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**FINAL REPORT
SUPPLEMENT**

**MODULAR DEVELOPMENT
MAT REINFORCING AND LINERS
CONTAINMENT/ANNULUS BUILDING**

**STONE & WEBSTER ENGINEERING CORPORATION
BOSTON, MASSACHUSETTS
J. Wainrib, Project Manager**

**Prepared for the
U.S. DEPARTMENT OF ENERGY**

**Under
Contract EY-76-C-02-4039
C. A. Thompson, Program Manager**

**Volume 1
June, 1978**

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VOLUME 1

This volume of the final report introduces and summarizes the data and results of the three major study areas which were examined for implementation of modularization techniques.

Volume 2 contains the analysis and results of the final report.

FOREWORD

The objective of this effort is to examine the potential for improvement in the utilization of field manpower and the construction schedule through the use of modular construction.

This report covers an extension of a previous study which was based on Stone & Webster's Pressurized Water Reactor Reference Design. The previous report is entitled "Plant Systems/Components Modularization Study" and was written under Contract No. EY-76-C-02-4039 for the U.S. Department of Energy (DOE).

The objectives of this previous study were to develop criteria against which to judge the viability of modularization concepts and to make a review of the Reference Nuclear Power Plant (RNPP) to determine which structures, systems, and components have potential for fabrication by either shop or site modularization. Recommendations were made to investigate the most promising areas for implementation of modularization by the industry.

Investigations were made into the development of a modular system of construction for the San Desert Nuclear Plant. The areas selected as the three most promising areas for modular construction were mat reinforcing, containment liners, and liners for the fuel pool, refueling cavity and the fuel transfer canal in the containment/annulus building nuclear island. The study was performed in conjunction with and jointly funded by the San Diego Gas and Electric Company using the San Desert Nuclear Power Plant located in Southern California.

The benefit derived from modularizing the mat reinforcing is indicated by a savings on the critical path of 10 weeks. The net cost savings associated with a 10 week early commercial operation date is estimated in excess of \$10 million which reflects reduced escalation and allowance for funds during construction (AFDC) as well as the added cost penalty due to modularization. A ten week schedule insurance can be obtained for a cost penalty of \$950,000 which is less than one days revenue derived from the working plant.

The schedule savings for the containment liner modularization and for the cavity liners are approximately 7 weeks each in the construction path for these items. The lower sections of the liner plates may lie along the critical path. If so, this can result in some added savings in construction time along the critical path. The benefits of the schedule savings are valuable as insurance against construction delays.

Modularization results in schedule flexibility to utilize manpower more effectively through peak reduction, reduction of overtime, more flexible allocation of construction equipment, and the ensuing improvement of labor efficiency.

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SECTION 1
CONTAINMENT/ANNULUS BUILDING
MAT REINFORCING

1.1 PURPOSE

The primary disadvantage of the current construction methods of installing reinforcing bars (rebar) in containment mats of nuclear power plants is the extended length of time required.

Current methods generally range from that of placing small bundles of rebar in the excavation and then spreading and tying, to that of modularizing or preassembling rebar on a very limited scale. Modularizing as referred to herein is taken to mean preassembling rebar into identical or very similar repetitive units or modules.

Because the containment mat occupies an important position on the plant critical path, the attractiveness of modularization is the opportunity to reduce construction schedule critical path time. A reduction in the time required to complete the mat will also result in increased efficiency in the construction of other critical path activities.

The purpose of this study is to confirm the technical capability based on past experience and to develop construction, engineering, and design innovations in order to modularize a containment mat.

This effort has been directed toward improving the utilization of field manpower and improving the construction schedule by using the above modular construction techniques. Modular concepts previously developed for the Stone & Webster Reference Nuclear Power Plant (RNPP) were utilized where applicable. These concepts are described in the "Plant Systems/Components Modularization Study" report completed under contract EY-76-C-02-4039 for the Department of Energy.

The purpose of this section is (1) to report on the investigation and development of a modular system for the construction of the base mat in Containment/Annulus Building nuclear island for the Sundesert Nuclear Plant, and (2) to report on the generic application of modular techniques to other Stone & Webster plants presently in the design phase.

1.2 SUMMARY

1.2.1 Conclusions and Recommendations

The feasibility of developing a modular system approach for the construction of containment mats has been established. The investigative results obtained from a plant used for the modular study has determined that (1) modularization results in a 10 week reduction in the construction schedule critical path over that for the conventional approach, and (2) modularization is cost effective and could result in a savings of approximately \$10,700,000.

Accordingly, it is recommended that the modular system approach be adopted as standard practice for the construction of containment mats.

This approach has been adopted by Stone & Webster and is presently being implemented on several projects, including: Forked River Plant for General Public Utilities, River Bend Project for Gulf States Utilities, Greene County Project for the Power Authority of the State of New York, and new generation plants for New York State Electric & Gas. Modular development on these projects has progressed to varying stages and to a point that modules have been identified, crane studies performed,

design of top mat support is in progress, and cadweld splice relocation to effect modularization is under study.

It is recommended that rebar modularization be studied and adopted for construction of other features including the primary shield wall and containment pressure boundary wall.

1.2.2 General

Modularization has been applied to various features of nuclear power plants in the past but not to as large an extent as taken in this study. This system consists of modules of a nominal 60 ton weight and a size approximately 60 by 60 feet. The size and configuration of the modules were determined following a review of (1) the technical ability to preassemble, transport, lift, set, and join the modules; (2) the engineering considerations as to the location of the splices; and (3) the industry fabrication practice and supply capability.

With modules defined, a study of assembly jigs to assure speed of fabrication and alignment control was made. The jig as finally developed allows for the simultaneous fabrication of from two to four modules. A single, expandable jig has been provided to accommodate the wide range in size of modules. In order to optimize design and serve as an interference check, the module

assembly jig with modules in place was physically modeled to a scale of 1 in = 1 ft-0 in and is shown in the photographs in Figure 1.2.1 through 1.2.3.

To lift and move the modules, a lifting frame and transporter, respectively, are required. Because of the wide range in size and weight of the modules, a lifting frame of a universal nature was developed. This system consists of a basic lifting unit plus two sets of outriggers. Alone, the basic unit can be used for the majority of the modules. With outriggers added, the remaining modules can be accommodated.

A study of commercial cranes indicates that only a crane with a special lift attachment such as a ringer or a guy derrick would have sufficient radius to install the modules. This reach requirement is based on the soil site actually studied. A rock site would present less stringent requirements. Because of the expense of a deadman and the cumbersome nature of the guy derrick, the ringer type crane is preferable. Following a location study of the cranes either in the excavation or on the edge of the excavation, the following options were considered in this study:

1. Manitowoc 4600 Series 4, ringer with an 880,000 lb auxiliary counterweight and 300 LF of No. 38 boom

located at the rim of excavation, two locations.
Purchase.

2. Manitowoc 4100W ringer, located in a travelway excavated around the perimeter of the mat. Purchase/rental.

3. Two 4100W ringers, one located the excavation at the base of an access ramp, the second on the rim of the excavation. Purchase/rental.

Option 1 is preferred and has been used as the bases for this report for mat and liner modularization.

1.2.3 Mat Construction

The complete modularization sequence for the construction of the mat was modeled and is documented and illustrated in the photographs in Figures 1.1.1 through 1.1.43. Note that the photographs show a rock site (vertical face) whereas Sundesert is a soil site.

1.2.4 Impact of Modularization

Modularization results in the following:

1. An increased work load is placed on engineering (1) to provide a large number of module drawings, although these same drawings may be used later as shop drawings once material lists and piece marks have been added; (2) to provide drawings for the appurtenances including assembly jig, top mat support, transporter, and lifting frame; and (3) to provide specifications and purchase orders earlier.
2. Increased construction planning to define the modules, perform crane study, and to develop the construction planning schedule and field guide.
3. Accelerated procurement of mat material and construction equipment is required.
4. Accelerated expenditure of craft labor is required.
5. Increased number of cadweld splices.

6. More site work area is required than for conventional construction.

1.2.5 Cost and Schedule Effectiveness

Modularization for this study results in a 10 week savings in the construction critical path.

The options available are:

1. The start of construction can be delayed 10 weeks and commercial operation attained as scheduled.
2. The start of construction can remain the same with 10 weeks of schedule contingency.
3. The start of construction can remain the same and commercial operation can be attained 10 weeks earlier.

The cost effectiveness of these various modularization options offers savings of \$0 to \$11.6 million in escalation and AFDC based on the total estimate and the option selected. These schedule related savings are offset by approximately \$950,000 in cost penalties due to the added modular appurtenances and the increased number of cadwelds as outlined in Section 1.2.4. The

net cost effectiveness for the various modularization options, therefore, will range from adding \$950,000 to the cost of the plant to a net cost savings of approximately \$10.7 million.

A cost benefit in increased worker productivity for performing modular construction under favorable conditions on a work slab with production equipment utilization can be predicted but has not been included in the cost analysis. As a realistic assessment however, a 12 percent increase in productivity by installing reinforcing will offset the \$950,000 cost of appurtenances.

The proposed Licensing Reform Act has as its goal the reduction of the licensing period for nuclear plants. When the goal is achieved, the critical path might depend upon delivery time of the reactor pressure vessel and the savings in escalation and AFDC could not be credited to mat modularization. Since many of the reactor vessels scheduled for the 1980's are on order, this effect would not take place for some time.

FIGURE 1.1.1 EXCAVATED SUNDESERT SOIL SITE
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FIGURE 1.1.17 ACTIVITY RM-011-012, FOURTH MODULE
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FIGURE 1.2.1 FINAL DESIGN, MODULE FABRICATION JIG

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FIGURE 1.2.4 FOUR BOTTOM MAT MODULES SET IN PLACE

FIGURE 1.2.5 DETAIL, TOP MAT SUPPORT FRAME MODULE

FIGURE 1.2.6 SECTION, TOP & BOTTOM MAT

FIGURE 1.2.7 COMPLETED MAT SECTION

SECTION 2

CONTAINMENT LINER

2.1 PURPOSE

Modularization in the form of jobsite prefabrication essentially localizes a maximum of specific work tasks in an area removed from the main stream of activity. Such an area is inherently more accessible and more easily managed when compared with conventional jobsite practices. This is recognized by the trend toward prefabricating containment liner dome modules for pressurized water reactor systems and liner wall modules for boiling water reactor systems.

Shop fabrications of containment liner, penetrations, embedments and other appurtenances similar in every respect to those generated for conventional jobsite fabrication and installation are shipped to the jobsite and stored in the usual manner. As scheduled, parts are delivered to the prefabrication area where liner plate is fabricated in multiple course rings to form a module. Penetrations, embedments, appurtenances and wind girders to round out the liner are welded to the liner where specified. Cables are attached to fittings in line with the uppermost wind

girder, the module lifted and set in place. Index fittings provide proper location in azimuth and alignment fittings ensure plate-to-plate continuity between modules. The common girth seam is butt welded to complete the installation.

The purpose of the present investigation is to evaluate potential savings in both cost and schedule by modularizing the containment liner for a single unit plant. For a plant with two units, as is planned for the Sundesert Nuclear Project, respective savings would be expected to be duplicated but more than likely would be improved upon in the second unit application.

2.2 SUMMARY

2.2.1 Conclusions and Recommendations

The result of this study including both direct savings of \$950,000 and nonquantifiable productivity benefits from improved ground-level working conditions indicates that the modularization method of prefabricating and installing primary containment liner should be adopted for Sundesert and future plants.

2.2.2 Design Criteria

The major lift crane technical analysis for the Sundesert project justified purchase of a single high capacity crane. For

modularization, the crane hook capacity is limited to 180 tons, as derined by a Manitowoc 4600 Series 4, with Series 3 Ringer and 880,000 lb auxiliary counterweight. The operating radius is 165 ft using 300 ft of No. 38 boom, and the toe of the crane being located at the wall of the foundation excavation. The annulus building structure in the way of boom swing cannot be completed until after the dome is set. This stationary crane provides service between a single prefabrication area and the primary containment.

2.2.3 Description of Modules

Wall modules consist primarily of two courses of 3/8-inch plate, 10 feet wide (meridional) and 30 or more feet long (circumferential) formed to a 137 ft-0 in inside diameter. Three regions containing service pipe penetrations, electrical penetrations and polar crane embedments were instrumental in compartmentizing the modules. Maximum weight at the hook is 148 tons.

Each of three dome modules consists of a mix of 1/2-inch and 1-inch plate formed into rings. The spherical outer radius is a constant 68 ft-6 1/2 in. The containment spray feed pipe, headers and pipe anchors are preassembled and lifted with the liner. Each module is within the maximum hook limit of 180 tons.

2.2.4 Cost and Schedule Effectiveness

For the Stone & Webster design with an independent polar crane support system, the containment wall is not on the critical path.

Improved utilization of manpower does result in a savings of 16,000 man-hours reflecting an activity savings of 7 weeks. This represents a cost savings of \$950,000. Dollars are based on present day costs plus escalation and allowance for funds during construction, referenced to commercial operation 17 October 1984. The three-lift dome is not reflected in these figures since this is conventional practice already factored into the SDG&E Sundesert program.

2.2.5 Historical Comparisons

Historically containment exterior wall erection is a congested work area. Removal of the liner work to a work slab will result in unquantifiable productivity increases to the rebar form and concrete work in addition to the liner work. As indicated previously, dome modularization is now conventional practice in one form or another. Wall modularization for pressurized water reactor systems is new. Besides the subject Sundesert plant, Stone & Webster working with containment liner fabricators is

proposing modularization on its pre-licensed standard plants. Containment liners for boiling water reactors are currently modularized. A Contractor working with Stone & Webster has already built the drywell liner for Long Island Lighting Company's Shoreham plant. This truncated conical shell in two modules is of 3/8-inch plate with a base diameter of 79 ft-0 in, upper of 35 ft-7 in and height of 85 ft-0 in. Cone semi-apex angle is a constant 14 deg - 20 min. A different Contractor, also working with Stone & Webster, is currently erecting Niagara Mohawk Power Company's Nine Mile Point-Unit 2 drywell liner, also in two modules. Plate is 3/8-inch thick, base diameter is 91 ft-0 in, upper diameter is 38 ft-0 in and height is 84 ft-0 in. Cone semi-apex angle at the base is 10 deg - 54 min and at the upper boundary, 33 deg - 23 min.

Non-Stone & Webster designed plants have utilized liner modularization effectively. Susquehanna Station and Grand Gulf Station are examples of BWR dry well liner prefabrication.

2.2.6 Photo Coverage, Models

Sequential builds and lifts of containment liner wall and dome modules were modeled and are shown in the series of photographs Figures 2.1. These are selected, limited scenes for an overview of activities. Full coverage is given in Volume II.

FIGURE 2.1.1 OVERVIEW OF PLANT, CUTAWAY SECTION
OF CONTAINMENT LINER WALL

FIGURE 2.1.2 PREFABRICATION, TYPICAL CONTAINMENT LINER WALL MODULE

FIGURE 2.1.3 COMPLETED MODULE

FIGURE 2.1.4 MODULE RIGGED FOR LIFT

FIGURE 2.1.5 INSERTION OF MODULE

FIGURE 2.1.6 INSTALLED MODULE

FIGURE 2.1.7 COMPLETED INSTALLATION, CONTAINMENT LINER WALL

FIGURE 2.1.8 SIMULTANEOUS PREFABRICATION, THREE-LIFT CONTAINMENT LINER DOME MODULES

FIGURE 2.1.9 INSERTION OF FIRST DOME MODULE

FIGURE 2.1.10 FIRST DOME MODULE INSTALLED

FIGURE 2.1.11 SECOND DOME MODULE RIGGED FOR LIFT

FIGURE 2.1.12 SECOND DOME MODULE INSTALLED

FIGURE 2.1.13 THIRD MODULE RIGGED FOR LIFT

FIGURE 2.1.14 TWO DOME MODULES INSTALLED,
INSERTION OF THIRD MODULE

FIGURE 2.1.15 COMPLETED INSTALLATION,
CONTAINMENT LINER DOME

SECTION 3

FUEL-RELATED CAVITY LINERS

3.1 PURPOSE

Shop fabricated floor and wall panels for five cavity liners were sized to meet shipping requirements. As scheduled, parts for a specific liner are delivered to a preassembly area. Floor panel sections are welded and wall panels are sequentially set and bolted together and to the floor. The seams are automatically welded, a lifting frame attached, the lift made, and the unit set on a prepared reinforced concrete floor. After a minimal amount of final installation tasks such as welding in connecting panels between modules, the floor is grouted, wall concrete is placed and seam welds are nondestructively examined to complete the installation. The discussion in the opening paragraph of 2.1.1 for containment liner applies equally well to cavity liners.

The purpose of the subject study is to evaluate potential savings in both cost and schedule by modularizing fuel-related cavity liners. A manloaded planning study for Sundesert in reference to conventional in-place construction serves as the basis for containment building and fuel building comparisons.

3.2 SUMMARY

3.2.1 Conclusions and Recommendations

A direct savings of \$355,000 coupled with considerations of intangibles, indicates that modularization of fuel-related cavity liners should be adopted on future projects.

3.2.2 Design Criteria

- a) Shipping mode is special rail for which height=13 ft over the rails, width=12 ft, length=60 ft, and weight=300 tons.
- b) A single prefabrication area is to be provided.
- c) Clearance between wall reinforcing bars and wall liners is 3 inches.
- d) Stiffen wall panels for concrete placement in 5-ft lifts.
- e) Wall panels on sides and bottom to be framed for bolted joint fitup in the shop for checkout and at the jobsite for seam welding.

- f) All pressure boundary welds in fuel building liners are to be backed with pressure-tight leak chase to provide test capability during plant operation and to prevent contaminating areas surrounding these pools which are continuously flooded.

3.2.3 Description of Modules

All panels are 1/4-inch stainless steel. Each floor is stiffened and framed with 3-inch deep carbon steel shapes. The perimeter is additionally framed with a carbon steel angle which serves as a weld-backing strip for the wall seam and coincidentally as part of the wall bolted fitup arrangement. Floor cutouts subsequently match with anchored embedments precast in a prepared concrete deck as footings for internal structures.

Wall panels are stiffened with 3-inch deep carbon steel shapes vertically on 18-inch centers and with 3-inch deep carbon steel angles horizontally on 48-inch centers. Bolted fitup frame members are angles. In the fuel building, frame members as leak chase are stainless steel. Thickened plate embedments are welded to panels in the shop.

Rigging for the lift is accomplished by stiffening the floor with three standard open web joists and framing any open wall with braced standard joists. Cables from the crane hook connect to wall vertical stiffeners with a spreader in the form of a braced

frame of standard joists. Each cavity liner may be built in place rather than preassembled as an option, ease of assembly being provided by the bolted fitup joint concept.

3.2.4 Cost and Schedule Effectiveness

Improved utilization of manpower results in a savings of 17,000 man-hours reflecting a activity savings of 7 weeks. This represents a cost savings of \$355,000. This activity is not on the critical path however and the overall schedule is not shortened. Dollars are based on present day costs plus escalation and allowance for funds during construction, referenced to commercial operation October 1984. In addition, reduction of congestion and increased crane availability will lead to productivity increases which are not quantified.

3.2.5 Historical Comparisons

Architect/Engineers are tending towards modularizing fuel-related cavity liners. Examples consist of liners for Palo Verde (Arizona Public Service) and San Onofre (SDG&E/Southern Cal. Edison). A supplier of liners, in published literature, shows expertise in the fabrication of modules to stringent tolerances, in rigging arrangements for lifting modules, and in the barging of modules. Stone & Webster, working with cavity liner fabricators and Federal Agencies, is proposing modularization on its prelicensed standard plants.

3.2.6 Models, Photographic Coverage

Figures 3.1.1 through 3.1.4 show models of design details of modularized reactor cavity and reactor intervals cavity liners. These modules comprise the refueling cavity liner, and the design concept of the wall bolted fitup joint. Wall horizontal stiffeners are not shown.

FIGURE 3.1.1 PARTIAL BUILD, REACTOR CAVITY LINER MODULE

FIGURE 3.1.2 COMPLETE MODULE, REACTOR INTERNALS CAVITY LINER

FIGURE 3.1.3 INSTALLATION, REFUELING CAVITY LINER

FIGURE 3.1.4 WALL BOLTED FITUP JOINT CONCEPT