating the structural, mechanical, and electrical disciplines.

As development of CAD systems has progressed, it has become apparent that the strength of computer graphics lies not in drawings only, but in its ability to link with calculations and data storage. CAD systems have been used, for example, to provide input to structural finite element analysis. It has also been used to provide the initial basis for piping lists, instrument lists, valve lists and other compendia. When used in this manner and properly designed, a computer system has the advantage that the latest revision of each drawing is always available and data throughout a project is consistent. CAD systems can also be used with computer models for interference checking.

Other specific computer applications that have proven quite successful are as follows:

- *Computerized Modular Modeling Systems*
  The capability that has been developed to provide computerized mathematical, steady state and dynamic module simulation of plant processes, has enhanced the industry's ability to identify and correct for system instability during the design stage as opposed to having to wait until the completed system(s) became available for full scale operating tests.

- *Computerized Control and Tracking Systems*
  Computerized tracking systems have been developed to monitor engineering and design progress of individual components. Computerized systems have also been developed to assure that design and constructibility criteria are not violated by tracking components on an individual level and to assure engineering data meets rigid project design criteria before the constructor is allowed to install components. Tracking design changes on a component level also provides the engineering, construction, and quality control teams with instant lists of components that need redesign, rework, and/or reinspection. By computerizing the control and tracking systems, design data is tested and any unusable data is filtered out before it reaches construction. Thereby, only components that are known to be verified are installed and design revision control problems are minimized. This assures that adequate project controls are available, costs can be tracked to a high level of detail, and schedules can be met reliably.

  Other computer programs have been developed that track the status of construction of plant systems or sub-systems based on release-for-test (RFT) boundries. These programs monitor the installation of mechanical and electrical components within the RFT boundary and identify those components that must be completed before the systems can be turned over to the start-up and testing activities.

- *Improved Structural and Seismic Analytical Capabilities*
  The safety requirements for the nuclear plant to withstand the design seismic event and come to a safe shutdown has resulted in the development of highly sophisticated computerized analytical capabilities. An architect-engineer firm has developed a capability within its dynamic piping analysis program which allows them to combine modal and time history analysis in a single computer run such that the time history analysis need only be used for those specific node locations where an overstress condition may have been indicated by the use of modal analysis. A utility in conjunction with a computer time sharing service has developed a graphic input preprocesser that allows structural analysis and design of supports based on simple stick figure inputs. These skills and analytical tools are used by industry today for developing more realistic and economical designs.

- *Computerized Plant Simulators*
  In addition to training plant operators, computerized plant simulators have been used to check human factors design considerations.

(3) ***Sophisticated Analysis Techniques***

- The emphasis placed on nuclear plant safety has resulted in the development of extensive techniques for analyzing the probability of an event occurring, and assessing the results of that event. The technique is known as Probabilistic Risk Assessment (PRA), and consists of a systematic evaluation of failure modes, effects of failure, probability of occurrence including determination of mean-time-to-failure, and forecasting of frequency of occurrence. These PRA techniques may be applied to many complicated industrial process where failures are expensive or hazardous. The results of the analyses indicate clearly where redundant equipment is justified to mitigate the effects of any specified failure.
- Techniques for the sophisticated and precise analysis of numerous hydraulic flow problems, including dynamic effects, have been developed in the nuclear industry. Analyses involve flashing fluids, high energy jets, ruptured pipe, jet loads, thrusts, reactions on components and structures, and local environment effects.
- An architect-engineer firm has justified elimination of analysis of jet impingement effects (from postulated breaks) on their design piping by use of statistical analysis of their design.
- Sophisticated math modeling of cooling lakes has been used to simulate heat dissipation and to determine temperature regimes in the lake. Results from this modeling help determine cost savings and other benefits that can be derived from different modes of power plant operation.

(4) ***Full Scale Module Testing***

Although the industry's capabilities in analytical analysis have improved by orders of magnitude, not all structural members/devices lend themselves to analysis under real life situations. In such situations conservative assumptions and design allowances become necessary to the extent that the designers judgment says that the product is over-designed.

In certain situations of this nature, the industry has been able to utilize "Full Scale Module Testing" to evaluate the capabilities of the design. Shake-tables have been developed that can closely duplicate the displacements and accelerations experienced under seismic events.

Shake-table tests have been conducted on various design configurations that have resulted in the qualification of certain hanger/support configurations for cable trays, piping configurations, instrument racks, control devices, switchgear assemblies, heating and ventilating supports, etc.

Such tests provide the industry with the desired level of confidence in achieving the performance characteristics of the design without excessive design margins that usually have to go with concepts and configurations that are not amenable to a pure mathematical analysis.

Full scale mock-ups have been utilized to advantage in testing for "fire-ratings" of materials and of fire-retardant concepts.

The lack of precedent in many first-of-a-kind design requirements encourages full scale testing in spite of the high costs involved. Multi project cost sharing has been resorted to when possible.

(5) ***Unique Designs***

- *Hurricane Wave Protection*
  A nuclear plant located on the Gulf of Mexico was designed to withstand the Probable Maximum Hurricane consisting of winds up to 150 mph, a surge in the Gulf of Mexico of 33.4' above mean low water, and waves of up to 26' in height. Various designs were considered for the protective embankment of the side of the plant subject to wave attack. The embankment was required to limit the wave runup, and minimize erosion around the plant. The final design is unusual in that it consists of two sets of 2' high reinforced concrete steps, separated by a 46.5' wide horizontal bench. Wave tank model tests were used to confirm that the combination of steps and intermediate bench is highly effective in dissipating wave energy and limiting wave runup.

- *Unique Circulating Water System*
  An ocean front nuclear plant has a main condenser consisting of 4 water circuits. Each of the 4 water circuits is served by a unique valveless circulating water system, consisting of 4 pumps, 4 separate conduits, and 4 discharge lines. Each of the circulating water circuits is started after it has been primed, and flow through the system is established rapidly without abnormal shocks, stresses, vibration or noise. The valveless system has been successfully operated since 1976, and is believed to be the largest valveless system ever installed in a once-through cooling system.

- *Ice Hazards on Submerged Off-Shore Structures*
  The submerged intake and discharge structures of a nuclear power plant being built on the shores of one of the Great Lakes have been designed to minimize the environmental impact and to withstand the impact of large floating ice islands crushing against the submerged structures. The off shore intake structures are protected against dynamic loads produced by floating ice islands by means of vertical concrete caissons placed in a circle around the structures. Each intake structure protection consists of 10 vertical concrete caissons, 6' in diameter anchored into the lake bottom shale.

- *Foundation Underdrain System*
  To reduce the effects that a high groundwater hydrostatic head can have on the design of a plant's foundations, a permanent dewatering system can prove to be the best engineering alternative to be used in the design of subsurface structures. The key element of the system is a concrete drainage blanket underlying the plant which collects the ground water and directs it by means of porous concrete pipe to manholes, where it is discharged by pumps to the adjacent Great Lake. A gravity discharge system constructed into the higher portion of the manholes assures groundwater will not exceed tolerable limits in the unlikely event the mechanical system is inoperable. Various monitoring systems and protective measures were designed into the system. The porous concrete mix was developed in a testing program designed to meet the system performance requirements.

(6) ***Combine Temporary Construction Needs Into The Permanent Plant Design When Possible***

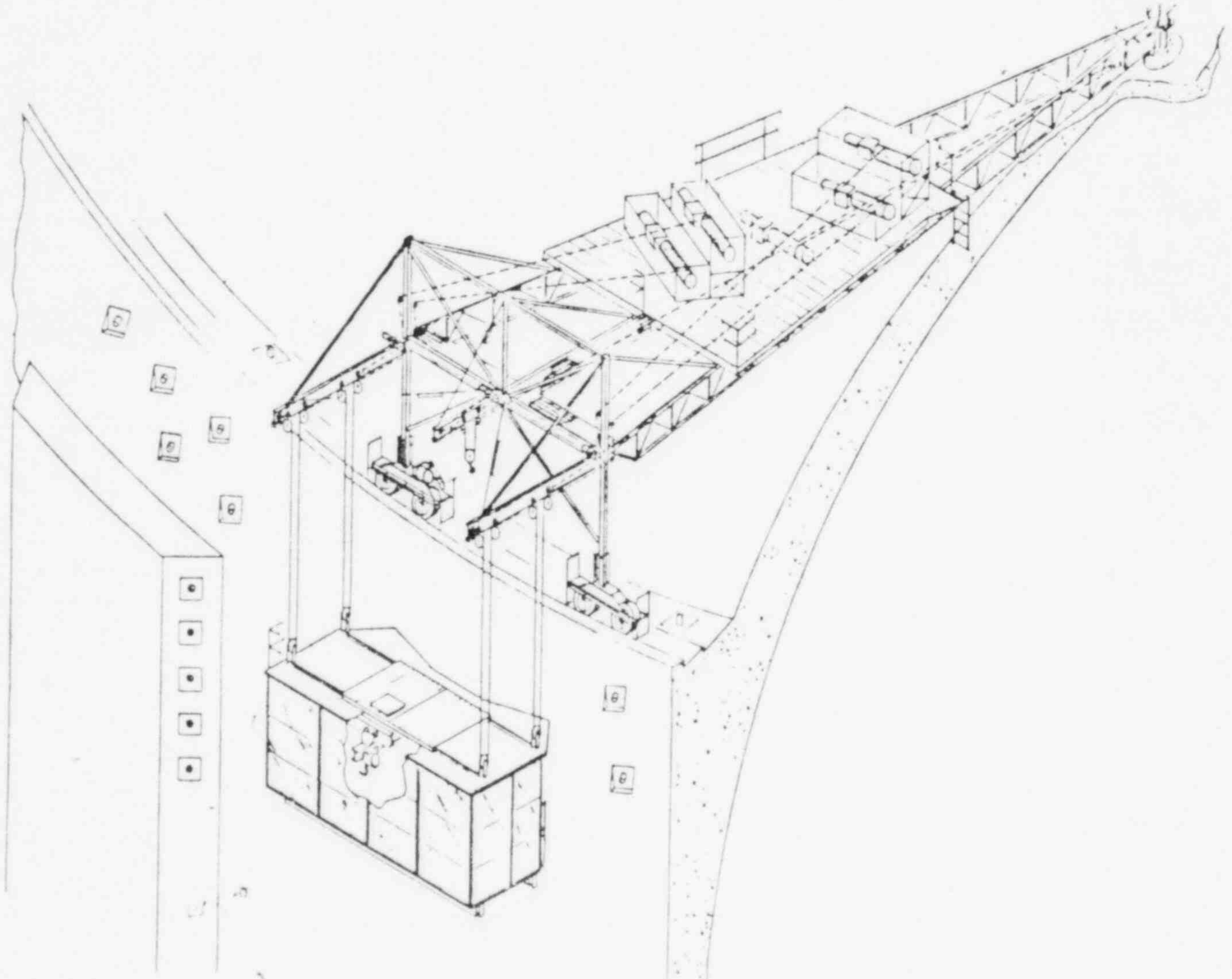
Substantial cost and schedule savings have been realized by the development of improved post-tensioning platforms for PWR containments. These movable platforms placed on top of the containment walls and pinned to the center of the dome, reduced the amount of time for the post-tensioning activity, reduced the number of men required to perform the work initially (and for subsequent inspections) and provided a significantly safer working situation for all involved.

Similar cost benefits can result from developing a permanent design that incorporates access walk ways with elevated electrical tray systems. Access during the construction period is then provided automatically along with the permanent plant access requirements.

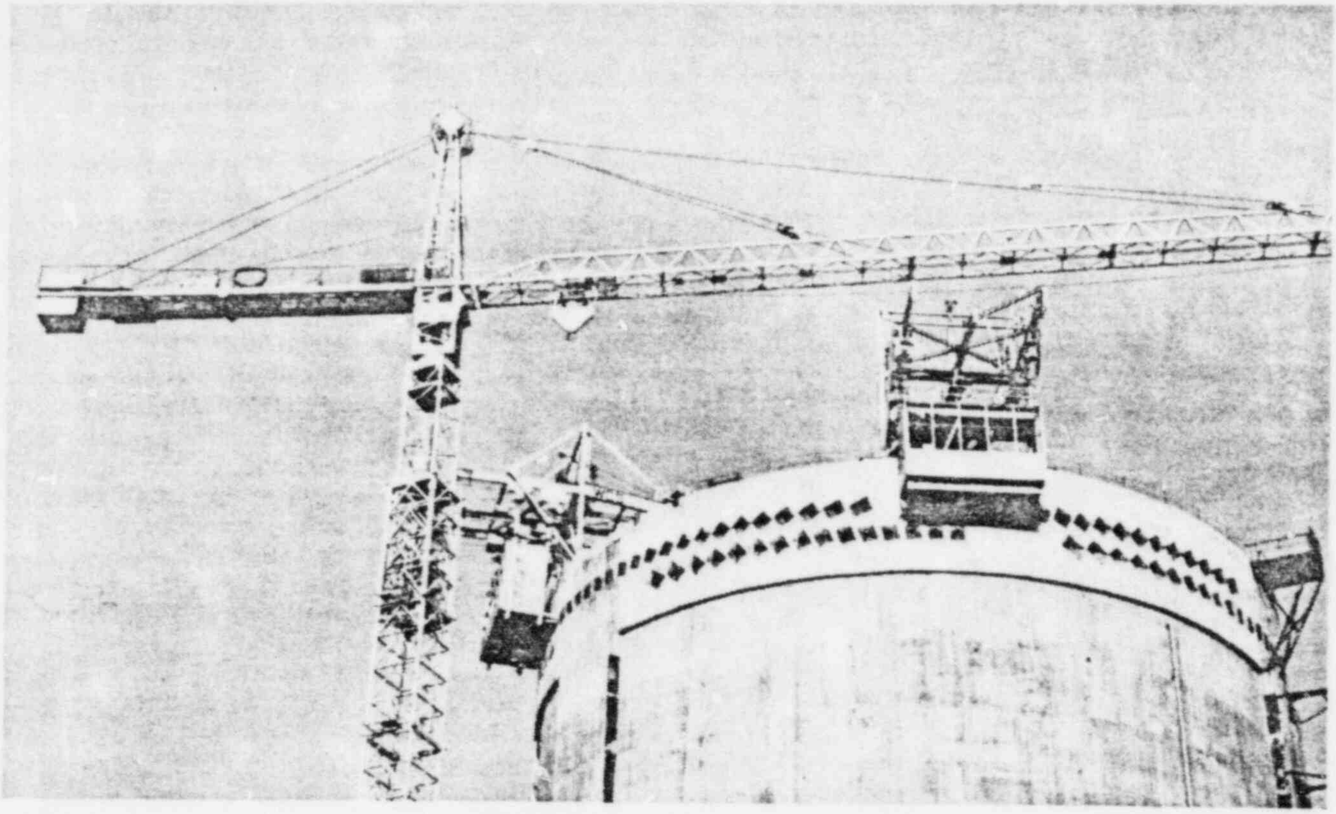
B. Concrete Construction

(1) *Advanced Concrete Placement Techniques*

Because of the large quantities of structural concrete to be placed on a typical nuclear power plant, concrete placement techniques can have great impact on the overall cost and schedule of a nuclear plant. In fact, significant improvements have been made, largely in placement equipment, that have resulted in lower concrete costs than would be possible using previous methodologies. Probably the placement method that has impacted the construction industry the most has been the development of high lift concrete pumps. With the larger high pressure, more efficient and more dependable pumps available, there is essentially no placement that is too large or too small for pumping. In addition to savings realized by faster placement of concrete, often forgotten are the savings realized because fewer or no crane hours are required to support the pour in general and considerably fewer manhours are required for clean up. This is especially important where top mat rebar of thick



POST TENSIONING PLATFORM



POST TENSIONING PLATFORM

slabs must be kept clean for two-lift pours. The advantage of concrete pumping in severe weather conditions is a good example of the adaptation of pumping to special construction situations. Concrete can be pumped into enclosed, protected placements where access must be limited to maintain specified temperature conditions. This condition is easily provided by pumpline installations.

Recent developments in pumping methodology have helped to resolve quality and cost problems for two specific placement situations. By pumping concrete from the bottom of the pour, concrete voids (honeycomb) can be eliminated for congested or access-limited pours such as the sacrificial shield wall. Also, partition walls (previously block walls) on the 'Q' side where access into the wall for placement and vibrating is almost nonexistent, can now be placed by pumping from the bottom and vibrating can be done by external form vibrators under these conditions. Placement is quicker, less expensive, cleaner and consistently of better quality than with walls placed using cumbersome windows in the forms.

Concrete placement using conveyor systems has also made concrete pours more cost effective. The development of mobile conveyor systems has improved the flexibility of this equipment considerably. Setup time is largely eliminated and cleanup after the pour is reduced. Because of the cost, scheduling and planning for using this equipment is very important. For mass pours that are accessible, this system is very cost effective. These improvements have resulted in a reduction of about 20% in the placement man-hours over conventional methods.

(2) *Concrete Mixes and Use of Super-Plasticizers*

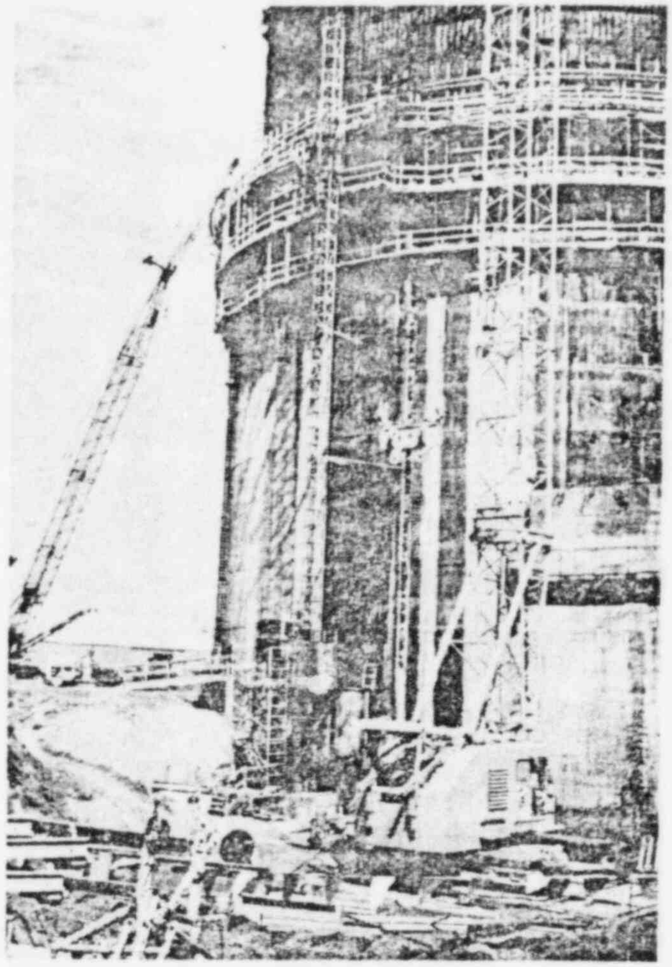
By doing careful design testing of concrete mixes such that their pumping capability is improved, the placement cost can be significantly reduced. Recently the concrete industry has produced a new additive called "super-plasticizer" which has the capability of making concrete more placeable without sacrificing durability and strength qualities. It has been found that the use of this additive can reduce placement costs and also eliminate voids in highly congested and complex concrete sections. Concrete with super-plasticizer exhibits excellent placing properties without segregation or bleeding and requires less consolidation and results in less equipment wear.

(3) ***Innovative Concrete Form Systems***
Innovative form systems used on nuclear work have resulted in cost and schedule savings. Jump forms for PWR containments and cooling towers are probably the most visible and widely used form system developed in the industry. Once the liner is complete, this form system allows the quick completion of containment wall concrete. Because fabrication is required only for initial installation on the first pour, a considerable number of manhours are saved. Also, because the forms are self-raising, crane-time is minimized.

Development of large gang-form systems for building walls also results in cost and schedule reductions. Units as large as 40' x 40' straight or curved sections can be fabricated efficiently and quickly on the ground in prefabrication yards or work areas adjacent to the construction area. When needed, these large panels are lifted into place quickly and economically. Overall manhours are reduced because the panels are assembled in the horizontal on the ground. Schedule is reduced because 1600 sq. ft. of forms can be set and aligned in a few hours.

Other specialty form systems, such as plate girder forms have been developed and used to resolve special problems related to eliminating required shoring under thick slab placements such as Turbine Pedestal decks, and spent fuel and dryer separator pool slabs. The area under these slabs is required to be clear to allow the early installation of equipment, such as the condensers and related piping. Manhours are reduced because shoring is eliminated. Schedule is reduced because equipment can be installed early.

Precast panels and related support systems have been designed to act as form panels. These panels can be used on the interior of buildings to act as finished concrete wall forms where the concrete surface is needed for an expedited schedule or where built-in-place forms would be expensive and



SELF-RAISING JUMP FORM

time consuming because of access, etc. With properly designed backing support and tie-rod system, the panels can be reduced to 3" or 4" thick to minimize weight and costs. The panel forms become integral with the reinforced, built-in-place wall when concrete is placed. When a specified architectural finish is desired for the exterior of plant buildings, precast concrete panel forms can be set and provide a finished exterior wall as well as the outside form for exterior concrete walls. Where required, insulation can also be included in the precast panel to meet cold weather concrete placement specifications and also to lower plant heating requirements during operation. In addition to reducing overall construction manhours for these walls, the system would provide for a quicker close-in of the plant and a protected interior work area for cold weather construction. Because of the unique support system designed for this concept, structured steel or other anchor systems are not necessary to hold the panels in location. For final alignment, they are treated the same as any other form system.

(4) *Scale Models for Concrete Construction*

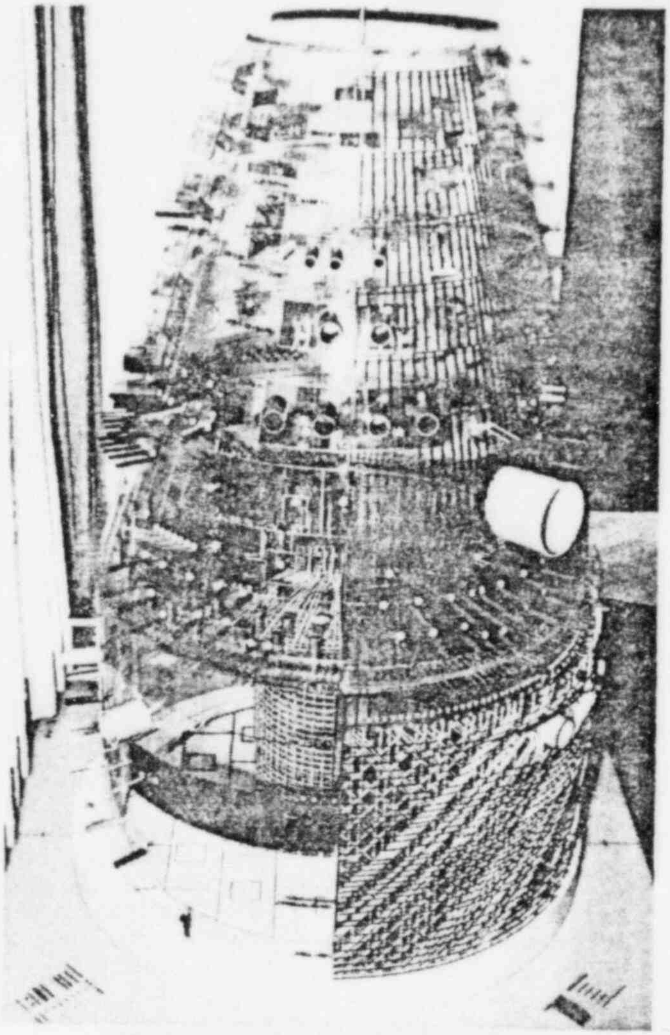
The use of scale models has long been recognized as a tool for improving the design and constructibility of nuclear plants including plant arrangement and layout. The use of scale models has been expanded to include the design of complex reinforcing concrete structures. Models which depict all significant features occupying the confines of the concrete outline (reinforcing bar, anchor bolts, conduit, pipe sleeves, and all other embedded plates and anchorages) have been constructed. These models have resulted in significant construction cost savings and improvement of schedule. Some of their advantages are:

- They permit pre-erection of reinforcing bar with sufficient accuracy to ensure a readily constructible system.
- They allow timely design reworking.
- They permit timely arrangement reworking to achieve improved concrete placement.
- They provide a tool for construction planning and construction.
- They provide an alternate, or supplement for checking placing details.
- They provide three-dimensional composite picture and check of all work within concrete dimensions.

The contribution that a rebar model can make to a project can best be illustrated by the comparison of costs for the installation of base mat rebar for a particular project that used the model-generated information against the costs of a similar rebar installation for a project that did not use this information. The costs for base mat rebar installation for the project using the model developed information, were approximately half of the costs for the project that established its installation and design sequences and procedures off the design document only.

(5) *Prefabricated Rebar Assemblies*

The reactor containment is a highly congested area with substantial



MARK II CONTAINMENT REBAR MODEL

amount of reinforcing bar in a small space. It is also on the critical path of construction of most nuclear plants. The practice of using prefabricated rebar wall panels, columns and other manageable units has increased considerably in the past decade. Major manhour and schedule savings result from this because the prefab work can be done on the ground where materials can be easily stored and handled. No climbing is required, thus providing a safe work environment. Additionally, prefabbing rebar on the ground eliminates most of the scaffolding or temporary supports required for in-place construction. Schedule-wise, walls that would take 2 to 3 weeks to build in place can be prefabbed and set in place and secured in as little as 1/10th the time.

Prefabricated wall panels are not restricted to straight walls alone. Templates for repeating curved or irregular walls can easily be made at ground level. Wall panels weighing from 10 to 15 tons and up to 60' in length are not uncommon.

Rebar prefabrication is also possible for slab rebar mats where grid patterns are similar and continuous. Slab prefabrication is especially advantageous in congested situations where lay down area at the work location is restricted and material to be installed would interfere with the installation.

Prefabrication of special installations has also become common. Examples include Turbine Generator Pedestal Legs (where box forms can also be prefabricated) and heavy beam rebar in walls. Often, as with Turbine Pedestal Legs, structural support systems are required to tie the rebar together to keep it from collapsing and for alignment before concrete placement. These structural support units provide excellent prefabrication templates when properly designed. Schedule savings similar to wall rebar construction can be experienced.

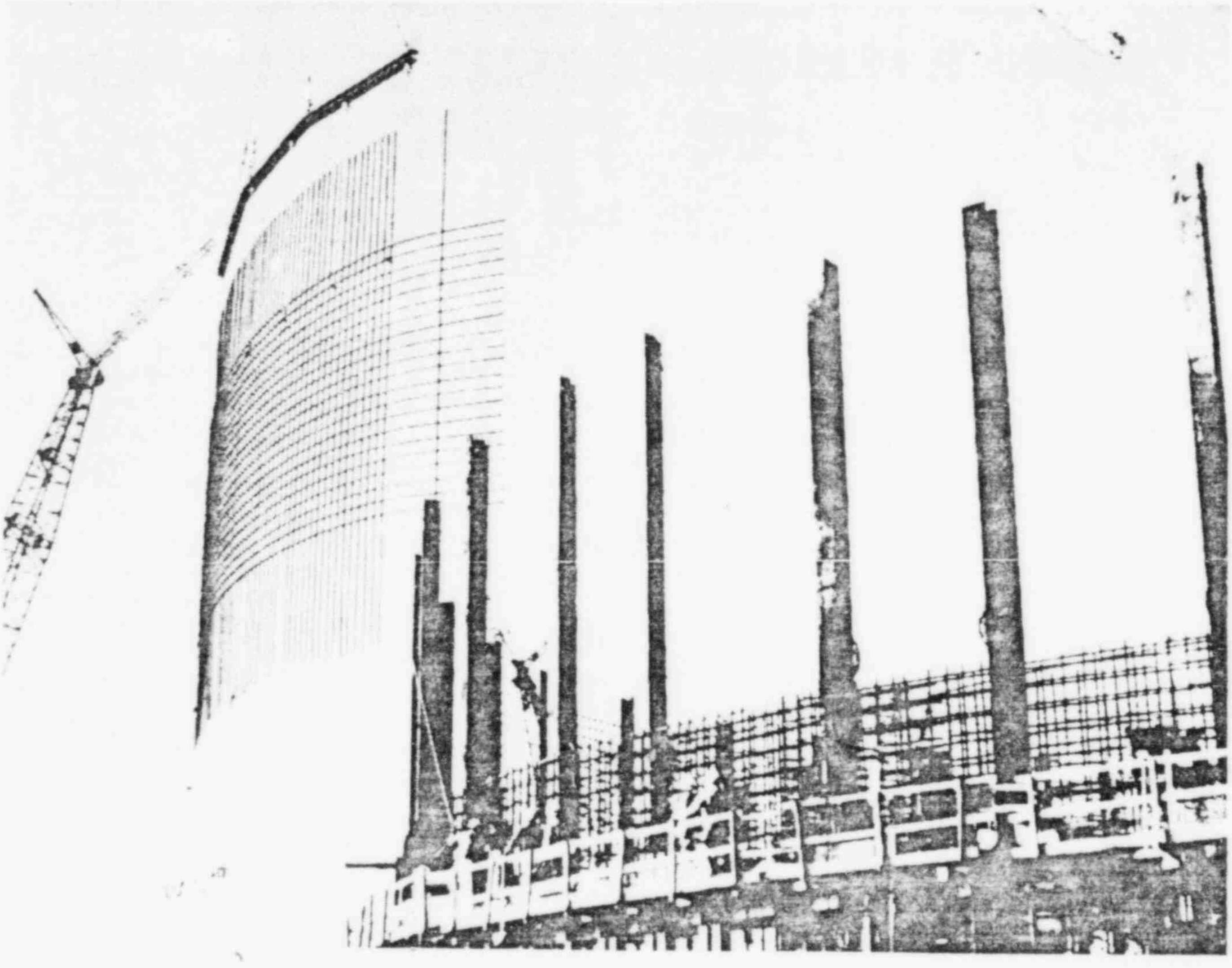
(6) ***Monorail for Erection of Rebar***

One architect-engineer firm found that by attaching a monorail system to the containment liner that efficiencies can be achieved in rebar installation by providing a simpler rapid means of lifting the rebar in place. This concept minimized the interferences and enhanced the installation sequences.

(7) ***Other Specific Project Experiences***

- *Project A*

  The secondary shield wall (containment building) was slip formed. This operation was completed in a total of 17 days (to the spring line) in contrast to the form-jacking methods which requires approxi-



PREFABRICATED REBAR CYLINDER WALL PANEL

mately 15 weeks. Since this operation sat directly on the critical path of the job, the 12 week savings was extremely valuable in terms of overall cost of the operation and available contingency for problems encountered later in the job.

- *Project B*
  This plant employs a reinforced concrete enclosure building aroung the primary containment. Cost and schedule savings have been achieved by designing a stay in place form for the large hemispheric dome.

  To reduce construction schedules, especially for two unit plants, it is desirable to do blasting for excavation at the same time concrete is being poured nearby. This became particularly desirable because of licensing delays and some resulting changes in construction sequences. The limitations previously used in the industry were very restrictive on blasting near green concrete and would have increased the construction time. The architect-engineer ran an extensive set of tests which allowed significantly higher limits and enabled excavation to proceed efficiently in parallel with concrete placement.

C. Structural Steel/Concrete Designs and Construction Techniques

(1) ***Use of a Steel Inner Frame in Concrete Buildings and Stay in Place Steel Decking for Forming Concrete Floors***

A design innovation now widely used in the industry in reinforced concrete auxiliary buildings has been the use of a steel inner frame. The steel inner frame has a number of advantages which increase the constructibility of the plant and improve the schedule. The steel inner frame along with stay in place steel decking eliminates concrete floor form support and makes available areas for other construction work (piping, HVAC, electrical, etc.) at an earlier time, thus improving the construction schedule. The steel inner frame is a convenient structural point for supporting the piping, HVAC and electrical cable trays, thus reducing the number of embedments. The steel inner frame also adds to the strength of the building, improving the seismic characteristics.

(2) ***Composite Steel/Concrete Turbine Pedestal Design***

The design criteria for the pedestal emphasizes its qualification for high seismic areas. By using prefabricated steel plate modules for the legs and deck of the pedestal, rebar is eliminated in the legs and is reduced to about 20% normally required for the deck. The leg modules can be fabricated offsite, shipped to the site, set over anchor bolts, aligned, secured and welded together where required at intermediate beams. The legs are then filled with concrete; no leg rebar is required. The deck units are similarly fabricated offsite, delivered and welded to the legs and to each other.

On a current project for which a detailed study was made, material costs were found to be essentially equal for the "composite pedestal" and for a conventional reinforced concrete pedestal. However, approximately 45% fewer field manhours were required to construct the composite pedestal and the normal nine-month construction schedule was reduced to 7 1/2 months. In addition to these cost and schedule savings, a greater flexibility in scheduling of turbo generator related work, such as the condensers, will result.

(3) ***Structural Wall Attachment Embedments***

The use of flat wall embeds to weld support tees for support of structural steel beams, results in overall savings in manhours. The flat embeds can be attached to the face of forms and anchored in the wall concrete. No block-outs or concrete repair is required later. The "T" seats are easily welded to the embed plates and then the structural beams can be set and secured. Although some drawbacks, such as occasional interference between rebar and embed shear lugs is experienced, the use of these embeds for securing structural beams to concrete walls is an improvement over the conventional method.

The use of difficult-to-install drilled-in anchors for attachment to concrete surfaces has been reduced substantially at many projects by the early provision of cast-in embedded strip plates and/or threaded inserts placed in a predetermined pattern.

(4) *Radar Rebar Finder*
It has long been recognized that use of embedment plates for attaching supports for other equipment is the cost effective way to design and construct a nuclear plant. Notwithstanding this widely recognized principle, it has been industry experience that it is frequently necessary to attach equipment in locations where there are no embedment plates due to design changes that occur later in the project. Attachments are usually made by using drilled in place concrete anchors. When drilling in the concrete to place the anchors it is important that reinforcing bar not be cut since this will reduce the basic strength of the building. In many cases drilling has become a time consuming task since holes must be made on a trial and error basis to miss reinforcing bar. Reinforcing bars can be accurately located using a device employing radar principles. This allows drilling that can miss the reinforcing bar, thus substantially reducing costs.

Where drilled-in anchors cannot be avoided, drills with motor interlock features are being used. These drills automatically stop when the bit contacts steel. The benefit of this device is the elimination of inspection requirements for damage to embedded reinforcing steel and related project engineering evaluations.

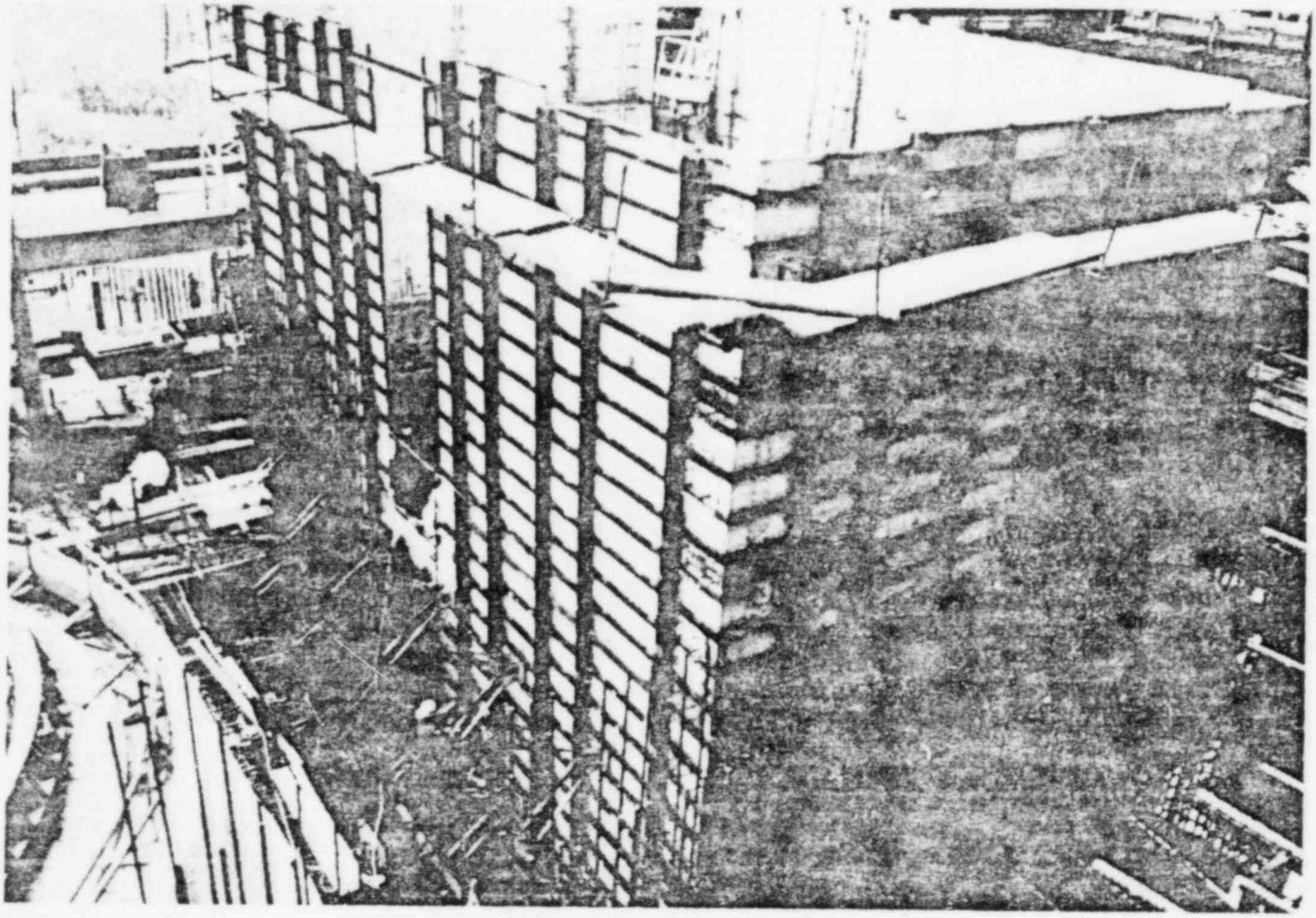
Three-D photos accurate to within +1/8 inch are being used at selected sites to permit location of interference-free points for drilling anchors.

(5) *Preassembled Pool Liner Assemblies*
Preassembling refueling facility pool liner assemblies has significantly reduced the number of field manhours required to construct these facilities. Additionally, installation and maintenance problems identified with the original "wall paper" schemes have essentially been solved with this improved liner technology.

With the earlier pool liner schemes, floors and walls for the pools were constructed using conventional construction methods, i.e., slab was shored from below, concrete placed and then walls formed and placed with shoring left in place. Embeds were provided in the concrete for welding to the thin gauge liner plate.

The second generation of fuel pool liners eliminated many welding and fabrication problems by using a thicker (1/4") gauge liner material. Also, considerable schedule savings have been realized by designing the pool liners for total out-of-hole prefabrication. Once the pool slabs are placed, the liners, including reactor well liner can be lifted into place. With internal bracing provided, the pool liners are used as the inside form for placement of the pool wall concrete. Schedule savings are realized because preassembly of the pool liners can work in parallel with construction required to complete the pool slabs. When the slabs are complete, the liner is ready to set, shortening the wall construction schedule considerably. Material and manhour requirements are reduced because no inside form is required for the walls. Additionally, a considerable amount of wall rebar can be installed prior to setting of the liners, further shortening the schedule.

(6) *Structural Steel/Concrete Composite Design*
The most significant application of structural steel/concrete is in slab designs which utilize structural steel/framing systems to support elevated slabs. This design practice is uniformly common to all major nuclear plant architect-engineers in the U.S. Manhour savings are realized by the elimination of shoring to support the slab, also elimination of form stripping. This is particularly significant where large pieces of equipment must be installed below slabs, such as tanks, switchgear, etc. A number of options are available for the constructor in building the affected walls and slab. After completing the first elevation walls, he may set equipment at bottom slab elevation, place first elevation structural steel and Q-deck and work connecting pipe & conduit to equipment below. If equipment for bottom slab elevation is not available to set, he can continue construction of walls to the second elevation above base, still come back and set tanks two elevations below, set steel and deck at elevation, set rebar and begin work on second elevation slab.



SPENT FUEL LINER IN PLACE

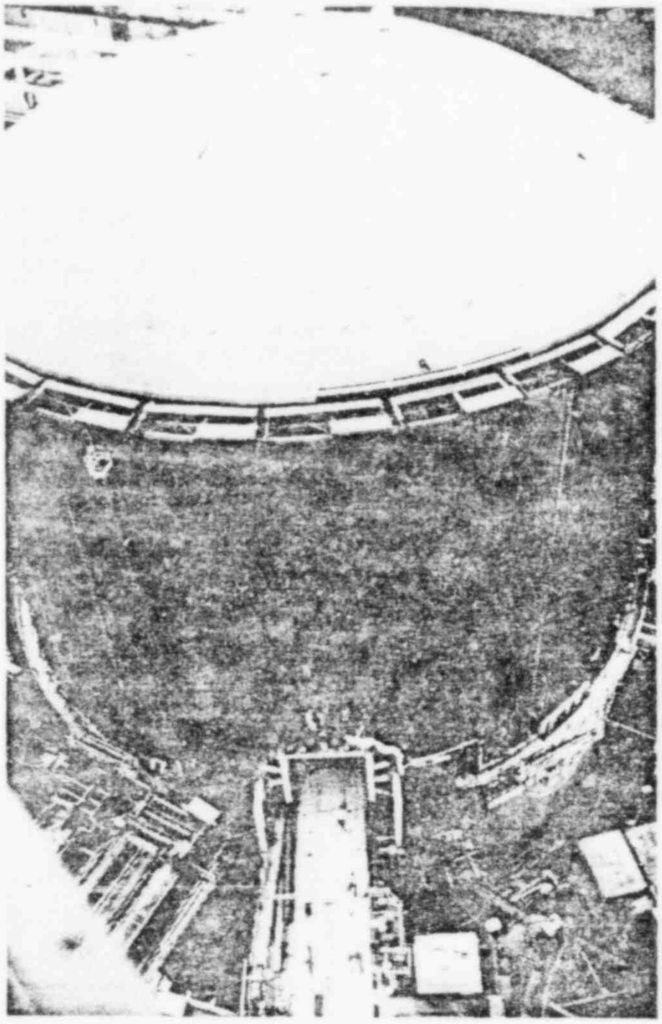
The important aspect of structurally supported slabs in addition to overall cost reduction, is the degree of flexibility that this design concept provides to the project to schedule construction activities. Delays that previously resulted from late receipt of equipment or materials now have a significantly reduced potential for affecting the overall construction schedule.

(7) *Aluminum Dome Over Containment for Work in Poor Weather*
The containment is on the critical path for most nuclear plants. A substantial part of the construction period occurs prior to placement of the permanent containment dome and thus enclosure of future work for weather protection. At a project in the Northeast, significant improvements were made in working conditions, especially for the winter months by using an aluminum geodesic dome for weather protection. Such domes are available in very large sizes at relatively low cost. Use of the dome enabled work to proceed through very poor weather conditions on critical path items during the cold winter. It also proved useful during the rainy spring. The dome is light enough that it can be lifted when necessary to allow major items to be installed.

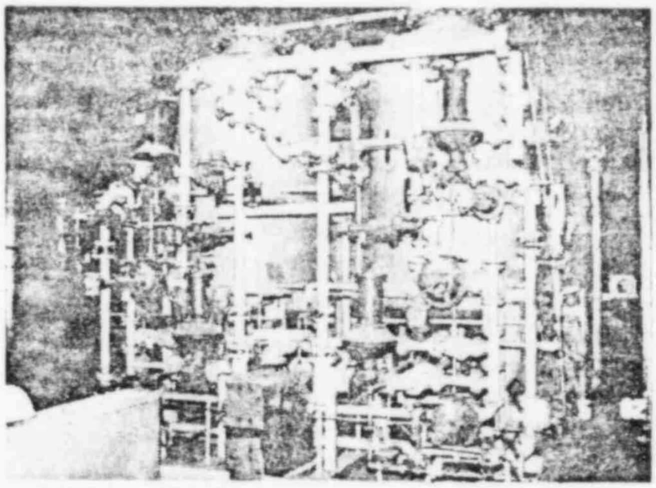
D. Prefabrication, Pre-Assembly and Modularization of Piping and Equipment

(1) The pre-assembly of components, equipments and sub-systems into modules that can be safely handled and transported from the point of pre-assembly to its ultimate location within the facility of which it is to become an integral part, reduces construction costs and shortens the overall schedule. Following are advantages:

- Engineers can utilize the facility design-model to maximize the modularization concept during the early engineering phases of the job.



ALUMINUM DOME OVER CONTAINMENT



TYPICAL PREFABRICATED SKID MOUNTED MODULE

- Prior to shipment to the job site complete "hook-up" can be performed with following items:
  - — equipment placement and alignment
  - — piping
  - — insulation
  - — electrical wiring and connections
  - — instrumentation
  - — certain pre-operational testing
- Individual design-models of the modules assure proper attention to component support, temporary and permanent, transportability to the site with appropriate off-loading sequences, and site movement to its final inplant location.
- Shop crafts and labor can be used in the preassembly effort as opposed to using the conventional less productive, less qualified, more costly field man hours.

(2) *Good Examples*

- A number of projects have adopted the practice of subassembling piping at or near the jobsite in a temporary facility equipped with automatic welding facilities. This practice permits greater control over welding quality. In addition, where possible, permanent supports are installed prior to installation of the piping to minimize the use of temporary hangers. This of course requires a well coordinated engineering and procurement effort throughout the job.
- Several projects fabricated the containment dome on the foundation mat inside the cylindrical containment liner. After the dome is coated, the spray headers attached, and the cylindrical liner is completed to the spring line; the dome is air floated into position and then lifted in place. The concrete for shallow domes is placed in two layers on top of the containment dome liner without additional supports. The weight of the first layer is within the load bearing capacity of the dome and contains only light reinforcing. The second layer contains all of the reinforcing and prestressing. Its weight is carried by the containment liner and the first layer.
- Another project decreased the erection time of the containment liner by constructing liner rings in place on the containment mat in parallel with constructing rings over to one

AIR FLOATING CONTAINMENT DOME INTO POSITION

side on a concrete pad. When a ring section of about 30 ft. high had been constructed on the pad to one side of the containment it was lifted in place on top of the 30 ft. high section which had been erected in place. This process was repeated several times until the liner had reached the spring line. This technique almost halved the liner erection time. Similarly the dome of the containment liner was erected to one side of the containment and lifted in place in two pieces.

- At a number of projects piping is painted in a field paint shop prior to delivery to the construction area. (Also, see "Qualified Paint Shop" in Section III.)
- *Pre Assembly of Condensers*
  The pre assembly of condenser units is an excellent example of field manhours and schedule being significantly reduced by component pre-assembly. The ultimate size of the condenser is restricted only by the capacity of on-site rigging schemes to handle the condenser modules. On more than one project, large, pre-tubed units have been successfully installed.

E. Material Handling, Heavy Lifting and Hauling

(1) *Warehousing and Material Staging*
The most significant cause of delays during construction is the unavailability of both bulk and engineering material for the construction crews when it is required. This unavailability can be caused either by non-shipment of material from the vendor or the inability of the site to locate equipment that has been received and placed in storage. A number of constructors have developed a standard approach to this problem by accumulating the equipment and material required for erection within the plant at predesignated locations. Equipment and material may be mounted on pallets or skids for easy transportation and placed in the predesignated locations during off shifts. In so doing, the construction forces may simply request the material they need by area to be delivered in time to support their efforts.

(2) *Advances in Rigging and Heavy Hauling*
In the past several years substantial improvements have been made in the

equipment and techniques used for rigging and hauling of the heavy components and equipment used in the construction of nuclear power plants. There are many benefits to be gained by using these new techniques and equipment and new applications for them continue to be developed.

First, very high capacity schnabel cars are now available which are capable of moving components which weigh up to 880 tons along rail lines. Using this equipment, prospective plant sites which were previously considered to be unsuitable for a nuclear power plant can often be shown to be acceptable. In the past, serious consideration of these sites were precluded because of the difficulty and expense of transporting the heavy components to these sites or the need to perform field fabrication of the heavy components which was either technically impractical or far too expensive.

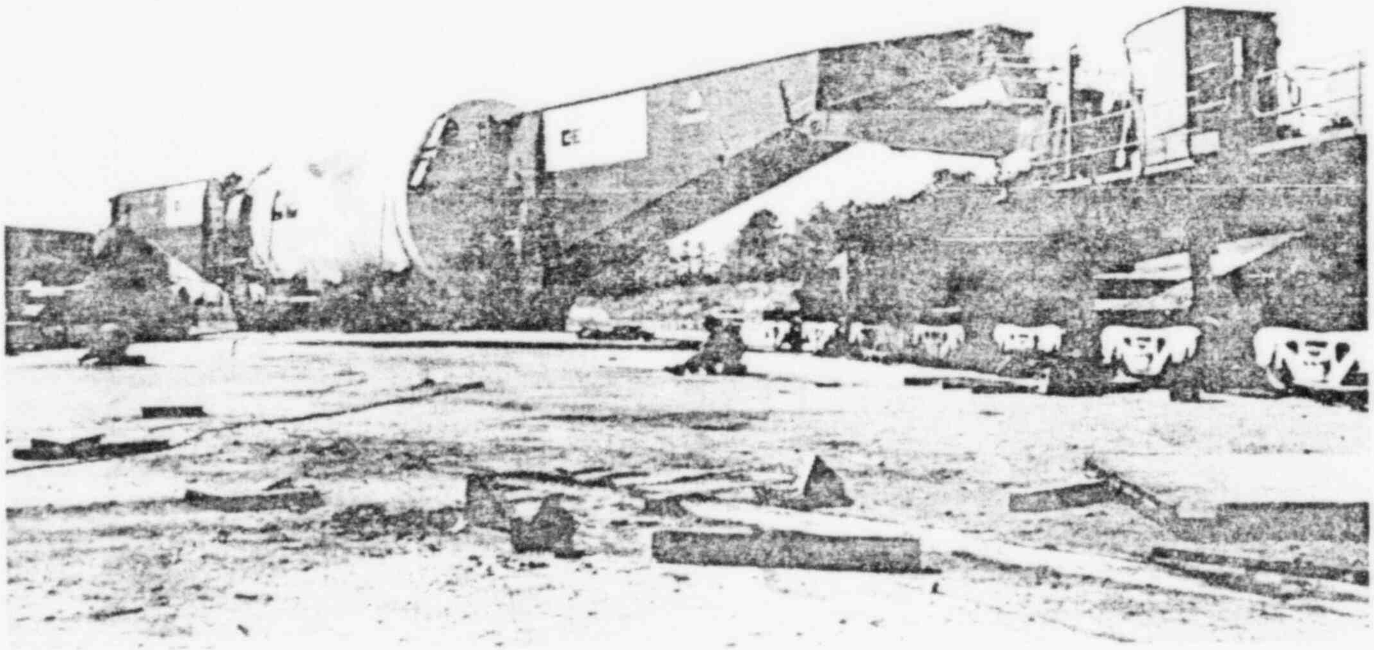
Now by the use of the schnabel car alone or in combination with conventional barge transportation, more sites which otherwise were considered to be good but which were previously considered inaccessible can now be utilized. A further advantage of the schnabel car is the unique capability it has to load itself.

The schnabel car is unusual because it supports its load between two individual car halves. The load is suspended between the two sections on arms which have self-contained power systems for lifting, lowering and otherwise maneuvering the load. The lifting arms can rotate laterally 45 degrees to either side of the car's center line and together will support 880 tons.

By separating the car halves onto tracks built on either side of a barge slip and rotating the arms over a load, the schnabel car can pick up its cargo without other special lift equipment. Once the load is properly suspended on the car it will proceed with an engine and auxiliary cars as an independent special train traveling at a maximum speed of 15 mph.

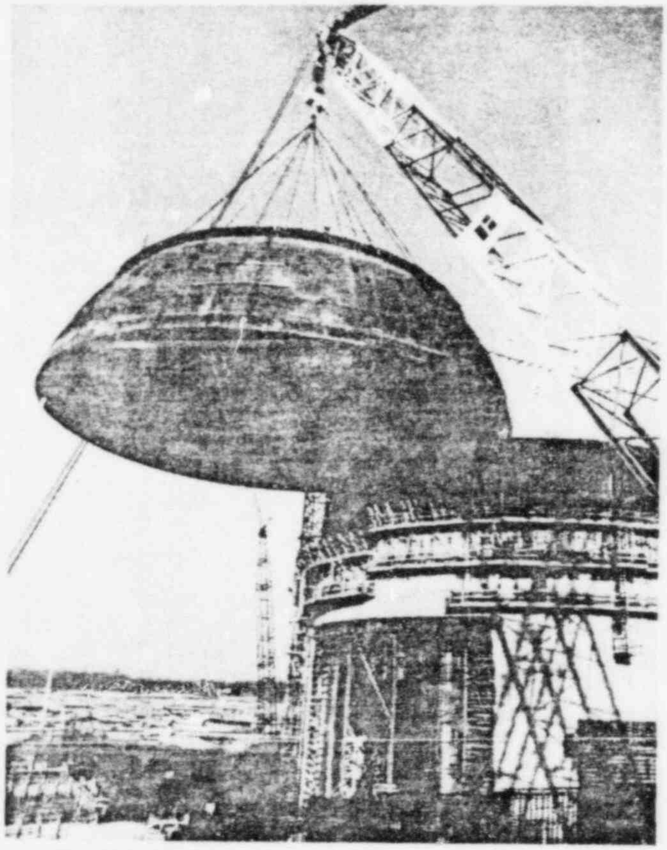
Once at the plant site, the railroad tracks can be arranged so that the component or other heavy load can be placed within the reach of todays's super heavy lifting cranes, which can place the component within the containment with no other intermediate rigging evolutions being required.

A second advancement made in equipment to handle very heavy lifts was the development of extremely high capacity crane systems. These cranes are capable of lifting the largest



SCHNABEL CAR

nuclear components over the top of the containment and placing them directly onto their foundations within the containment. These operations which previously required weeks to perform can now be accomplished in days. By using this system, there is no longer a need to leave large openings in the containment during construction. The scheduling flexibility that this system now provides the constructor is considerable. Much of the equipment and construction work which had previously been on the critical path can now be performed as parallel effort with little lost construction time due to unforeseen delivery delays or construction problems.

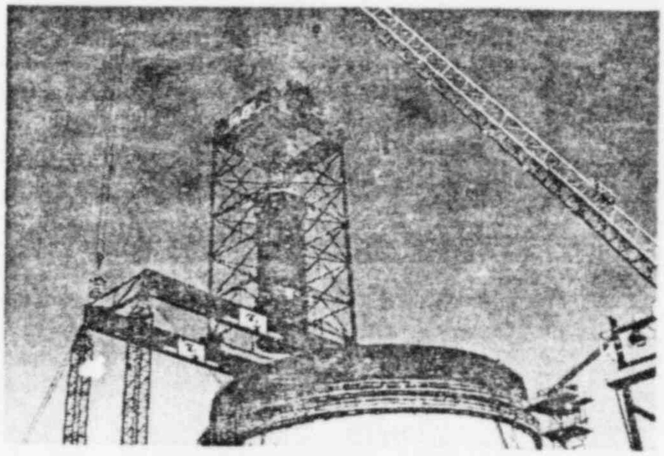


PREASSEMBLED CONTAINMENT DOME PLACEMENT

High capacity crawler cranes have been used at numerous projects to accomplish major lifts in a short time span and to provide as much as possible flexibility to the construction schedule. Major lifts on a current project include:

- Primary Shield Wall — 934 tons (includes concrete in the PSW as well as rigging attachments).
- Reactor Pressure Vessel — 908 tons (includes rigging attachments).
- Drywell liner — 276 tons (includes rigging attachments).
- Stator — 403 tons (includes rigging attachments).
- Containment Dome — 619 tons (includes rigging attachments).

High capacity tower cranes have been used for heavy lifts on projects which have limited area adjacent to the containment. This rotating crane can service 240,000 square feet with a lifting capacity of 132 tons at a distance of 269 feet from the tower center. Larger lifts can be made at lesser distances from the center.



REACTOR VESSEL PLACEMENT

F. *Piping*

(1) *Installation and Welding*

Automatic welding has been utilized at many projects. Proper training of welders has yielded qualified technicians to operate the welding machines and thus improve both quality of welds and timeliness of completion. This technique virtually eliminates rejected welds and attendant repair man-hours.

Special washer-like spacers are now being used to automatically achieve and maintain proper fit-up in small bore socket weld fittings. This eliminates the time-consuming practice of scribing and measuring the joint to achieve proper fit-up. An approximate 20 percent man-hour saving is being projected in the fit-up process resulting from the use of these spacers.

At one plant it was found that improvements in productivity were obtained on the primary loop piping work by performing large diameter welds with automatic welding machines and using backing rings in lieu of consumable inserts. The backing rings were removed after welding. The use of backing rings reduced fit up time and eliminated purging requirements.

It has been found that use of the gas tungsten arc welding process for the welding of Class I and II socket welds in lieu of manual metal arc welding produces several benefits. The amount of interpass cleaning is reduced, grinding of finished welds is eliminated, and the finished weld is acceptable for nondestructive examination.

(2) *Small Bore Pipe Bending*

At several nuclear projects, welded fitting joints are being eliminated by using automated bending machines for forming small bore pipe spool configurations. An approximate 30 percent man-hour saving over conventional welded fittings is projected for this technique. In addition, further down-stream savings are projected for plant operations due to the elimination of debris traps present in conventional fittings.

(3) *Supports and Restraints*

A number of projects combine support functions insofar as possible, such that a single support may contain HVAC Duct, Cable Tray, Conduit and Piping. In addition, these supports function as both dead weight supports and, where required, seismic supports. The use of physical models has provided a significant advantage in determining the optimum locations for these composite supports.

One particularly successful project placed special priority on engineering, design and delivery of piping and hangers. These were scheduled for delivery a full 18 months prior to the installation start date. The result was that hanger installation preceded pipe erection and minimized the need for temporary support devices. This resulted in an orderly pipe installation program.

G. Electrical Installation

A typical nuclear plant will include over 30,000 electrical circuits. The problem of efficient routing of these circuits while maintaining separation between safety channels, voltage classes, analog signals and power circuits is more complex than can be efficiently accommodated by human beings. As a result, sophisticated cable routing programs have been developed to computerize the selection of the cable route, accounting of cable length, recording cable tray fill, keeping track of cable inventory, and maintaining required cable separation.

Automated programs have been used to manage and control the voluminous data associated with raceway, circuit design and installation. An initial data base is created by entering plant reference data such as the plant column lines and the tray and conduit raceway network. Circuit information is later entered and consists of the "from" and "to" locations for automatic cable routing, cable type code and other descriptive information. The program then determines an acceptable tray route while maintaining safety class, voltage separation and tray fill limits as criteria. Concise reports are then available to the designers, constructors, and project management to show status, progress and provide organized summary and detailed listings of the data.

The primary output from the program is the Cable Pull Slip which contains all the information necessary for a crew to pull the cable. Pull slips are supported by various reports intended for construction use to verify latest data and provide planning tools for construction management. To further aid the owner or constructor for installation status, features such as Tray and Conduit Installation Cards and Termination Installation Cards can be provided. The Cable Pull Slips and the Installation Cards are signed off at the site after an installation task is completed and the information is then entered in the data base. The raceway, circuit or termination is marked as installed and various reports of items installed and not installed may be generated.

There are currently over 50 reports available which sort and extract information to meet the needs of those involved in plant design, construction and maintenance. Example reports available are:

- Tabulation of cable in a given system
- Status of cable installation by system
- Status of raceway installation by plant area
- Statistics of terminations installed by system and by area

- Cable inventory data

The program has been utilized successfully on numerous domestic and foreign fossil and nuclear projects.

Special tooling has been developed for automatic cable lubrication, thereby dramatically reducing the effort and manhours required for long electrical cable pulls. A related advantage exists in that the A/E can now design longer runs with fewer manholes or pull points. The net effect of this technique is an anticipated saving of about 30 percent installation man-hours for this type of activity.

It has been found that construction labor savings can be obtained in curved cable tray installation by using tray fittings with tangents (2" to 5") in lieu of fittings with no tangents. Seismic cable tray connectors have wrap around sides which are very difficult to install on trays without tangents. By using trays with tangents substantial field labor savings were obtained.

The lighting of a nuclear plant during the construction phase is very important. To achieve cost efficiencies there has always been the consideration of lighting the work areas entirely by temporary means which results in additional cost, or installing the permanent lighting early exposing it to damage or possible replacement and additional cost. One method found to be successful is to install the permanent lights, which are pendant type of long stems (8' to 10'), initially on short stems close to the ceiling and out of the areas where they would be damaged. After all the piping, HVAC and insulation is completed the lights can then be lengthened to their design height. This system saves a great deal of temporary lighting, avoids damage to the permanent lighting and minimizes the overall cost.

The use of an Electrical Panel Shop at a construction site allows for fabrication and wiring of electrical cabinets and panels on site. This centralizes purchasing and inventory of materials, reduces complexity of vendor-furnished items, reduces damage due to shipment, provides more time for wiring design and implementation, allows for greater scheduling flexibility, reduces overall cost, and provides for a higher quality end product.

The development and use of an Electrical Material Inventory Control System at a construction site has maximized material availability at the issue point, enhanced inventory reporting and accounting, provided for controlled issue of expensive components, and has provided readily available usage history information for future reference.

H. Heating, Ventilation and Air Conditioning (HVAC)

(1) *HVAC Ductwork Analysis*

Improved capabilities to analyze by computer the HVAC ductwork, from design inception until the installed system is balanced, have helped accomplish cost effective ductwork designs for nuclear power plants.

The ductwork is a costly component of the plant HVAC systems due to the relatively stringent design and construction requirements, such as the leak-tightness, seismic and environmental qualifications, and heavy supports requirements. In addition, ductwork represents a great potential for physical interferences and rework in the design and construction of the plant, because it is an extensively routed commodity with large dimensions. The duct routing and dimensions are critical to the system's performance. Any change to the duct routing and/or dimensions is directly related to the HVAC equipment size and/or performance. An accurate design of HVAC ductwork, is therefore, critical to the cost and schedule of the project.

Computer aided programs allow efficient initial ductwork design suitable for the optimization of the HVAC systems, subsequent verifications of the design after changes, and analysis of the final and as-built design to help accomplish the startup and operation of a well balanced system. In addition, the analyses will help to confirm in the design process the absence of design deficiencies, such as undesirable duct fittings, oversized or undersized HVAC equipment, and system's incompatibility with the design objectives.

(2) *Ambient Conditions Analysis*

An analysis capability using a computer to determine the ambient conditions profile, such as temperature, humidity, condensation, during anticipated operational occurrences or postulated accidents has been used successfully. The program is able to analyze a compartment or room with different construction configurations and characteristics, and predict the ambient temperature and humidity excursions resulting from an upset in the heat and/or moisture released in that room. The predicted performance of the normal space cooling equipment during that upset condition is also analyzed and factored in the temperature and humidity profiles.

This capability has improved the HVAC designs because the program helps to identify the need for unique design features in the normal space cooling system to ensure that the ambient temperature and humidity excursions during the anticipated operational occurrences or postulated accidents are within the acceptable limits from the plant safety, licensing, and equipment qualification standpoints.

This program also has improved the capability to better define the design ambient conditions for the environmental qualification of safety related equipment. The use of temperature and humidity profiles in lieu of the predicted or averaged maximum values has significantly increased the availability and capability of suppliers to furnish qualified equipment. The net result has been an improvement of the cost effectiveness of equipment qualification programs.

I. Improving the Startup Process of a Nuclear Facility

(1) Integrated planning between engineering, construction, and startup activities must be accomplished if an optimum overall duration is to be achieved.

The decision believed to have the greatest impact on project completion and startup, is the date scheduled to begin systems turnover. This means changing the construction methodology from a bulk mode to a system-completion or punch-list mode. These changes are directly associated with the plant energization milestones and are very crucial decisions.

Prior to the start of the system completion mode, construction workers have complete and free access to the plant. However, with the systems-completion mode, they'll find cordoned-off test areas, tagged-out equipment, and "hot" panels and termination cabinets. The construction quantity installation rates will then drop off markedly. There should, therefore, be only a small amount of installation work left at this point.

When the scheduled dates for plant energization approaches, a hard look must be taken at the remaining bulk quantity installations to be certain that the reduced rates that will result from this mode can be tolerated. If the plant quantities installed are not close to the forecast curves, a detailed analysis must be made to determine if it is really in the best interest of the project to energize the plant as scheduled.

(2) One project that used an integrated Utility/A-E/Constructor management team credits their successful start-up phase to a philosophy of early acceptance of equipment, components and partial systems. This was done in order to enable early testing and problem identification of system components. The utility's start-up program plan and schedule required early on-site presence of Operating Department personnel (35 months prior to the scheduled "Start of Fuel Load" date). The early work of these approximately 64 people consisted of a number of tasks, the highlights being to:

- Define Start-up system boundaries
- Prepare Pre-operational test procedures
- Establish Construction turnover sequence
- Establish Pre-operational test requirements
- Determine Start-up (Construction and Operation) manpower levels
- Establish target milestone dates

The detailed start-up schedule was then integrated with the construction schedule to develop one combined schedule that the jobsite worked to and home office Engineering and Design also supported. In the course of the start-up phase, the Construction Organization objectives gradually shifted from a "bulk" quantity installation and area concept of control, to total support of Start-up turnover requirements and work performed on a discipline basis.

(3) A number of projects have found that it is beneficial to schedule the in-

tegrated leak rate test (ILRT) after major construction work in the containment is completed. There are penalties that go with stopping all containment work to run a ILRT in advance of completed construction, i.e., the containment must be completely isolated and all work stopped to run the ILRT.

(4) *Generic administrative and technical Startup Manuals and Procedures.*
Many generic methods have been developed for handling the myriad of complex activities associated with the startup of a nuclear plant. These include generic administrative and technical startup manuals, generic procedures, etc. In most cases money, time, and human resources have been saved by utilizing generic procedures and documents.

III. MANAGEMENT PROGRAMS AND TECHNIQUES

A. Quality Assurance/Quality Control (QA/QC)

The verification of quality workmanship is very beneficial to any project. The objective is that everybody concerned with the project is cognizant of the requirement of quality work. Procedures on how to accomplish the work are written and documents are generated to indicate that the work has been performed accordingly.

(1) ***Use of Joint Utility Management Audits***
The establishment and use of Joint Utility Management Audits of nuclear quality assurance programs has provided objective audits by highly qualified people who can effectively contribute to corrective action and program improvement. It has further provided insight to auditors regarding program approaches and problem solutions by others.

(2) ***Engineering Audits***
Historically, Quality Assurance audits in the nuclear industry have been primarily system or process-oriented, as opposed to "product" oriented. This has particularly been true in audits of engineering, where the product is paper, e.g., design output documents.

Recent experience in the industry indicates that concentrating QA audits of Engineering solely on verifying compliance with procedures that prescribe the design process, is not the best use of resources to determine adequacy of the design product. There have been instances where the procedures adequately define the process and audits have verified procedural compliance, yet the design output was deficient.

To remedy the foregoing it has become common practice to conduct technical, or "product" audits of Engineering. In this manner, the effectiveness of the system is verified by examining the adequacy of the output of the system. The purpose of such technical audits, using engineering specialists as members of the audit team, is to assure the proper application of theory, guides, codes, regulations and other criteria in the performance of engineering design. Further, it provides a technique to cover implementation of responsibilities and procedures, such as for the checking function.

Continued and increased emphasis on "product" versus process self audits of engineering by design organizations, should be productive in mitigating concerns with quality of design of nuclear power plants that has received increasing criticism in recent years. Further, such self audits under cognizance of the independent QA organization could possibly help to reverse the present trend toward independent "third party" audits and/or the extensive design reverification program currently in vogue.

(3) ***Field Construction Procedures and Inspection Plans***
At a large midwestern PWR project, site-specific Field Construction Procedures (FCP's) for quality sensitive and complex activities were developed in concert with companion inspection procedures. FCP's and inspection procedures interface with each other, with the plans and specifications, and manufacturers' instructions. All conflicts were resolved prior to issue.

The scope of this program includes general installation activities (i.e., concrete placement, structural steel erection, etc.), specific installation activities (installing the RPV, offloading the polar crane to storage, etc.), and administrative/support activities (i.e., field procurement of safety-related components, site access control, material handling and storage, etc.).

Identification of procedural and inspection plan needs was initiated by the site planning staff well in advance of the scheduled activity, a preparation assignment was made, a draft prepared, and a joint review performed by the Owner, Engineering group, Constructor, and QA/QC group. Mutually agreed resolutions were incorporated and the procedure published. The quality verification inspection plan (IP) was finalized in approximately the same time frame, incorporating the essential elements or attributes conveyed in the engineering documents and the installation procedures. If deemed necessary, training of supervision, craftsmen and QC personnel was then conducted using the FCP's and IP's. Unless dictated by specifications or codes, all verification was performed in-process.

The broad benefits of this approach include drawing all organizational elements into the mainstream of prerequisite planning and task execution; keeping the prime mission of each organizational element in focus, minimizing crew downtime due to inspection activities, avoiding needless inspections, acquainting each element with the needs of other elements, and strengthening the team approach to achieve the project's cost, quality, and schedule objectives.

Without a doubt, this program contributed greatly to such positive achievements as placing the completed reactor containment dome in approximately two hours, placing concrete mats at rates in excess of 225 cu yd/hr, and achieving x-ray quality weld rejection rates of less than 1.0 percent of the length of weldment. Another measure of the positive aspect of this program is a record of installation infractions of less than one per 750,000 craft man-hours expended.

B. Site Engineering Capability

It has been found to be generally beneficial on nuclear projects to establish a semiautonomous project engineering office on site which includes all disciplines; engineers, designers, drafters, and technicians, along with data processing capability. By this means, response time on technical questions is minimized, thereby reducing craft inefficiencies caused by waiting for engineering answers or direction. This on site engineering presence also greatly assists in defining engineering priorities and urgency through hands-on daily association with the plant construction and inspection efforts.

C. Design Change Control

The second unit of a nuclear power plant in the Southeast was successful in controlling design changes such that they would have minimum impact on the overall construction schedule. Early in the unit two design process there was a comprehensive review of the unit one design by both Construction and Engineering personnel. The construction people recommended design enhancements that could be made to improve productivity and costs. The engineers reviewed all unit one changes, i.e., backfit changes, operational enhancements, and regulatory requirements, in order to ensure their consideration and disposition for unit two at an early stage. Later on during the construction phase a Change Review Board consisting of Engineering, Construction, Operation, and Project Management personnel reviewed additional changes arising out of licensing commitments, system enhancements, and operations improvements. From this review, it was decided which items must be implemented prior to Core Load and which should be deferred for later Backfit. This insured a defined scope and helped assure realistic schedule dates.

D. Complete Installation Information

Management programs are now being used which, in most cases, provide the constructor with all the information required to perform a task on a single document. Adjustments are incorporated on the original documents and not through issuance of separate supplemental partial instructions. The aforementioned site engineering capability facilitates this program.

E. Integrated Cost and Schedule Control

Many projects have developed and use a computerized cost and schedule control system in which the interdependent variables of scope of work, schedule, and resources are integrated. Deviations from these variables can be readily identified and evaluated so that corrective action can be implemented quickly. This network-based management system integrates the scope of work, schedule, and resources of a project to provide:

(1) A scope of work definition enabling precise assignment of responsibility.

(2) Identification of the specific engineering and construction activities.

(3) Visibility for control of manpower and material.

(4) Task, time, and cost performance reports tailored to the needs of each level of management.

F. On-Site Qualified Paint Shop

Generically, the industry has experienced significant difficulties in obtaining acceptable safety-grade coatings on the structural steel, flat plate and miscellaneous steel-shape, fabricated items, as delivered to the site, for use within the containment. A large number of suppliers/fabricators are always involved and each is required to supply and apply specific coatings on their fabricated products to very rigid and high levels of quality. Application procedures are required to be prepared and submitted for prior approval and related documentation is required to accompany the fabricated products when shipped. Understandably, these various suppliers usually view the "coatings" of their final product with somewhat less concern than they view its fabrication. As a result, high levels of touch-up and re-do are found necessary when the materials are received in the field.

In an effort to minimize this problem one project set up its own on-site "Qualified" paint shop. Therefore, instead of having 119 different suppliers attempting to supply qualified coatings on their products, the on-site qualified paint shop has provided this documented service in a timely manner.

Excellent results have been achieved to date for coatings for structural steel, miscellaneous steel items, embedments, pipe hangers (over 28,000), etc., as well as for non-safety-related applications. The project has been able to establish and maintain excellent quality control, product scheduling and production costs.

G. Labor Management

(1) *The Use of Triple Shifts*

Good success has been achieved by implementing an industry practice of triple shifting work which lies on the critical path of the job. This is especially significant in the early stages of construction, where concrete placement is the main activity taking place at the jobsite and each day saved is reflected directly on the completion date of the job.

(2) ***Nuclear Power Construction Stabilization Agreement***

In a major step in management/labor cooperation to assist the viability of nuclear power plant construction, the Nuclear Power Construction Stabilization Agreement (NSA) was created. The creation of this agreement was primarily intended to allow management and labor to work together in the effort of achieving the common goal on large nuclear projects. The worsening performance in both cost and length of construction of a nuclear power plant was reducing the economic benefits of such a power plant. Recognizing a serious problem that must be addressed in order to regain the momentum of the industry, four major engineer/constructors and the Building and Construction trades negotiated the NSA to successful completion.

This agreement is co-signed by four major engineer/constructors, the Building and Construction Trades Department, and sixteen of its affiliated international unions. It should be noted that the NSA is applicable to nuclear power plant projects only.

A nuclear proj[illegible] which has in effect an NSA, is [illegible]g rolling 4 day 10 hour shifts. [illegible]us far, the results are reported to b[illegible] positive.

Many other projects have project-specific labor agreements which incorporate features similar to those in the NSA.

(3) *Work Sampling*

Work sampling consists of synthesizing work efficiency from a series of random observations of the construction workers. Work sampling techniques have been applied to a number of major projects and the analysis of the results of such sampling have led to increased productivity.

H. Statistical Methods

Statistical methods for long and short range trend analyses are used to control and improve the quality of construction. In one example each commodity or operation is assigned a key word and each characteristic is assigned an attribute code. Inspection report data is inserted into a computer and those items found to be unsatisfactory are listed on a computer report by inspection report number, key word, responsible craft or contractor, date inspected, attribute code, ratio of unsatisfactory items to number inspected, and a brief description of the unsatisfactory condition. Based on this information, corrective action can be initiated.

Further analysis of these data enables the key words to be ranked or prioritized by month and accumulative totals recorded for long-term trend analysis. Because these quantitative data are generated monthly, long- and short-term trends in the construction progress can be graphically displayed. Due to the many variations which affect these data, a measure of quality performance is determined by dividing the total number of unsatisfactory attributes for the month by the total number of man-hours expended for the month. This technique results in the ability to evaluate performance as a function of compliance with the engineering instructions.

IV. ANALYSIS OF EXPERIENCE AND TRENDS FOR APPLICABILITY TO CURRENT OR FUTURE PROJECTS

All of the items discussed in the previous section should be considered for implementation when applicable on current and future projects. Plant features which have been designed and have been proven to be constructible and operational with a minimum amount of problems will be repeated without requiring any redesign. Utilization of proven concepts and designs will reduce construction costs and time and maintenance costs on future projects. To design, procure and construct a duplicate plant from proven as-built documentation, is of course, the ideal. Using a design model to design, procure and construct a number of identical plants is probably next best. An example of this is the SNUPPS project wherein a common design was developed (except for the site sensitive areas) for six plants.

In the following paragraphs of this section are additional analyses of design and construction experience and trends for applicability to current or future projects.

A. Percentage Design Completion Prior to Construction

The design of nuclear power plants should be scheduled as to permit about 50 percent completion of engineering prior to the release of engineering documentation for construction. The endless backfit, rework, rescheduling problems and cost overruns that plague all of todays plants result primarily from their fluid, unfrozen, technical scopes and designs. This provides the industry with an object lesson. It emphasizes the need for engineering to be in an advanced state and the design (and NRC approval) frozen in advance of the major construction effort. Future projects should be scheduled for a high degree of engineering completion prior to the construction. However, no amount of engineering completion will provide a smooth construction schedule unless regulatory requirements are stabilized.

B. Engineering Specifications Should be More Performance Oriented

Experience has shown that designing systems around quality standard products that are available in the market place, in lieu of non-standard, one-of-a-kind items with lower levels of confidence in their performance, reduces costs. There is an effort at this time to develop more performance-oriented procurement documents that are associated with standard manufactured product procurement. This will have a positive impact on costs and deliveries of plant equipment and systems.

C. Vendor Performance Feedback

All purchasers of safety-related items for nuclear power plants have some mechanism for evaluating suppliers and maintaining a qualified suppliers list. The programs are known by many names . They usually include a composite listing of supplier quality information extracted from surveys, quality program evaluations, quality surveillance activities, and audits. These data are normally fed into a computer system and made available to designated parties via system terminals and periodic printout distributions. Essential features include supplier identification and location; the commodity manufactured, fabricated or supplied; and the results of the surveys, audits, etc. A feature of one such program is that the supplier is given one of five evaluation designations, and all suppliers are listed, even those designated as unacceptable, rather than only listing approved suppliers.

A group of utilities and purchasing agents also coordinate supplier quality information through the "Coordinating Agency for Supplier Evaluation" (CASE), a computerized industry-wide system for sharing and distributing this information.

D. **Experience Feedback**

Organizations involved in designing and constructing nuclear power plants have a variety of methods to identify and report on problems detected in the design, equipment manufacture, and construction activities. There is a heavy volume of problem information generated and disseminated. These include 10 CFR 21 and 10 CFR 50.55e reports, Flyers, Bulletins, Problem Alerts, Procurement Supplier Quality Action Requests, etc. Some have developed computerized information dissemination systems using a common format and coding system. One such system has a coding subsystem that permits it to be used as a trending tool. Computer runs can be made, for example, to detect recurring problems with specific suppliers, commodities, or types of construction activities. The runs are then analyzed for generic problems, leading to investigation of root causes and action to prevent recurrence.

The Institute of Nuclear Power Operations (INPO) conducts information exchange programs that provide feedback vital for safety in nuclear power plants. Through INPO's Significant Event Evaluation and Information Network (SEE-IN), plant experience data is compiled, systematically analyzed, and communicated to the nuclear industry. The Nuclear Power Reliability Data System (NPRDS), also operated by INPO, provides feedback on the reliability and operating history of a broad range of equipment in nuclear power plants. INPO's Nuclear Notepad telecommunications system, often called the "jungle telegraph" of the nuclear industry is being extensively used for distributing Significant Event Reports (SERs). These systems are steadily growing in importance and usefulness to the nuclear power industry.

EPRI programs of previous years have evaluated operating plants with high availability to identify areas where design improvements may be made. Improvements to balance-of-plant support facilities are being reflected in the design of nuclear projects on-the-boards to the extent that utility resources permit. Example: On a current project, the maintenance and machine shops, warehousing, outage management offices, etc., have been added to the plant or greatly increased in size and included in the recently added structure contiguous to the plant. These improved support facilities represent the learning curve from an EPRI sponsored study on design, and the realities of outage maintenance and operating experiences of two earlier units.

It is now obvious that providing the needed support facilities on-site to accomplish the required maintenance work expeditiously, will contribute to reducing the outage duration and cost, as well as to improving plant availability.

The use of site master plans to effectively coordinate and prioritize the development of the many facilities now required, as well as to allocated the site spaces and the utility's resources over the operating life of the plant, is also another means to improve the design of both existing and future plants sites. The final plant arrangement must reflect the movement of men and materials from initial site preparation through construction, startup and the subsequent refueling process.

E. **Instrumentation and Control**

A control panel constructed a few years ago would have contained an indicator corresponding to each sensor in the plant. On occasion, the indicators would be grouped in mimic arrays corresponding to the functional location of the sensors. All manual controls would be by hard-wired switches. Automatic controls would be in hard-wired instrumentation systems with feedback from a limited number of sensors and possibly proportional, differential, and integral controls. Auctioneer functions would be used for trip circuits. The indicators would be supplemented by annunciators to bring the operator's attention to unusual conditions. A computer would be used, but limited to collecting, storing, and displaying alpha-numeric information. A cathode ray tube might be available, but it would be limited to displaying a limited amount of information including the results of some calculations.

In the past decade, computers have found increasing application in instrument and control systems. They first found application in instrumentation systems, such as radiation monitoring systems where control functions are absent. Most radiation monitoring systems being installed today are computer-based. The computer stores information, displays it on a cathode ray tube, alarms for abnormal situations, performs calculations, and prepares reports required by the NRC. As a result of new requirements stemming from the Three Mile Island (TMI) accident, the radiation monitoring system will also predict the direction and magnitude of radioactivity being emitted from the plant.

Control system designers realized early that computer-driven displays could improve the presentation of information to operators. The use of cathode ray tubes increased. Some of the more recent plants, now under construction, use several cathode ray tubes to present information. Computers are used to format the information, The operator is able to call up a selection of displays. The displays are usually schematic and designed to help the operator diagnose conditions in the plant.

Analysis of the TMI accident showed that control board improvements, including techniques as described above, would have aided in coping with this accident. Therefore, the industry has developed means for improving existing control boards and control boards for units under construction.

One of the improvements is an upgraded display of safety-related information, i.e., a cathode ray tube Safety Paramenter Display System (SPDS). This display, which has no control function, is computer driven and provides the operator with pertinent information and helps in diagnosis of an incident. The computer also drives an information display in a separate area, outside the control room, called the Technical Support Center. The Technical Support Center provides an area where personnel can receive information about the plant's status without being in the way of operators.

The Three Mile Island accident also made it obvious that the arrangement of instrumentation on many control panels needed improvement. A technique known as human factors engineering used extensively in the aero-space industry has been getting increased attention in the nuclear industry and is being used to improve the arrangement and presentation of information on the panel. A human factors engineering analyst is an expert on how human beings interact with their environment, such as a control room. His analysis may suggest changes in lighting, position of instruments, labelling, color of parts of the panel, or other factors to improve the operator's effectiveness and reduce the chance of making errors. All nuclear plant control panels are being evaluated and improved by human factors engineering analysis.

The designers of future nuclear control boards will probably continue to increase the use of computers. The development of microprocessors and the continued improvement of central computers has made this development attractive. The use of microprocessors in control circuits permits more complex control functions than are possible with currently applied equipment. Computers are being used instead of hard-wired control and interlocking circuits. Microprocessors in field located terminal units make possible a form of multiplexing wherein sensor data and operating commands in digital form are transmitted over a redundant data link called a "data highway."

This information is then available through the terminal units to any device that needs it, whether it is a computer, controller, indicator, or similar device. Use of data highways will greatly simplify the placement of instrument cable, conduit, and trays throughout the plant. The volume of such equipment is very great as a result of the complexity of a modern nuclear plant and cable separation requirements. Because of regulatory difficulties, safety-related equipment will continue to be hard-wired until microprocessor based equipment is approved by the NRC for this use.

Multiplexing can be used to considerably reduce the amount of wiring in a plant. Cost savings are expected due to reduction in building volume and bulk quantities. Past studies for large two unit standard plants have shown savings in excess of 5 million dollars. Schedule improvement due to reduction in bulk cable quantities can be expected.

A plant currently under design uses multiplexing for the cooling tower and circulation water systems; another uses it for the Safety Parameter Display System.

F. Probabilistic Risk Assessment

The probabilistic risk assessment will become a common tool to evaluate the risk to the public by nuclear power plants and to show that they comply with the safety goal established by the regulators. These assessments are very helpful in the determination of the need for and use of safety systems.

G. Integrated Approach

The Integrated Approach developed for the Department of Energy is an analytical tool that can be used to examine a nuclear power plant in a systematic manner to ensure economical, reliable, and safe nuclear power production. An extension of the defense-in-depth philosophy, its basic premise is that all nuclear power plant equipment and general industry activities of design, construction, operation, and maintenance can be associated with one of four goals:

(1) To maintain the capability to produce power,

(2) To maintain core and plant protection in the event that the first goal cannot be maintained,

(3) To maintain control of radioactive material release for those low probability events which result in failure of the first and second goals, and

(4) To maintain adequate emergency preparedness to protect the health and safety of the public for those extremely low probability events which result in failure of the first three goals.

Through the use of the Integrated Approach, improvements to the physical plants or to the organizations that support them can be identified in a systematic manner, thereby bringing about more effective plant operation. The Integrated Approach can be helpful in the assessment of economic risk. Identification of plant systems improvements where cost and risk reduction can be most effective will yield the balance needed to improve reliability, operability, and safety of plants without the addition of unnecessary equipment. Similarly, the examination of the role of humans during operation and maintenance activities, especially of the man/machine interface, will yield improvements in the area of plant reliability and availability.

The Integrated Approach is based to some degree on probablistic risk assessment findings. However, the principles and practices used in PRA are complex in usage and interpretation. The Integrated Approach is a useful tool in communication of PRA-based findings to decision makers, executives and legislators, as well as the general public. Thus, it should help those in authority to formulate rational decisions of complex problems.

H. Elimination of Pipe Whip Restraints

Recent licensing developments on operating reactors, indicate that it is possible to eliminate the requirements for Reactor Coolant System pipe whip restraints by demonstrating that the probability of guillotine pipe breaks is so low as to be considered incredible. In order to accomplish this, both a probabilistic and deterministic fracture mechanics analysis of the Reactor must be performed. These existing analytical techniques are under review by the Nuclear Regulatory Commission for some current applications. It is expected that 10 CFR 50.55 will be revised to allow the use of a deterministic analysis to eliminate consideration of guillotine pipe breaks for both operating plants and those under construction. The benefits of this program are both immediate and long term.

The elimination of the need to consider double-ended guillotine breaks of Reactor Coolant System piping eliminates the need for the costly design, fabrication and installation of massive pipe whip restraints and their embedments. This will reduce construction costs and time spans. In addition, this program will significantly reduce structural loads which previously had been governed by this design basis event. Therefore, the strength and size of many of the supports which will then need only be designed for normal and seismic events can be considerably reduced. The required load carrying capacity of the embedments will, as a result, be less. Because of the reduction in required load carrying capacity, shield wall structural design will be less complex. Furthermore, because blowdown to the reactor cavity from only relatively small breaks will now need to be considered, the design of the reactor vessel cavity and radiation streaming shield will be simplified. As a matter of fact, it appears that it may be possible to install the refueling canal seal permanently. Currently this seal must be installed between the reactor vessel flange and the refueling cavity walls prior to each refueling and be removed when refueling evolutions have been completed. The purpose of this seal is to prevent refueling water from draining into the reactor cavity during refueling. The reason it has to be removed after each refueling is to allow adequate area for venting the large quantities of steam which would flow into the reactor cavity during a postulated pipe rupture. Since the size of a credible rupture will be severely reduced by using these analytical techniques, it is likely that this vent area will no longer be required.

In addition, the elimination of the double-ended guillotine break of a main reactor coolant system pipe as a design consideration will either preclude the need for or drastically reduce the complexity of relatively expensive asymmetric load calculations which are currently required to be performed by the NSSS vendor and the architect engineer.

In the longer term, the elimination of pipe whip restraints will simplify required inservice inspections and normal maintenance and refueling evolutions by improving the accessibility to components and piping systems. Some of the currently existing pipe whip restraints need to be removed for inspections and reinstalled when the inspection has been completed. Elimination of restraints will improve availability and at the same time reduce occupational radiation exposure.

I. Cold Weather Protection

Innovative weather protection schemes, such as the air tent used on a recent power plant construction project during winter months in North Dakota, have been developed, which allow essentially unrestricted construction activity during severe winter weather conditions. Many of these schemes provide major breakthroughs in construction protection during weather conditions that impose heavy losses in productivity and efficiency. Although the plant was not as large as most nuclear projects, there is no reason why this scheme could not be used on any size project to some degree. When considering that up to six months of schedule and over 15 million dollars were the estimated savings to the project, it seems plausible that even larger savings could apply to larger, future projects.

J. Quality Assurance

There is a trend toward greater use of third party inspection of the processes, practices, and products related to nuclear power plant design, construction, procurement, manufacturing, and testing. This is to provide the regulators, the rate payers, the owners, and the general public with greater confidence in the quality and safety of new plants. The nuclear industry has initiated a construction project evaluation program managed by the Institute of Nuclear Power Operations. These independent evaluations assess individual utility construction programs based on the best experience and practices in the industry. The goal is to assist utilities in achieving a consistent level of excellence in building quality into nuclear plants.

V. LICENSING

The AIF report "Licensing, Design and Construction Problems: Priorities for Solution," published in January 1978 noted that review of projects designed and constructed under the then current licensing conditions shows that the licensing process adds approximately 3 years to the schedule during the capital intensive period after award to the reactor supplier. And, if pre-award extensions, due to early planning and site reviews are added to this, the licensing process adds approximately 4 to 5 year to a project. The report recommended that in order to shorten this time and improve the confidence in predicting the duration for engineering and construction that reasonable stabilization of the licensing process and requirements for design and construction must be established. Licensing reform, therefore, is the foundation on which other industry reform measures must be built.

Currently, proposed legislation before Congress focuses on establishing in the Atomic Energy Act a single-stage licensing process. Supporting this single stage process, procedures for and terms of design, site and related approvals and certifications have also been incorporated. The utility executives believe that they will be in a much better position to proceed again with conviction on new construction projects if a one-stage licensing process is put in place.

Despite the above mentioned problems, a recent project has achieved a measure of success in the licensing process. To insure that their licensing effort was supportive of the project's objectives, an overall plan was developed for this phase of the project. The plan called for preparation of what was designated as the Design Defense/FSAR Interface Document. To minimize "Ratcheting" that occurs during the licensing review cycle, with the unforeseen additions to the project scope, a three party (Utility, A-E, NSSS Vendor) group reviewed the plant design against the NRC Standard Review Plan to document the degree of compliance and identify possible areas of contention. The resultant Design Defense document thus served to organize and develop in a rational manner the Final Safety Analysis Report (FSAR) for the plant.

With the FSAR and Environmental Report docketed, the review process with the NRC consisted of a series of meetings between the Integrated Licensing Teams and the different branches of NRC where all questions were answered during the meeting and followed up with formal responses. This allowed the review process to proceed expeditiously without the tedious rounds of formal questions, answers and clarifications which have tended to stretch out the process. As a result of these efforts and team approach with the NRC, licensing was removed from the critical path of the project.

VI. ACHIEVEMENTS IN FOREIGN COUNTRIES

In most free world countries, nuclear power technology is based on American technology, either directly or indirectly. The most important exception to this rule is Canada, which uses their own type of reactor called CANDU. They have also exported a few reactors. Some nations, such as Germany and Sweden now use their own reactor designs derived from American technology and export them to other countries. Great Britain has, in the past, applied their own gas cooled reactor technology. Their latest reactor plant project is a planned pressurized water reactor using American technology. Future reactors will likely follow this precedent.

It is dangerous to generalize on such a broad topic as success in applying American nuclear technology throughout the world. It could be said that schedules are shorter and performance better in general. To make such statements more definite, experience in some of the more active countries is reviewed below.

A. France

France has the most vigorous and successful nuclear power program in the world. The NSSS systems are based on American design. The balance of plant is French, based on american practice with some advice from the United States. Safety practices use american regulations as a basis, but are modified and administrated by French practices.

Since the present French construction program began in 1970, 19 reactors have been placed in operation (as of December 1981). There are 26 more reactors under construction. Currently, construction time from reactor order to initial operation is five years.

Unique features of the French program are rigid control and standardization. Opportunities for opposition to the established program are extremely limited. For example, there is very little local input into siting decisions, although the rules are now being liberalized to an extent.

All 19 of the reactors mentioned above are identical. Because there is only one utility in France — Electricite de France — they are able to insist on a single design. Also, because France is to an extent a managed, rather than laissez-faire economy, standardization can be enforced down to a component level. All 19 reactors, for example, use the same turbine-generator set. Future reactors in France will be constructed to a single variation of the design for the first 19 units, or to a single design for a larger unit (1300 MWe versus 900 MWe).

It has been possible to construct French nuclear plants on a short schedule because of the factors mentioned above and because there was a growing need for electricity. Presently, the demand for electricity in France is growing at a slower rate. It may therefore be expected that schedules for some of the plants now under construction will be stretched, and other plants now planned may not be built.

B. Spain

Spain also developed a strong nuclear power plant construction program beginning in 1972. In Spain several regional utility companies exist, each privately owned. They chose to apply American technology, buying NSSSs from American firms. The balance of plant also used American technology. The designers of the balance of plant were predominantly Spanish firms with American participation. The balance of plant conceptual designs were performed in the United States, and the remainder of the design in Spain.

Initial experience was very good. Schedules were longer than in France because experience prior to this construction program was not available in Spain. As a result, the first unit in this series, Almaraz I, entered service in 1981 after a nine year design and construction period. The next three units in this series (Asco I, Almaraz II and Asco II) are proceeding successfully on a similar schedule. Two other units, Lemoniz I and II, have been delayed by terrorist activity.

More recently, Spain has experienced the same slackening of load growth that other countries have encountered. As a result, the schedules for later plants have been extended.

C. Taiwan

Taiwan has one of the most rapidly growing economies in the world. As a result, electrical load growth has been very rapid. A vigorous power plant construction program, initially based on oil and coal fired power plants, has provided the necessary electricity.

Starting in 1969, nuclear power plants have been ordered. Taiwan has chosen to apply American technology. NSSS systems have been purchased from American firms, and the balance of plant design performed by a joint American-Taiwanese firm.

The initial experience has been good. Three nuclear units are now in operation after schedules of eight or nine years. Three more units are now under construction, and negotiations are in progress for two more. It appears that these units will be built on similar schedules.

VII. CONCLUSION

The foregoing are representative of intensive ongoing efforts in both technical and managerial aspects of nuclear power plant construction projects to produce positive results. Although, in some instances, the benefits of these positive developments are difficult to quantify, the net effect has clearly resulted in benefits to the nuclear construction industry through improved performance. Further, many of these features can be and are being applied to conventional power, process, and industrial work with similar positive results.

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Appendix A

DESCRIPTION OF TYPICAL NUCLEAR POWER PLANT DESIGN AND CONSTRUCTION PROCESS FOR MID-1980'S COMPLETION

By Year: −2

By this time, the site has been selected, site layout prepared, conceptual design of the buildings developed, NSSS supplier selected, preliminary layout of major equipment within the building performed and the cooling cycle selected (cooling towers, spray ponds, etc.). Conceptual design of plant systems is complete and detailed design has started. Preparation of specifications has begun for equipment with early site need dates or long lead times. Preliminary design loads have been established for the Heating, Ventilation and Air Conditioning (HVAC) and cooling water systems and the major electrical distribution systems. Preparation of the Preliminary Safety Analysis Report (PSAR) is nearly complete.

By Year: −1

Civil design bases have been set and detailed structural design (rebar, steel and concrete) is proceeding. Detailed systems design is proceeding as well as preparation of specifications for piping, instrumentation, mechanical and electrical components. Control room design has begun and control panel sizes have been set. Estimated loads have been determined for the diesel generators and the preparation of the specification has started. Layout of piping has begun. The PSAR has been submitted.

By Year: 0 (Construction Permit)

Structural design has progressed to release of rebar and structural steel for fabrication and the issuance of site preparation drawings for construction. Mechanical, electrical and instrumentation design bases have been set by completion of detailed systems design and the placement of purchase orders (POs). Early vendor document submittals are being reviewed. Instrument arrangements in the main control board panels are becoming finalized and panel specifications are being prepared. The high energy line break evaluation has begun. Piping component purchase orders are being issued. Detailed layout of piping and equipment is proceeding and design of pipe supports has been initiated.

With receipt of the construction permit, site excavation and backfill are started.

By Year: +1

Detailed structural design of foundations, walls and floors is proceeding with drawings being issued for construction. The majority of instrumentation, mechanical and electrical equipment is committed by issue of the POs. Significant engineering effort is required to review vendor document submittals. Mechanical and electrical equipment are beginning to be delivered to the jobsite. With issue of the PO's, HVAC, cooling water and diesel generator capacities are set (with some spare capacity). The control room panel arrangement is set and PO issued. The final safety analysis has started. Piping design and layout are complete and the preliminary stress analyses have been performed.

Excavation and backfill are complete at the site. Rebar and structural steel are being delivered and installation started. Pouring of concrete foundations and exterior walls has begun.

By Year: +2

Essentially all POs have been issued. Large efforts are required by engineering to review vendor document submittals and to complete issuance of all design documents for construction. Large quantities of equipment are being delivered to the jobsite with delivery of the HVAC equipment complete. Design modifications resulting from the high energy line break evaluation have been incorporated.

Major structural details, foundation load capacities and seismic response spectra have been set. Placing of concrete for foundations and exterior walls is completed. Pouring of interior walls and floors has started. The containment structure has been poured which includes setting penetrations and establishing system interfaces through the containment. Installation of mechanical and electrical equipment has started with the installation of major equipment sequenced with the pouring of interior walls and floors. Large pipe, valve and hanger installation has started as well as installation of conduit and cable tray.

By Year: +3

Increased engineering support for construction is required to resolve field identified interferences, vendor documentation and hardware problems, problems with implementation of design improvements and to incorporate design improvements. Design modifications resulting from the safety analysis have been incorporated. Cable routing has begun.

Pouring of interior walls and floors along with installation of equipment, piping, cable trays, etc. have set separation, fire, radiation and security zones. Installation of small pipe and supports has started.

By Year: +4

Large effort is required by engineering to support construction activities in resolving problems and updating design documents to reflect as-built conditions. The turbine generator and Nuclear Steam Supply System (NSSS) primary loop components have been delivered and the reactor pressure vessel has been set. The control panels have been delivered and installation has started. Bulk installation of piping, hangers, conduit and cable tray continues. Cable pulling, cable terminations and instrument installation have begun.

By Year: +5

Engineering support of construction continues along with the beginning of startup procedure preparation. The diesel generators have been delivered. Remaining construction openings are starting to be closed. The turbine generator has been set. Construction is continuing with bulk installation of piping, hangers, cable, etc.

By Year: +6

Engineering preparations of startup procedures are complete — field support continues. Construction has changed from bulk installation to completion of systems. Installation of mechanical, electrical and control systems equipment is near completion which, in conjuction with piping and electrical installation, completes systems for startup testing. All construction openings have been closed and all major equipment is installed utilizing available building space.

By Year: +7

Lead systems have been completed by the construction group and turned over to the startup group. The startup group has begun check-out and system testing and has energized major switchgear. Final system acceptance tests are being run.

Engineering support is split between Construction and Startup as well as in updating design documents to reflect as-built conditions. Preparation of the FSAR has begun.

By Year: +8

Construction is nearing completion on all systems required for the operating license. Startup is continuing with system testing and turn-over of systems to the permanent plant operating staff. The cold, reactor coolant system hydrostatic test has been performed.

Final reconciliations of as-built piping, supports, structures, etc. with the design calculations are being performed. All design documents (drawings, calculations, equipment indices, etc.) are being updated to reflect as-built. A final safety analysis verification is being performed. Startup support by engineering continues. The Final Safety Analysis Report (FSAR) has been submitted to the NRC.

By Year: +8-1/2 (Operating License)

Construction and startup testing are complete on all systems required for fuel load and low power testing. All design documentation on these systems has been updated by engineering and ASME Section III systems have been code stamped. The permanent plant operating staff is preparing for fuel load and subsequent systems' testing.

Startup and engineering support continue on systems not required for fuel load.