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Advanced Light Water Reactors

Volume IV: Enhancing Constructability Through Design

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Preface

Legal Notice

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Introduction

Focusing the program

From the early phases of this program, an objective was to influence two key areas:

- Inputs to plant design that can enhance constructability
- Improvements in the construction process

The investigations, workshops, meetings, and studies focused the program topics toward these areas. From that focus, Volume III has become *Improving Construction Performance*. Volume IV is *Enhancing Constructability Through Design*.

Developing this volume

Most of this volume's development (particularly Sections 1 and 2) comes from the Designing for Constructability efforts. The Industry Review and Construction Technology efforts also contributed to each section, primarily Chapter 3.

Issues

The report is arranged to produce sections on major issues in each subject. At the end of each section are significant conclusions divided as:

- Recommendations—Conclusions worthy of acceptance.
- Considerations—Conclusions that were not universally accepted in the discussions but should be taken into account.
- Cautions—Conclusions that should be evaluated to avoid past problems.

Definition of Terms

Term	Definition
A/E	Architect/Engineer.
ALWR	Advanced light water reactors.
AP-600	Advanced passive 600-MWe PWR plant design concept being developed by Westinghouse/Burns and Roe/Avondale team.
Bechtel arrangements (initial)	Basis of discussions in the second Designing for Constructability workshop. February 1988 version of the study on PWR general arrangements performed by Bechtel Group, Inc. as part of the development of EPRI's Chapter 6. (Excerpts from this study are in Appendix A.)
Bechtel arrangements (current)	Version of the Bechtel study on general arrangements which is contained in Revision 0 of EPRI's Chapter 6, issued November 1988.
Containment Constructability Study	Comparative Constructability Evaluation of Advanced PWR Containments study performed by Bechtel North American Power Corporation under the Design for Constructability Program.
BWR	Boiling water reactor.
DOE	United States Department of Energy.
DPCo	Duke Power Company.
EH	Equipment hatch.
EPRI	Electric Power Research Institute, Inc.
EPRI Document	Thirteen-chapter <i>ALWR Requirements Document</i> being developed in EPRI's ALWR program.
EPRI's Chapter 6	Chapter 6 of EPRI Document, titled <i>Building Design and Arrangements</i> .
HP	Health physics.
HVAC	Heating, ventilation, and air conditioning.
NPSH	Net positive suction head.
NSSS	Nuclear steam supply system.
Offset	Reactor Pressure Vessel and Reactor Coolant System loop offset dimension from containment centerline on a PWR.
O/M	Operation/Maintenance
PAL	Personnel airlock.
Program	Design for Constructability Program. DPCo's DOE Contract Number DE-AC03-86SF16566.
QA	Quality Assurance.

Definition of Terms

- SBWR** 600-MWe boiling water reactor concept being developed by General Electric Company, Bechtel, and the Massachusetts Institute of Technology.
- SG** Steam generator.
- SWEC** Stone & Webster Engineering Corporation.

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Introduction

Cooperative studies in plant arrangements

As discovered in the first and second Designing for Constructability workshops, several studies in plant arrangement had to support each other to be successful. These studies include:

- A Bechtel study evaluating the constructability of various PWR containment types.
- SWEC's DOE Construction Program, which includes some of the same topics from the Designing for Constructability workshops.
- EPRI's Chapter 6 of the Requirements Document, created using industry inputs and the Bechtel's development of conceptual PWR plant arrangements.

Because support of these studies was important, workshop discussions specifically addressed PWR arrangements. However, many discussion concepts would also apply to BWR and other future reactors.

Bechtel arrangements

The first workshop identified generic construction items that can be improved in plant arrangements. Initial Bechtel arrangements were used as the basis for the second workshop's discussions to develop details of plant arrangements. The resulting discussions influenced, and often changed, the PWR arrangements, as reflected in current Bechtel arrangements. Reviews of the initial Bechtel arrangements resulted in reduced detail in the current Bechtel arrangements, which, with EPRI's Chapter 6 text, explain how drawings and details should be used.

Operations and Maintenance (O&M) Inputs

Importance of O&M inputs

O&M and construction groups must provide input up front to identify problem areas and potential work spaces in the plant layout. Areas requiring O&M personnel's experience and expertise include deciding:

- The number of equipment hatches (EHs) or personnel air locks
- Offset issues
- Containment type
- Containment diameter
- Security fence

How O&M topics are interrelated

Working meetings (as described in Volume II) helped obtain input on O&M areas and revealed that the topics are too interrelated to be discussed separately. For example, talks on equipment hatches included:

- Relationships to plant embedment.
- The usefulness of operating floor equipment hatches vs. hatches below the operating floor.
- Two large equipment hatches (EHs) **or** a large and small EH **or** an EH and personnel air lock.
- Steam generator removal options.

The discussions' conclusion

Throughout design development for any ALWR project, experienced O&M personnel must provide primary input combined with input from design and construction.

Layout/Accessibility

Introduction

Plant layout—both for the site and inside buildings—has greatly influenced nuclear plant construction, operation, and maintenance. A lack of detailed planning creates congestion problems in areas such as pressurizer cavities. Planning and improved use of space have been more successful than simply increasing space to provide adequate accessibility.

Layout

A concentrated effort should be made to optimize column spacing and floor elevations. This effort must begin in the early design stages. Other considerations include:

- The resulting trade-off of construction consistency for larger rooms.
- Physical limitations on equipment movement, based on final:
 - Equipment size
 - Configuration
 - Location design information

Reemphasizing standard practices

Most workshop information reemphasizes standard practices. For example:

- Straight, flat, and square structural items (e.g., walls, floors, and beams) are more constructable.
- Reserved aisles and shafts are needed to provide access.
- Layout must consider mechanical requirements, such as pump NPSH.

Construction fabrication work areas

Experiences at Braidwood Nuclear Plant show the value of designing a floor plan with areas that are exclusively for construction fabrication work. These areas eliminate the need to continuously move craft gang boxes and other fabrication equipment. Maintenance crews can also use the areas during outages and for normal operating maintenance.

On-site concrete batch plants

At River Bend Nuclear Station, a concrete batch plant was located on-site near the structures. From the plant, pumps piped concrete throughout the structures.

International planning

International construction companies have devoted much attention in the design phase to plant layout/accessibility. Experiences indicate that an independent review to address layout/accessibility helps minimize future problems. For example:

Planning and using temporary walkways and ramps provides access inside plants. Using steel grating and scaffolding planks rather than wooden versions also increases the walkways' benefit; damage is reduced for permanent items that could be walked on, such as cable raceways.

Ontario Hydro's efforts

Early in design, Ontario Hydro made clear-cut decisions in their plants' layouts and accessibility, such as:

- Sizing the reactor building based primarily on the building's equipment and access.
- Determining how to remove and replace major equipment (e.g., steam generators).

Planning at Tsuruga II

Construction access at Tsuruga II was incorporated in the building design because the relatively small site did not allow for any significant laydown space outside the main buildings. To help circumvent this problem, elevated roadways were strategically located throughout the construction area. The roadway supports are incorporated into permanent facilities. (Standardized designs allowed flexibility in application.)

Including the control room and Fuel Building on the common basemat

The control room's and Fuel Building's (FB) impact on the common basemat must be considered. The control room must be located:

- Low enough in the building to be available for early testing.
- Between the containment and turbine Buildings.

Locating the FB on the common basemat creates additional building space below the FB. When arranging these buildings, designers must therefore consider commodities and the impact on schedule and adjacent building areas.

Fuel Building

The FB should be located on the opposite side of the containment from the Turbine Building. Potential penalties for including the Fuel Building on the basemat include:

- Quantities
- Fuel Building schedule
- Cost

Including the FB on the common basemat also benefits nuclear island design.

Control Building

The control room structure must be available early enough in construction to eliminate it from the critical path, particularly with regard to testing. Including the control room on the common basemat also benefits nuclear island design. To avoid critical path, arrangements should allow availability of HVAC in the control room. Guidelines for location include:

-
- To accommodate parallel electrical activities, the control room should be located as low as possible, but not below grade (for precautions against flooding).
 - Control room location is important because of significant piping and cable interfaces.
 - The control room should be located on the common basemat between the Reactor and Turbine Buildings and as close as possible to the main switchgear.
 - Compatibility with main steam and feedwater routings should be considered.

Diesel Generator Building

Near-term regulatory decisions on 3 diesels or alternatives (e.g., gas turbines) could significantly influence Diesel Generator Buildings. Having individual buildings for each diesel system is unappealing for construction. Diesel Generator Buildings should be located at grade and as close as possible to essential switchgear.

Recommendations

- Locate the control room between the Reactor, Auxiliary, and Turbine Buildings.
- Locate the control room low enough in the building so that:
 - Electrical construction can begin earlier.
 - The control room can be available for testing needs.
- Remember that configurations with tangential (rather than inline) turbine orientations relative to the Containment Building may offer some benefits for multiple-unit sites. These benefits include:
 - Sharing facilities and systems.
 - Reducing piping from inline configurations.
- Establish adequate, meaningful, and measurable points exist in buildings.
- Make certain that areas on site and in buildings are accessible for equipment, materials, tools, and personnel.
- Segregate non-safety areas from safety areas. The areas should be physically separated and worked on by different work groups.
- Do not handle conventional work in the same manner as nuclear work.
- Develop detailed plans and drawings for potential equipment replacement.
- Route pipe and cable away from access areas.
- Have fewer, larger structures to minimize the total number of buildings.
- Investigate the feasibility of making temporary utilities and facilities permanent parts of the plant. After construction, maintenance crews could use these areas during outages and for normal maintenance.
- Design permanent elevators primarily for freight rather than personnel. Elevators should be sized to accommodate the largest equipment component in the service area.

- Carefully lay out material handling equipment (e.g., cranes and monorails) to ensure components are moved efficiently during construction and operation.
- Give special consideration to using modular construction.
- Thoroughly plan the layout of temporary roads and consider paving these roads.
- Install permanent roads as early as practical for use during construction.
- For multiple units:
 - Make certain the layout ensures that construction on one unit will not hamper efforts in another unit.
 - When possible, share equipment between units to reduce costs.

Considerations

Consideration	Comments
Plant layout requires a great deal of planning.	<ul style="list-style-type: none"> • For example, after construction, interior and exterior accessibility must be designed for: <ul style="list-style-type: none"> ◦ Inspection ◦ Testing ◦ Operation ◦ Maintenance
The layout design must consider all phases of the plant's life.	<ul style="list-style-type: none"> • Benefits achieved after construction include reduced radiation exposure and simplified operations. • To plan adequately for all phases of a plant's life, an independent review team, experienced in all phases, should critique the plant design. • To be the most beneficial, this critique should occur before construction begins.
Layout of support facilities around highly active areas can either expedite or impede construction and/or operation.	<ul style="list-style-type: none"> • Careful planning ensures that neither construction nor operation is impeded.
Standardized relative elevations between plant floors and between plant structures can expedite construction and make operation easier.	<ul style="list-style-type: none"> • Story height should permit adequate access.
Current licensing criteria concerning turbine missles encourages using configurations with in-line (rather than tangential) turbine orientations relative to the building.	<ul style="list-style-type: none"> • The tangential configuration may have some special benefits for multi-unit sites, including: <ul style="list-style-type: none"> ◦ Possible sharing of facilities and systems ◦ Reduction of piping compared with in-line configurations • If benefits from tangential configurations are sizable, research to justify exception to the licensing criteria may be justified.

Consideration	Comments
Plant layout to incorporate radiation and missile protection will result in some configurations using labyrinth doors and vents.	<ul style="list-style-type: none"> • Because labyrinth doors and vents make access difficult during construction, they could significantly increase construction time. • Alternatives to satisfying design criteria may improve access.
Containment type affects many areas of plant design, construction, and operation and greatly influences overall plant constructability.	<ul style="list-style-type: none"> • A selected configuration can: <ul style="list-style-type: none"> ◦ Control the construction schedule. ◦ Affect accessibility for construction, maintenance, and testing for the entire life of a plant.
Advances in instrumentation and control will probably allow multiplexed control circuitry and advanced fiber optics, at least in areas without harsh design environments.	<ul style="list-style-type: none"> • Implementing such technology will definitely impact the overall plant layout to satisfy criteria for areas such as: <ul style="list-style-type: none"> ◦ Fire protection ◦ Security ◦ Postulated piping ruptures • Impacts on the above areas will show up in improved layout.
Piping configuration will be affected by incorporating advanced design techniques (e.g., increased seismic damping properties and leak-before-break).	<ul style="list-style-type: none"> • The quantities of piping supports and snubbers should be significantly reduced. • The advanced design techniques create a need to concentrate on implementation procedures that take advantage of the new configurations. • Increasing in importance will be: <ul style="list-style-type: none"> ◦ Fabrication techniques (e.g., selecting installation pools, prefabricating) ◦ Welding issues ◦ Procedures that affect design and installation of supports
Selecting simple plant configurations has implications that extend far beyond actual construction of the structural component itself.	<ul style="list-style-type: none"> • Though some structures may not permit rectangular configurations, selecting circular arrangements greatly complicates construction. • Establishing equipment and support locations by linear measurements off known reference points will eliminate the need for surveyors in every operation.

Plant Embedment

Decisions on plant embedment

Several considerations must be included in deciding plant embedment. For example, groundwater elevations and the depth of competent soil or rock are site-specific considerations. Other considerations include:

- Ensuring accessibility.
- Providing temporary construction services in the plant.
- Planning for impacts of adverse weather.

Accessibility

Accessibility has potential impact on the construction schedule. Personnel, materials/equipment, and equipment for handling material (e.g., cranes) must all have access to various building entrances. Equipment hatch/construction openings must also be considered. It is advantageous to place the hatch and opening at grade or as close as possible to grade. However, the NSSS vendor design and layout dictates the benefits of the opening's location for interior access below the operating floor. The costs of accesses with openings above grade (e.g., ramps) should be studied.

Developing optimum embedment

To develop the best embedment, consider all design aspects, such as:

- Accessibility.
- Other items affecting schedule (e.g., common basemat).
- Design issues (e.g., flood control and provisions of NPSH for pump arrangement).
- Integrated results of these cost and schedule effects (e.g., minimizing quantities).

From this optimum embedment, design arrangements can be flexible enough to accommodate embedment adjustments based on site conditions.

Recommendations

- Remember that minimum plant embedment has definite advantages to plant constructability, but embedment must be integrated with other arrangement decisions (e.g., locating the equipment hatch).
- While considering the base case, develop standard plant arrangements to incorporate flexibility in the embedment depth from at-grade basemat to embedment with the equipment hatch at grade.

Considerations

- Decisions on each critical path construction schedule should include the integral relationship between:
 - Plant embedment
 - Common basemat
 - Operating floor
 - Vertical hatch
 - Equipment hatch
 - Fuel pool
 - Cranes
 - Ground fuel transportation
- The type high-pressure safety injection pumps selected should be considered in decisions on plant embedment and common mat.
- Groundwater elevations and depth of competent soil or rock must be studied.

Nuclear Island Layout

Bechtel arrangements

The nuclear island layout on initial Bechtel arrangements was discussed during workshops and working meetings. In the arrangements, the control room was shown to the side of the Reactor and Auxiliary Buildings. As stated earlier, the optimum layout has the control room between the Reactor, Auxiliary, and Turbine Buildings. Current Bechtel arrangements, along with EPRI's Chapter 6, were adjusted to include a common basemat and a symmetrical layout. (See below.)

Benefits of the optimum nuclear island layout

This optimum layout allows symmetry and accommodates symmetrical electrical and mechanical system train separation along the same axis. Other benefits of this arrangement include:

- Early crane accessibility
- Simplified pipe and cable routings
- Control room availability early in the construction schedule, critical for system testing and checkout

A layout with the control room between the Reactor, Auxiliary, and Turbine Buildings requires relocation of diesel generators, possibly to locations outboard on each side of the control complex. Compatibility with main steam and feedwater line routings must also be considered.

Placing Class 1 structures on the common basemat

Class 1 structures (e.g., Reactor, Auxiliary, Control, and Fuel Buildings for PWR) benefit construction and design when placed on the common basemat. The symmetrical layout described above supports using a common basemat, though space must be allocated carefully. For example:

When used, a common basemat creates space below the fuel pool because of the fuel pool's required relationship to the Reactor Building's operating deck. Designers must therefore consider this extra space—and the possibility of pool leakage—if including the fuel pool on the common basemat.

Benefits of placing Class 1 structures on the common basemat include:

- Elimination of concerns about differential settlement
- Shared building walls
- Simultaneous construction of adjacent structures

Integrated layouts

The arrangements described above illustrate an integrated approach to many layout decisions, particularly with such an optimistic schedule. Critical path scheduling must consider the relationships between:

- Plant embedment

-
- Common basemat
 - Operating floor
 - Vertical hatch
 - Equipment hatch
 - Fuel pool
 - Crane
 - Ground fuel transportation

For example, a common mat that includes the control room and deeper plant embedment may cause the parallel schedule path through the Control Building to become critical.

High-pressure safety injection pumps

The one-level plant embedment shown on initial Bechtel arrangements appears to be a good compromise for design, construction, and operation/maintenance. However, high-pressure safety injection pumps affect plant embedment and the possibility of a common basemat. Vertical pumps would have supported a one-level, common basemat arrangement; however, because of inexperience with vertical pumps and other considerations, the current Bechtel arrangements include 2 levels of embedment that could accommodate the horizontal pumps. O&M personnel indicate that this deeper embedment may have other O&M benefits over the plant's life.

Common Basemat Considerations

Introduction

The common basemat theory deserves further, more detailed investigation. Opinions vary on the overall benefit of integrating a common basemat with other influences, such as:

- Equipment hatch locations
- Plant embedment
- Aspects of design

General conclusions

- Arranging buildings at the same elevation benefits construction and design, whether the buildings are on common or separate basemats.
- A design with a common basemat has a single, more complex design model. A design with separate basemats has more, but simpler, design models.

Design simplifications

Simplification of designs has been challenged in discussions and studies since the workshops. Simplification appears certain when only the basemat is considered. Tying the walls together at higher elevations and modeling the interfaces, however, would be more complex. The realistic advantages for designing these structures should be investigated. Also included in this investigation should be the impact that any real structure simplifications might have on other plant items, considering seismic simplifications. If a common basemat does simplify design, design and construction cost savings could occur. For example, a common basemat would:

- Eliminate differential settlement concerns.
- Help with differential seismic motion.
- Allow a wider range of soil properties.
- Support standardization.
- Be compatible with integrated structure design.
- Eliminate shake space.
- Simplify seismic design for structures and other plant items.

Bechtel's concerns

Bechtel expressed concern on common basemat's quantity benefits because of experience with Japanese plants. The "wrap-around" arrangement created by a common basemat causes equipment arrangements that require more and longer runs of items such as pipe and cable. These runs must be evaluated against overall impacts on commodities and quantities. Studying foreign experiences with standardized foundations would also be helpful.

Reducing building size and commodity quantities

Building size and commodity quantities must be reduced during general arrangement design to effectively locate buildings on a common basemat. This reduction can occur by efficiently placing equipment and materials (e.g., relocating items to lower elevations whenever possible). The Fuel and Control Buildings are particularly affected by reducing building size and commodity quantities.

Further study on common basemats

To support the first Design for Constructability workshop, Duke Power authorized Bechtel and Sargent & Lundy to review experiences in decisions on plant embedment and common basemats. The results of these studies were used in later workshop discussions. (See Volume II.)

Recommendations

- Investigate the use of a common basemat, with advantages that include:
 - Many construction and design benefits to common elevations of buildings, whether on common or separate basemats.
 - Savings in design and construction costs.
 - Elimination of different settlement concerns and assistance with differential seismic motion.
 - Wider range of soil properties.
 - Elimination of shake space.
- Locate Class 1 structures, including the Fuel Building, on the common basemat.
- Carefully analyze the locations of buildings on the common basemat, especially the Fuel, Control, and Diesel Generator Buildings.

Considerations

- The fuel pool's required relationship to the Reactor Building's operating deck creates space below the pool when included on the common basemat. Use of this space and pool leakage are key considerations for including the fuel pool on the common mat.
- An integrated approach should be considered for decisions relating to:
 - Common basemat
 - Buildings and their arrangement on a common basemat
 - Plant embedment
 - Containment type and arrangement of containment items
- Design model number and complexity varies between common basemat and separate basemat.

Cautions

- The idea of a common basemat may require more and longer runs of items such as piping and cable to accommodate the resulting equipment arrangements.

Containment

Solving previous containment problems

Some attempts must be made to alleviate containment difficulties, which have included:

- Bellowed penetrations, complicating design, construction, and testing.
- Field post-weld heat treatment (PWHT), which created scheduling problems.
- In-containment space, which created access problems for construction and O&M personnel. (Associated problems are due partly to lack of space or inefficient use of space during arrangement design.)

Containment considerations

- For high-pressure containment, bottom-head and flat-based configurations must be evaluated.
- How the containment integrates with adjacent structures—tied or independent—impacts the construction sequence.
- Progress in rebar placement can affect scheduling.
- Diagonal reinforcing bars and large layered bars should be eliminated as much as possible.
- Various schemes for polar crane support (e.g., off of liner, crane wall) must be studied.

Containment's effect on plant arrangement

Investigation for the first Industry Review workshop revealed that the choice of PWR containment type has a great impact on overall plant arrangements. "Comparative Constructability Evaluation of PWR Containments" is a study effort on this subject and produced a report provided in Appendix B.

Equipment hatch(es) (EH) and personnel air lock(s) (PAL)

Options for EH and PAL have been widely discussed, considering the following issues:

- Access during construction and maintenance at these points of exit and entry.
- Construction and maintenance plans, as well as equipment removal plans, detailed at the design phase.
- Installing and removing equipment through the dome.
- Usefulness of an EH below the operating floor, which relies on the NSSS vendor. Access to that hatch from grade elevation during construction and maintenance must therefore be examined.
- For maintenance, EH convenient to HP, security, and hot shop/decontamination facilities.

Importance of integrated design

Decisions on EHs and PALs are important to arranging containment. An integrated approach is important, however, because of the relationships between key elements, such as:

- Common basemat
- Building arrangement on a common basemat
- Plant embedment
- Containment type
- Arrangement of containment items, including the number and locations of EHs and the NSSS offset

Recommendations

- Remember that the selected containment type:
 - Influences many aspects of plant design, construction, and operation.
 - Dramatically affects plant constructability.
 - Can control the schedule.
 - Can affect accessibility for construction, maintenance, and testing for the entire life of the plant.
- To select containment type, use an evaluation similar to "Containment Constructability Evaluation of PWR Containments."
- Develop detailed plans and drawings for potential equipment replacement.
- Route pipe and cable away from access areas.

Considerations

- Bottom-head and flat-base containment configuration options must be evaluated.
- Rebar placement and the resulting impacts on schedule should be considered.
- Various schemes for polar crane support should be investigated.
- Installing and removing equipment through the dome should be considered.
- Construction and maintenance plans, as well as equipment removal plans, should be detailed at the design phase.

Cautions

- Bellowed penetrations have provided many complexities for design and construction.
- Field post-weld heat treatment has caused severe scheduling problems.
- Misuse of in-containment space has made access difficult for construction, operation, and maintenance personnel.

Offset Concerns

Offset in 2-loop and 4-loop plants

Workshop discussions determined that using an offset in a 2-loop layout may be very different from offset in 4-loop layouts, so that ALWR standardization is not supported. Offset in a 2-loop plant redistributes laydown space, whereas offset in a 4-loop plant is not as beneficial: rather than creating new space, this redistribution in 4-loop plants actually moves space from one area to another.

Loss of building symmetry

Offset would provide useful space for laydown of major equipment and maintenance, but building symmetry would be lost. Lack of symmetry is a particular design concern with ALWR's in-containment refueling water storage tank. This tank, with approximately 500,000 gallons of water, significantly influences buildings' seismic analysis and associated seismic spectra (e.g., piping analysis, penetration design, equipment anchorage).

Offset placement

Although the initial Bechtel arrangements show the offset away from the fuel pool, the offset should be towards the fuel pool. This placement:

- Minimizes the refueling canal area.
- Simplifies refueling.
- Better uses the operating floor.

Congestion and space allocation

Another concern is the congestion on the side opposite the offset. The proposed ALWR arrangement is based on a 150-foot diameter containment. For O&M, maximizing the offset, even with that large containment, could cause as much congestion as in the current generation of plants. This congestion would continue to create construction and maintenance problems not adequately considered in the past, such as:

- Personnel and small-equipment access must be provided for maintenance and inspections.
- ALARA principles are more effectively implemented by isolated work areas that are sufficiently sized.

Supporters of offset argue that space allocation does not vary from current plants. To best use the overall layout, however, ALWR's differences (e.g., number of safety systems, commodities, and routing of pipe and cable) must be considered.

EPRI's Chapter 6 and the Bechtel arrangements

Workshop discussions and O&M working meetings resulted in changes to EPRI's Chapter 6. The current Bechtel arrangements:

- Place a non-dimensioned offset in the direction of the fuel pool.

-
- Describe offset as an option for the designer to accomplish by considering several parameters that include access space for maintenance and inspection, especially the space between the shield walls and containment wall.

Recommendations

- Locate the offset toward the fuel pool to:
 - Minimize the refueling canal area.
 - Simplify refueling.
 - Better use the operating floor.

Considerations

- Offset can be used to the greatest advantage only after considering several parameters, including:
 - Access space for maintenance and inspection
 - Building symmetry
 - Offset direction

Material Mobility and Equipment Hatch(es)

Importance of hatch placement

The quantity, size, and location of equipment hatches (EHs) is important to material, equipment, and personnel mobility.

Dual equipment EH

The initial Bechtel arrangements show 2 equipment hatches: one at the operating floor for steam generator removal and one at grade. Dual EH allow for conducting outage operations (e.g., scaffold delivery) in parallel, saving significant maintenance time and money. A major concern, however, is the impact on the structure—aligning the EH near each other affects rebar complexity. Using the second EH also:

- Adds commodity cost (e.g., added rebar and the EH's cost).
- Increases the possibility of leakage and other mechanical problems.

Vertical EH

A vertical EH has been used successfully to move equipment through the operating floor. Although it requires 2 lifts, this hatch placement is a manageable way to move items from the operating deck to grade level. Materials can be moved efficiently when vertical EHs are effectively laid out and lifting devices are correctly sized, because this arrangement frees valuable operating floor space.

Using only one EH

One EH at grade is adequate with a vertical access way to the operating deck. The second EH is therefore not cost-effective. The EH should be sized to allow the reactor coolant pump motor to be removed in a vertical position.

Hatch location

O&M emphasizes EH access at grade for trucks or low-boys. Staging areas should be provided inside and/or outside the EH with dedicated crane support. WNP-1 placed the EH at the operating floor, with a 150' x 150' staging area outside the EH and ramps down to grade.

Cranes

Smaller (10-ton) cranes, at various locations to free the polar crane, have been used successfully at several plants. This arrangement is particularly important given the critical polar crane uses for construction and maintenance.

Recommendations

- Use one EH at grade, with a vertical access way to the operating deck. The EH should be sized to allow the reactor coolant pump motor to be removed in a vertical position, rather than sizing it for one-piece removal of the steam generator.
- Establish staging areas inside and/or outside the EH, with dedicated crane support.
- When planning EH, consider:
 - Location relative to grade
 - Number of hatches
 - Convenience to areas such as HP and security
- Consider using smaller (10-ton) cranes at various locations to free up the polar crane.
- During construction planning, investigate making crane layout similar to the layout at Japan's Takahama 3 and 4.

Steam Generator (SG) Removal

Industry input

- Removing the steam generator in one piece should **not**:
 - Dictate the building layout.
 - Significantly influence the parameters of containment design.
- Improvements in NSSS equipment and cleaning process, along with technological advances, should help lessen the need for removing the SG.
- According to O&M personnel, SG life should be prolonged through:
 - Improved tube material
 - Reduced T_{HOT} from 650°F to 600°F to lessen tube stress corrosion and cracking
 - More stringent water chemistry requirements
- EPRI's current criteria to replace SG in 120 days, in lieu of one-piece SG removal, should influence parameters and layout.

Options for one-piece removal

Several options were discussed for any required one-piece SG removal, including:

Option	Description
SG removal through the dome	
An equipment hatch (EH) located at the operating deck and large enough for one-piece removal	<ul style="list-style-type: none">• A second EH on the operating deck used exclusively for SG removal is not warranted economically.
A removable concrete plug or hatch or removable precast concrete sections	<ul style="list-style-type: none">• This plug or hatch should be planned for during design.• For steel containment, this option is relatively simple because the containment plate could be cut in a predetermined section. The Reactor Building, providing only missile shielding, could have a larger door on tracks and rolled out of the way.• For concrete containment vessels, this option is more difficult because the steel liner plate must be cut and removed and the concrete rebar must be cut and demolished. A study on this option for concrete containment appears in Appendix N in Volume II.

Option	Description
Crane options	<ul style="list-style-type: none">• The polar crane capacity could be strengthened.• Crane cable access could be allowed through the dome.• Shell wall-mounted cranes large enough to handle SGs (over 150 tons) would have large design loads that complicate wall connections and therefore affect constructability.

Considerations

- One-piece steam generator removal should not significantly influence containment design parameters and building layout.

Reactor Vessel Head Enclosure

Using a cubicle below the vessel head

The French successfully used a design in which the vessel head has a cubicle below the operating deck. During refueling outages, the head is lowered into the cubicle, which is then covered with shield plugs. Because the enclosure is shielded and ventilated, maintenance can be performed on the head with minimal airborne contamination or worker exposure. Workshop participants, especially O&M personnel, believe this option is excellent and could be incorporated in ALWR designs. (WNP-1 has a feature similar to the French's option but does not have a shield plug to totally enclose the vessel head.)

Recommendations

- For reactor vessel head enclosure, consider a storage cubicle on the operating deck, where the head could be lowered to provide shielding during maintenance.

Access and Personnel Airlock(s) (PAL)

Importance of personnel mobility

The mobility of personnel within the plant has a tremendous affect on construction cost and schedule. This mobility will also affect O&M costs for years to come.

Success in securing mobility and access

Success in this area is encouraged by concepts developed through efforts such as the Design for Constructability Program. Completing a high percentage of design before construction and using new modeling techniques (plastic and computer) will help future constructors provide sufficient mobility and access. Technological developments such as modularization and CAD/CAE are also important.

Incorporating ideas on space allocation

Front-end efforts are essential to incorporate ideas on space allocation into plant arrangements. These ideas should:

- Be provided by personnel from design, construction, and O&M.
- Include plans for:
 - Personnel access
 - Use of construction materials and equipment
 - Installation of plant material and equipment
 - Inspection, testing, maintenance, repair, and replacement of plant items

Just as important, however, is establishing a control process during construction and modification to ensure that the allocated space remains available. Using additional floors rather than expanding the plan layout can optimize this space as additional space requirements are identified. Other decisions on space allocation and accessibility should be based on O&M needs and used as possible by construction. Other considerations include:

- The importance of access being provided through continuous vertical and horizontal paths
- A shaft open to the roof (and covered when not in used) with pyramiding floor platforms

Facilitating movement of personnel and equipment

Doors, hatches, and PAL

- Make hatches and doors easy to operate.
- Minimize the number of doors and hatches.
- To use 2 PAL:
 - Locate one standard-size PAL at the operating floor near the equipment hatch.

-
- Locate the second PAL below the operating floor, central to maintenance activities and slightly oversized to give personnel and small equipment/tools access to lower containment areas.
 - Remember that 2 PAL provide greater flexibility than the current use of standard and emergency air locks.
 - Locate the PAL in different building sectors, close to HP areas.
 - Optimize PAL access by avoiding locations at walls and stairs and using ramps as needed.

Elevators

- Provide equipment and personnel elevators that are:
 - Rugged
 - Properly sized
 - Suitable for the environment
- Study the idea of using only freight elevators.
- Use additional elevators inside containment to to:
 - Benefit construction and maintenance.
 - Improve operational reliability.
- Carefully review the location of elevators near PAL to ease equipment and personnel movement.
- Avoid locations near high radiation areas, such as the fuel transfer area.

Floor elevations

- Design the Reactor and Auxiliary Buildings' floor elevations to coincide so that architectural barriers do not hamper—or completely prohibit—personnel or equipment movement.

Recommendations

Access and PAL

- Place 2 PAL as follows:
 - One standard-size lock at the operating floor near the EH.
 - One slightly oversized lock below the operating floor and central to maintenance activities.
 - Both locks close to HP areas.
- Make certain that the Reactor and Auxiliary Building floor elevations coincide so that accessibility is not impaired. Standardized relative elevations between plant floors and between plant structures expedite construction and facilitates operation.
- Carefully consider elevator number, type, and location.
- Design permanent elevators primarily for freight rather than personnel.
- When studying alternate layouts (e.g., labyrinth doors) for missile and radiation protection features, remember that these features can make access difficult during construction and may increase construction time.
- Ensure access for equipment, materials, tools, and personnel, both on the site and in buildings.

-
- Investigate accessibility carefully because of its potential impact on the construction schedule (e.g., access for personnel, materials/equipment, and crane/material-handling equipment).

Reserved access and work areas

- Use space allocation to simplify construction, operation, and maintenance.
- Have design, construction, and O&M personnel provide input on space allocation. This input should include ideas on:
 - Personnel access
 - Use of construction materials and equipment
 - Installation of plant material and equipment
 - Inspection, testing, maintenance, repair, and replacement of plant items
 - Reserved areas for construction and O&M activities.
- Make construction utilities and facilities (including work areas) a permanent part of the plant. If not possible, plan for removing these facilities to ensure minimal work requirements.
- Remember that careful planning ensures that support facilities located around high-activity areas do not impede construction or operation.
- Use fewer, larger building structures to minimize the total number of buildings.
- Thoroughly plan layout of construction roads (or very early installation of permanent roads), and consider paving these roads.

Considerations

- To accommodate space requirements, additional floors can be used instead of an expanded plan.
- Additional items related to space should be studied, including:
 - Using continuous vertical and horizontal paths.
 - Planning for easy transport of personnel and material.
 - Maximizing flat, straight structural items.

Item Segregation

Importance of segregating items

In a nuclear plant, items' nuclear grades and operational statuses significantly influence adjacent items' construction, operation, maintenance, and testing. For example, it is very important to study the need to locate components/systems in each area. Constructability and other benefits occur by relocating some nonsafety-related components/systems from the Auxiliary Building to "less expensive real estate" such as the Radwaste Building. Security fences and construction segregation can play important parts in segregation.

Considerations

- Additional items related to space should be studied, including relocating nonsafety items to "less expensive real estate."

Construction Segregation

Definition

Construction segregation is the separation of safety and nonsafety construction aspects.

Savings

Segregation can save time and cost by eliminating the "nuclear mindset" on the secondary side. In fact, potential savings have been quantified in recent studies. The appropriate solution depends upon whether construction segregation is imposed by physical barrier or management approach.

Separating organizations

Decisions must be made as to what part of the design organization, including field engineering support, should be segregated. Also affected by these decisions would be procurement areas and construction management. Having 2 construction management organizations, under 2 construction managers and with separate workforces, could be warranted but:

- Contracts and contractors would be negotiated and handled separately.
- Managing the overall project becomes more difficult.
- Inefficiencies are created, such as limitation of flexibility in allocating personnel and construction equipment.
- Inventory and control of material flow is essential to segregation's success; warehouses and issue stations must be separate and part of a process that allows only safety-grade materials on the safety side.

Fossil vs. Nuclear Turbine Building

Studies have illustrated savings between a Fossil and Nuclear Turbine Building. As described above, however, inefficiencies are costly and could prove imprudent. Additional reliability is also brought by the over-stringent Nuclear and Turbine Building installations. These issues must be investigated in any efforts to gain cost and schedule savings on the conventional side of the plant.

The best solution

Combining several aspects of segregation may be the best solution. Design arrangements must optimize segregation of nonsafety hardware, (e.g., relocating it to a different building or establishing a nonsafety area on the nuclear island). As part of the separation, the scope of safety items may be reduced. From that point, decisions should be made on:

- The amount of the design and construction effort to be contracted
- Involvement of labor unions
- Ability to manage the project

These decisions will help evaluate management of workforce performance against the provided criteria rather than by enforcing performance using a physical barrier.

Deciding construction segregation

Construction segregation should be an option for site management. Some management may choose to use a physical barrier, while others may decide administrative controls are enough to ensure adequate separation. The temporary construction fence is now included as a consideration in EPRI's Chapter 6.

Recommendations

- During design, optimize segregation of nonsafety hardware, even by relocating it to a different building or by establishing a nonsafety area on the nuclear island.

Considerations

- Using temporary construction segregation physical barriers (to separate nonsafety areas from safety areas) is an option for site management.

Security Fences

Introduction

Permanent plant security is a major issue in segregation. The initial Bechtel arrangements proposed a layout with the security fence between the Turbine Building and the nuclear island. This layout supposedly allowed crews to work on the secondary side without extensive security training and clearance. A concern with the layout, however, is restricted access for workers within the primary side and these workers' entrance into the secondary side when needed.

Concerns with security fences

- The NRC currently favors paying more attention to items that are "important to safety." This tendency may develop into more security requirements on the secondary side.
- Large separation between buildings may result from:
 - Routing the security fence between the Turbine Building and the nuclear island.
 - Providing required surveillance.
- Fewer security levels provide more access flexibility and therefore improve productivity.
- Personnel control may be a problem when several access points exist into the protected area.
- The security clearance level required for access into the unprotected area should be determined.
- Vehicle access into the protected area must be provided.

Sequoyah

After the workshops, TVA provided information on the security fence at Sequoyah, the only plant to use Bechtel's proposed security fence arrangement. TVA had anticipated savings on security forces, personnel training, and documentation requirements for the nonsafety side. Watts Bar was initially designed to include the same arrangement, but O&M personnel at Sequoyah have had substantial negative feedback:

- Operations personnel have been overly restricted from access to the secondary side.
- Maintenance personnel lost significant productive time because of access difficulties and unavailability of tools and materials.

An ongoing industrial engineering study will describe and qualify these difficulties. This study will recommend and justify:

- Not using Sequoyah's layout at Watts Bar.
- Changing the security layout at Sequoyah from current to conventional.

Considerations

- Security issues to be considered include:
 - "Important to safety" items
 - The physical feasibility of a fence
 - Number of required security levels
 - Personnel control and access points into the protected area
 - Vehicle access to the protected area
 - Level of security clearance required for access into the unprotected area

Caution

- Designers considering using Sequoyah's security fence layout should review the study's report and discuss difficulties with TVA.



Section 2. Modular Approaches

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Introduction

Problems in plant construction

Over the past decade, problems with nuclear plant construction have been numerous, including:

- Public acceptance
- Plant financing
- Licensing problems (e.g., continuous changes in NRC technical requirements)
- Backfitting operating plants to requirements developed because of Three Mile Island
- Incorporation of new technological developments not mandated by the NRC
- Assurance of quality
- Construction management failures leading to missed schedules and overruns in cost

Another unresolved issue in the U.S. is selecting the size and type of nuclear plant to provide electricity at the lowest bus bar cost **and** achieves a suitable safety level. While this issue is unresolved, the entire issue of using nuclear energy remains unresolved as well.

Definition of modularization

Modularization is the process of preassembling portions of a plant at a location other than the final assembly point. Industry experiences show that modularization could significantly reduce both cost and schedule.

Modularization's role

In its many forms, modularization has the potential for contributing short-term **and** long-term solutions to several of the problems listed above. A vigorous study of the area is therefore needed. Modularization could:

- Reduce capital costs by substituting shop labor for field labor, permitting development of skills to be used for other plants' construction.
- Improve labor relations and management quality.
- Reduce:
 - Overall plant construction schedule
 - Maintenance costs
 - Decommissioning costs
- Simplify the licensing process through standardized modules

Past use of modularization

Despite potential benefits, nuclear plant constructors have used very little modularization to date. Experience has been limited to a few applications, such as:

- Skid-mounted equipment and systems
- Rebar cage modules
- Pipe assemblies
- Instrument panels
- Condenser modules

Construction costs

U.S. nuclear plant construction has basically been "stick-by-stick" using field labor, often resulting in very high construction costs. The construction phase of a nuclear plant accounts for 50% of the total capital costs for the project. These costs have increased partially because of:

- Congestion
- Complexity
- Degree of required modification

If management and labor teams are properly motivated to considerably increase modularization, costs can be decreased and quality increased.

William H. Zimmer Generating Station

The William H. Zimmer Generating Station, a recent success story, reduced construction schedule by about 1 year, resulting in reduced project costs and leveled manpower requirements. These results are attributed to:

- Extensive up-front planning
- Innovative techniques (e.g., modularization)
- Excellent working relationships between labor and management

Other industries' experiences

Successes with modularization in the shipbuilding, aircraft, and automotive industries influenced the nuclear industry to use modularization. Examples:

- Avondale Shipyards restructured their organization to fully use the "zone outfitting" approach to construction. As a result, the company reduced costs and became successful fixed-price bidders on several projects.
- Boeing modified their Seattle aircraft assembly plant to take advantage of modular construction.
- General Motors has upgraded automobile assembly plants to reflect advances in modular construction.

The DOE Task Force on Modularization concluded that other industries' advanced modular construction techniques could be extended to the nuclear industry.

Modularization at Braidwood Nuclear Station

Efforts to use modular construction techniques at Braidwood Nuclear Station have not resulted in sizable rewards. Instrument panels and skid assemblies have not fit well between prepour of the base and installation of the panel or skid.

Modularization at River Bend Nuclear Station

River Bend Nuclear Station's entire control board was constructed by General Electric in their factory. After being successfully tested, the board was partially dismantled and shipped in modules to the plant. (Modifications to the board were required after installation because of incomplete design. Some risk was associated with these modifications, and problems did occur during construction.) Modularization was also used on the containment plate, rebar, and pipe supports.

International uses of modularization

As in the United States, international nuclear construction benefitted from experiences in other heavy industries.

At Tsuruga II: The Japanese used modular construction to fabricate the containment liner plate. The shop-fabricated sections were preassembled before being placed in their final location. Preassembly occurred at the plant because the final size precluded shipping from a steel fabrication plant. This practice eliminated up to two-thirds of the in-place circumferential seam welding.

At Muelheim-Kaerlich: New and spent fuel racks were built using modular techniques. The design allows for easy removal and reinstallation while providing the benefits of factory fabrication (versus site construction).

Recommendations

Recommendation	Comments
Although modular construction techniques have proven successful, the potential exists for much greater success.	<ul style="list-style-type: none">• To maximize benefits, modularization must be considered in the design phase to allow full, appropriate use of off-site and on-site techniques for module prefabrication.
Scope, responsibilities, ground rules, and jurisdictions must be clearly defined and understood up front.	<ul style="list-style-type: none">• Scoping is important because of the high initial cost of any applications of modularization.• The definitions must address quality and documentation issues such as change and configuration control.
Extensive interaction and cooperation between disciplines is required during the design process, especially on multi-discipline modules.	Appropriate organizations need to have input during design to: <ul style="list-style-type: none">• Ensure the plant can be well-constructed and easily maintained.• Evaluate access for installation, operation, and maintenance.

Recommendation**Comments**

Modularization should create an environment more conducive for quality installation.

- Work areas will be less congested.
- Jigs and module manipulators can facilitate construction.

Potential tradeoffs exist with modular construction.

- The increased up-front engineering expense may not outweigh the benefits achieved during construction.
- Modules reduce the amount of flexibility available during construction.
- Modules may not fit up in the building because of tolerances.

Key elements to modularization's success include:

- Completion of design before construction begins
- On-schedule module availability at the erection location
- Quality assurance, including interaction of these inspections:
 - Vendor
 - Installer
 - Owner
 - ANI
 - NRC
- Traceability concerns
- Design criteria
- Packaging and shipping
- Organized approach to in-plant decisions, scope, and specific layout versus and on-site or off-site approach
- Use of the best areas for modularization

Prime candidates for modularization include:

- Instrument panels
- Equipment skids
- Rebar cages
- Pre-tubed condensers
- Reactor vessel head assembly with elements such as control rod drive mechanisms (CRDM), shields, and tensioners
- Reactor internals
- Fuel pool liner plate
- Spent fuel racks
- Piping assemblies and their supports
- HVAC duct
- Cable trays
- Conduit

Owner Commitment to Projects

Introduction

Because of anticipated advantages, modularization will probably be incorporated into each ALWR plant design. A modular design may therefore be the only nuclear option available to future owners (i.e., licensees). In spite of this possibility, much workshop discussion centered on:

- Generic concerns the owners would have.
- What owners should consider when committing to constructing a modularized plant.
- Issues that vendors and A/Es should address in developing modularized design, given that owners will use these issues to evaluate future design and plant packaging options.

The primary owner concerns focus on:

- Changes in timing of project commitments
- Outlay of funds
- Risk factors

First-of-a-kind plants

One potential concern for the owner is whether a first-, second- or "nth"-of-a-kind standardized plant is being considered. Becoming involved in a first-of-a-kind plant is more difficult than on a proven design and plant package. For the first plant, modularization will require more up-front engineering and design; up-front cost will decrease sharply for later plants built to the same standard design.

Vendor availability

One issue, particularly with first-of-a-kind plants, is availability of qualified vendors. In addition to vendors supplying normal plant items, qualified and capable module fabricators must fabricate, store, deliver, and help install modules.

How the owner does business

When convincing an owner to commit to modularized plant design, "institutional" changes in the way the owner does business must be resolved. For example, the owner must:

- Have different cash flow and capital plans.
- Commit to a communal plan (quality assurance plan).
- Be more involved in design.
- Learn about construction alternatives (e.g., modularization, stick-built, and a combination of the two).
- Be involved in early decisions, such as the degree of modularization used (e.g., full, partial, combination, or none).

-
- Use a prudent modularization process to “get the rate regulator on board.”
 - Bias site selection toward a site that compliments modularization, including site logistics and access for standard modules.

Reviewing design options

Owners will consider several issues when reviewing available design options:

- The degree of modularization should have been specifically defined.
- The decision to maximize, minimize, or optimize must be prudently established. (It may be better to install some items conventionally.)
- A balance must exist between the amounts of modularization that:
 - Reduce construction costs, assuring these costs will not be overrun.
 - Increase plant availability by reducing down time.
 - Increase plant life and facilitate decommissioning.
- Risks must be minimized.
- The plant must be laid out and designed for the defined degree of modularization, including module types and quantities (e.g., equipment, piping, structural).

Managing interfaces

Another challenge will be managing the many interfaces. A module prefabricator, perhaps several, must be integrated into the production control system. This integration should be thought of as a means to manage construction activities away from the construction site. The owner must be able to rely on the system to provide insight into the status of several activities, including module completion. The module fabricator would enter material and fabrication status into the data base as the constructor would enter information on module delivery, installation, and inspection.

Recommendations

- Properly motivate management and labor teams to use modular design and construction of ALWR to:
 - Reduce costs.
 - Shorten the construction schedule.
 - Increase quality.
- To overcome modularization concerns and to make a modular approach successful, have all project participants commit to modularization up front.
- Keep in mind that the primary owner concerns focus on:
 - Changes in timing of project commitments.
 - Outlay of funds.
 - Risk factors involved.
- Make certain that the plant is laid out and designed for the established degree of modularization.

Considerations

- When convincing an owner to commit to modularized plant design, "institutional" changes in the way the owner does business must be resolved. For example, the owner must:
 - Have different cash flow and capital plans.
 - Commit to a communal plan (quality assurance plan).
 - Be involved in early decisions, such as the degree of modularization used (e.g., full, partial, combination, or none).

Cautions

- Availability of qualified vendors is one concern, particularly with a first-of-its-kind plant. In addition to suppliers of normal plant items, qualified module fabricators must be able to fabricate, store, deliver, and help install the modules.

Cash Flow

Modularization's effect on cash flow

Modularization creates certain site schedule and cost benefits. The overall schedule duration, from initial project commitment through fuel load, may be substantially shorter with modularization. One of the owners' primary concerns is changes in the outlaying of funds during the project. The modular approach causes early procurement, which changes the cash flow profile:

- Before construction begins, enough time must be provided (about 18 months) to obtain materials and components and to make and assemble modules.
- Cash flow for components will be earlier in relation to pouring first concrete but **may** be the same or earlier relative to fuel load.
- Funds for civil items will be expended later in the schedule relative to fuel load.

The owner must be assured that these front-end expenditures "buy" something toward the project's completion.

Using "just in time" delivery

Benefits: "Just in time" delivery has cost benefits, including delays in fabricating, assembling, and delivering each module until the site is ready for installation. This delay could substantially impact cash flow, because the major costs are in materials and labor. Other savings would occur in storage and damage protection costs at the site.

Risks: In spite of the above benefits, the risk involved with "just in time" delivery must also be evaluated. Sophisticated, reliable monitoring systems must be in place to assure on-schedule delivery. Before implementing, a risk analysis must support this type of delivery (series vs. parallel-path installation).

Cash flow questions

- Who will pay for engineering up front, since modularization requires complete up-front design?
- What is the impact of moving AFUDC forward relative to the construction permit date?
- Who finances the project? How is this financing influenced by the consortium approach?
- How does the module fabricator, either as a vendor or equity partner, affect cash flow?
- What effect will exist because of the difference in owner and manufacturer fabrication cost of capital? When costs are cheaper, the owner may want to push as much cost as possible to the fabricator (e.g., COD or net 30 days). However, this involvement with the fabricator may produce disadvantages (e.g., a loss of control or use of cheaper components in the modules).

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- Can owners make certain they pay only for those things needed early (engineering needed for components)?

Analysis

Before the owner commits to the project, a real-dollar cash flow analysis for each alternative must be available. This analysis would show options that could reduce utility costs (e.g., by a broader financial base, equity interest, or consortium). The analysis should take these approaches:

- From a cash-flow standpoint, where is the "breaking even" point between modularization and stick-built construction? With a plant's commercial operation date much the same for either option, how much shorter must the modular construction schedule be to compensate for the earlier cash flow, since the cost per kilowatt is the same for each option?
- For a present-worth analysis, a modular constructed plant should be compared to a stick-built plant of the same design. Because of potential unknowns with each plant, a sensitivity analysis should be performed to incorporate the unknowns' impacts in the design process. The sensitivity analysis may indicate that:
 - The stick-built plant is the preferred option, since unknowns are better defined than with modular design.
 - The plant with the higher present worth is the preferred option because the risks are fewer.

Recommendations

- Make a real-dollar cash flow analysis available for each alternative before the owner initially commits to a project. This analysis would show options that could reduce utility costs (e.g., a broader financial base, equity interest, consortium).

Considerations

- With modularization, early procurement will change the cash flow profile.
- Who will pay for engineering up front, since modularization requires complete up-front design? Increased costs of up-front engineering must be offset by benefits achieved during construction.
- What is the impact of moving AFUDC forward relative to the construction permit date?
- Who finances the project? How is this financing influenced by the consortium approach?
- The module fabricator, either as a pure vendor or equity partner, must be considered in cash flow.

Introduction

If nuclear power is to compete for new electrical generation, historic uncertainties and financial risks must be reduced. Assurances must be made to prohibit schedule delays and large cost increases.

Concerns with modularization

Modularization involves a new set of risks, including:

- Earlier commitment to an outlay of funds.
- Responsibilities for procurement and inspection.
- Partnership arrangements.
- Difficulties specific to the first standardized plant.
- Potential rebellion within participating organizations (e.g., owners' engineers, vendors) about the amount of required standardization.
- Viability of selected:
 - Vendors
 - Component supplies
 - Module fabricators
- Greater dependability of delivery schedule (a **critical** concern).
- Sensitivity to events that could damage the schedule.
- Failure to meet the schedule and the failure's effect on AFUDC.
- Less flexibility in the construction schedule to accommodate potential risks encountered by modular construction.
- The owner losing some control to other controlling entities.
- Managing numerous interfaces. The modular approach requires more owner control, particularly with the module fabricator's shop, so managing a modularized project is like managing several smaller projects in addition to the larger plant project.
- Involvement at the fabricator's shop to ensure that warranty requirements are not diluted or infringed.
- Added vendor requirements, such as system tagging.
- Higher indirect ratio from inspecting and expediting module fabricators.
- "Tops off" construction.
- Added storage protection/care.

Delivery

The "just in time" delivery approach poses additional concerns and therefore may not be prudent. A balance must exist between the delivery schedule and the absence of a "critical" module, especially with the cascading effect of late items. For example:

- How are items out of the fabricator's control handled?
- Who obtains and expedites components within the module?
- Are all components standardized, including equipment outline dimensions and drawings? (This standardization would indicate preselecting a vendor or group of vendors?)
- Who is responsible for vendors' performance in supplying components?

Owner risk

The owner wants significantly less risk than a decade ago. Means exist to help alleviate some of these concerns and risks:

- An approach must be considered to allow sharing risks with other project participants.
- Contingencies can be added in contract negotiations for the component delivery schedule.
- Insurance can be obtained to protect the owner against the impacts of schedule delays.

Another possibility is that the fabricator could bond work based on quality and scheduled module delivery. A possible penalty could only apply to critical path modules, although a concern then exists on the ownership of float. An incentive could be provided by the fabricators' involvement in planning. This involvement could provide opportunity for input in areas such as:

- Transporting modules (key to module size)
- Schedule and commitment dates
- Any contingency plans

Reducing risks with modularization

Modularization also has the potential to reduce risks. Some workshop participants see little difference between modularization and conventional construction. The portion of the plant that the fabricator assembles should be completed under better control and to more predictable schedules and costs. The module fabricators have:

- A stable workforce (motivated by job security)
- An improved work environment
- Reduced congestion in work areas
- Improved productivity

Flexibility

The modular approach allows extra flexibility for:

- More parallel work
- Reduced work hours for fabrication
- Possible rate reduction in the shop
- Simplified site craft work
- Reduced demands for site labor because of activities shifting off site
- Reduced social/environmental impacts on site areas

Other benefits

Modularization also causes preselection of a vendor or group of vendors, which:

- Leads to shared risks and penalties.
- Helps establish equity partnerships.
- Supports the team concept and standardization.

The owner must realize that, although items such as preselected components may initially be more expensive, offsetting benefits include schedule savings and reduced risk.

Risk analysis

An analysis must assess how risks associated with modularization compare with conventional construction risks. This evaluation should:

- Include any changes in risks to nonconstruction issues such as:
 - Licensing
 - Maintainability
 - Plant performance
 - Life extension
- Consider approaches that allow project participants to share risks.
- If possible, include risk analysis of individual modules.

Recommendations

- Provide an analysis to assess how risks associated with modularization compare with risks associated with conventional construction.
- In the risk analysis, include any changes in risks to nonconstruction issues such as:
 - Licensing
 - Maintainability
 - Plant performance
 - Life extension

Considerations

- Modularization represents a new set of risks, including:
 - Sensitivity to events that could damage the schedule.
 - Earlier commitment to an outlay of funds.
 - Owner losing some control to others.
 - Responsibilities for procurement and inspection.
 - Partnership arrangements.
- Approaches must be considered to allow all project participants to share risks (e.g., added contingencies in contract negotiations).
- A potential also exists to reduce risks with modularization. The portion of the plant that the fabricator assembles should be completed under better control and to more predictable schedules and costs.

Commitment of Participants

Getting participants to commit to modularization

To overcome concerns and to make modularization successful, all project participants must commit to modularization up front. From project conceptualization through detailed design, modularization should be incorporated whenever modularization is deemed economical. These choices, and all other aspects of the design process, should incorporate input from the owner, constructor, and operator. This participation:

- Provides a sounder base for decisions.
- Helps carry the commitment to modularization into construction and operations.

Design

Completing design early

Not only must there be commitment and participation during design, but the design must be complete far earlier than previously anticipated. Before construction begins, sufficient time (about 18 months) must be allowed for:

- Obtaining materials and components
- Fabrication
- Module assembly

These early activities require complete layout designs and specific completion of design details for each module. Design drawings and module bills of materials will, by necessity, become final when the assembly is manufactured early in the project. Benefits of this completed design include a more stable design (avoiding past problems with fast-track engineering) and fewer field changes.

Plant layout

An entirely new approach to plant layout may be appropriate, possibly beginning with "a fresh sheet of paper." Flattening the building layouts rather than using the customary vertical layout may be advantageous, especially by reducing risks with modularization. This alternative layout could handle modular concerns and improve management issues (e.g., personnel access, crane usage). On the other hand, concerns with this layout include:

- Added commodities
- ALARA
- Sabotage
- Access to Reactor Building levels

Handling design

The overall plant design must receive additional and early attention. Integrating modules into the layout while assuring that plant systems remain compatible requires consideration of issues such as:

- Grouping systems
- Accessibility
- Sizing modules

Standardizing designs greatly enhances the benefits of modular design and permits the full benefits of off-site fabrication.

Recommendations

- Commit to modularization and design participation and complete design far earlier than was previously anticipated.
- Allow sufficient time (about 18 months) for:
 - Obtaining materials and components
 - Fabrication

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- Module assembly
 - When modularization is selected, carry the approach through every phase of:
 - Conceptual and detailed design
 - Procurement
 - Fabrication
 - Installation
 - Inspection

Considerations

- An entirely new approach to plant layout may be appropriate, even by beginning with "a fresh sheet of paper." Flattening building layout may be beneficial, reducing risks with the modular approach.

Standardization

Introduction

Modularization necessitates commitment to the final design of specific modules early in design and construction, thereby taking full advantage of factory production. Modularization therefore achieves its full potential with standard, license-approved designs. Because of this key link, much discussion on modularization focussed on standardization and the degree of standardization necessary to enhance modularization. These discussions related to replicate plant layouts and structures but also included specific module standardization.

Vendors

Complete, adequate standard design to support modularization requires up-front component dimensions and outline drawings. Preselecting or prequalifying vendors is part of this approach. Standardized equipment specifications, possibly to a single supplier, would ensure that each module fabricator uses the same components and materials. (The owner would not want to maintain a plant with many different component types when one type will do.) This concept raises anti-trust and free-trade restraint concerns that may require legal investigation. However, preselecting vendors is a major advantage to standardization. Even if vendors cannot be preselected, prequalification to replicate critical characteristics on specific components (e.g., nozzle locations, dimensions, load allowables) is required from every vendor to make standardization work.

Design

As already indicated, design must be completed very early, including specific module design. Module drawings would be developed in addition to discipline drawings. The A/E, constructor, and, if possible, the owners, would be involved up front to design and identify candidates for modularization. With design standardized down to specific component and material (e.g., standard 1" globe valves), standardized modules become a real possibility. (For more information, see "Modules" on page 2-23.)

Plant configuration

Even with a standardized plant, managing and controlling the plant configuration is important. With modularization, few changes can be anticipated after the design is released. However, a process must exist for handling needed design changes. "Design freeze" should be considered at some stage, as it has been a useful tool in the past.

Data management

The electronic data base, as part of the information management system, is a significant tool for the future. With design on the data base and accessible to the fabricators and constructors, current documentation would be accurate and readily available. For standardized plants, the data base must include:

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- Specifications for worst-case scenarios (e.g., the ability to accept any site location).
 - Module traceability.
 - Environmental and logistic specifications for each type of module. (For example, a module with delicate equipment has different requirements than a module containing only piping.)

Recommendations

- Use a standard and license-approved design to achieve modularization's full potential.
- Remember that a significant tool for the future is making the electronic data base part of the information management system. With the design on the data base and accessible to the fabricator and constructor, current documentation would be accurate and readily available.

Considerations

- Complete, adequate standardized design to support modularization requires component dimensions and outline drawings. Preselecting or prequalifying vendors becomes part of this approach. Preselecting major equipment and "envelope" parameters for other critical items may also be appropriate.
- Managing and controlling plant configuration is important, even with a standardized plant.

Modules

Specifications

Concerns that the owner and constructor have with the modular approach are influenced, and often addressed, through decisions about the modules themselves. A standard module specification should be developed to address these decisions. This specification should provide a thorough description of module types (e.g., structural, equipment, composite modules) and address:

- Accessibility
- Maintainability
- Procurement
- Electrical issues
- Rework
- Module delivery for installation

Standardization

As described earlier, module standardization is possible and enhances the approach. Standardized modules should be used as much as possible to minimize the number of site-specific modules. Modules can be standardized between replicate plants, and groups of similar modules can be designed for repetition of fabrication, assembly, and installation.

Size

Module size should be described in the specification. Module size is set by integrated decisions among parameters of:

- Technical requirements
- Cost considerations
- Transportation

Some questions influencing decisions on size include:

- The optimum size module for the plant layout must consider:
 - System grouping
 - Access for moving modules within buildings
 - Use of "tops off" construction
- Transportation (road, rail, or barge) appears to govern module dimensions and weight but depends on site requirements and limitations. One method may be to size modules for road and rail. When barges are available, more modules may be joined before shipment. Another transportation issue involves difficulties with acquiring permits for road transportation.
- Module configuration is a limiting condition for delivery, transportation, and storage. These factors should be considered and integrated into the construction plan and schedule. By designing for modularization instead of modularizing a design, module sizes may be reduced and optimized. This method reduces transportation concerns by not "shipping air."
- Decisions must be made about assembling on site, off site, or both. For example, even if modules are sized for road/rail transportations, benefits

may exist for assembling several modules to sizes for barges on site and out of "the hole."

- Decisions must be made about on-site vs. off-site testing and inspections.

Accessibility

The design specification must mandate access for close-out inspection and inspections for shipping damage. Access must exist to connect modules, whether welded or flanged, and for maintainance, operation, and possible module removal.

Maintainability

Maintainability has generally been considered part of the design and layout. Some concern has been expressed, however, for accessibility during construction, operation, and maintenance because of the discussions on compressing systems for module assembly and transportation.

Procurement

The procurement issues described elsewhere should be included in the design specification. Decisions must be made on who buys components. Experience indicates benefits from the owner/designer purchasing components.

Procurement issues include:

- Responsibilities
- Expediting
- Documentation
- Number of vendors

The number of suppliers and number of component types should be limited to improve the ability to interchange components and standardized designs.

Electrical

The means of pulling power cable must be evaluated in the design specification, including a description of methods in which:

- The cables fall entirely on the module.
- The majority of cables run on one module.

One alternative may be the use of plug-in instruments to permit terminations on the module. Modularization is favored by innovations in multiplexing (distributed controls) and local power distribution and protection.

Rework

The appropriate steps for minimizing and avoiding rework must be included in the standard module specification. Tight tolerances should be used, especially at interfaces such as piping and concrete walls. A uniform data base allows design consistency and aids configuration control. Common coordinates and, possibly, a master grid system, should also be described.

Module delivery for installation

The standard module specification should describe responsibilities and processes for the module, from module assembly to module installation. This information would include:

- Inspections
- Packaging and preparing for shipment
- Handling
- Receiving
- Storage (including concerns for nitrogen blankets, humidity control, and motor rotation)
- Module and component protection

Recommendations

- Develop a standard module specification.

Considerations

- Among the issues possibly included in the specification are:
 - Description of module types (e.g., structural, equipment, composite)
 - Module size (for transportation)
 - On-site vs. off-site inspection and testing
 - Accessibility and maintainability
 - Materials (e.g., procurement, delivery, storage, protection)

Construction Plan

Fabricators

Other ingredients exist for making modularization a success. Managing the numerous interfaces is an added challenge. Module fabricator(s) must be involved in the production control system (PCS) to manage construction activities away from the construction site. The effects on the PCS complexity rely partially on the freedom given to fabricators. One example is purchasing components within the modules: decisions on the purchase influence the interfaces and PCS.

Developing a construction plan

A significant amount of up-front planning and preparation must occur. As described earlier, design must include inputs on construction and plant startup. Construction also plays a major role in developing the standard module specification (see "Modules" on page 2-23.). Other planning and preparation involves developing a construction plan, as described below.

Information to Be Included	Comment
Integration of modular construction with a schedule controlled by start-up testing.	
Possible conventional installation in specific areas or cases.	Major benefits from modularization are in areas of concentrated activities.
Degree of modularization.	For modules on critical path, a certain level of completeness is accomplished before installation. The construction plan may account for shipping and installing partially complete modules to avoid altering the critical path.
Decisions made about on-site module assembly.	These decisions influence the need and provision of on-site fabrication facilities.
Development and description of the module installation sequence, including "tops off" installation and moving modules on site.	Large crawler cranes could be considered based on module size. For example, Westinghouse plans to use a Lampson Translift LTL 1500 for AP600 site activities.
Contingency planning for late receipt of critical and noncritical modules.	The schedule may have to be revised if the late module is structural. For equipment and pipe modules, however, the option exists to stick-build the modules in place. The construction plan should have sequencing with contingency that permits deviation without totally disrupting the schedule.
Fabricators' comprehensive, integrated review.	

Information to Be Included	Comment
Fabricators' flexibility to fabricate modules in a sequence that permits balancing the shop workforce without impacting delivery of critical-path modules.	This sequencing impacts the owner because early delivery of noncritical modules means storage is needed before installation. Contractual agreements may require the fabricator to store noncritical path modules until the site is ready to accept them. In either case, the owner eventually pays for the storage.
Effective communication with the fabricator to update planned sequences for changes and contingency.	Incentives could be used for delivering completed modules on time, and in the planned sequence. These incentives would encourage planning material lead time to support objectives.
Material issues.	The plan must define practices and responsibilities for material: <ul style="list-style-type: none"> • Procurement • Damage protection • Storage Also considered would be the impacts of site delivery on the construction schedule and storage issues.
On-site material control.	Site management must determine whether administrative control is enough or if physical separation is required. Experiences illustrate benefits of both methods.

Recommendations

- Remember that significant up-front planning and preparation is required for a successful modular approach.
- Include construction and start-up inputs in the design. Construction also plays a major role in developing the standard module specification.
- Develop a construction plan.

Considerations

- Issues which must be considered in developing the construction plan include:
 - Integrating module construction with a schedule driven by start-up testing.
 - Possible conventional installation in specific areas or cases.
 - Degree of modularization.
 - Managing the numerous interfaces.
 - On-site vs. off-site module assembly.
 - Need and provision for on-site fabrication facilities.

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- Sequencing installation to include "tops off" methods and on-site module movement.
 - Appropriate use of on-site and off-site modular construction should be planned during design.

Cautions

- Alternatives must be evaluated because cases occur in which conventional installation may be more cost-effective.
- Difficulties may include:
 - QA/QC documentation.
 - Fabrication and installation alignment tolerances.
 - Contingency planning for late receipt of modules.
 - Effective communication with the module fabricators related to updating the planned sequence for changes and contingency.
 - Material control.

Standardized Quality Assurance (QA) Plan

Developing the standard QA plan

A standardized QA plan must be developed during project planning and preparation and before the start of engineering processes. The development process would include the owner and all project participants, particularly considering the potential for multiple vendors and multiple fabricators. Planners should remember that quality starts with design and includes up-front owner involvement. This standardized plan must consider, and conform to, the standard QA features of 10CFR52, Appendix B.

Information included

The standard QA plan would describe:

- The QA organization's functional and administrative structure.
- Lead responsibilities for the organization.
- Overall accountabilities for QA activities.
- Responsibilities for implementing the QA program.
- The owners' role, with guidance on delegation of lead responsibility.

Results

One standard QA program is developed as part of the standard QA plan. The program defines the levels of QA responsibility, especially inspection and audit responsibilities for:

- Vendor(s)
- Module fabricator(s)
- Constructor(s)
- Owner(s)

The primary QA/QC level is with the participant: the vendor, fabricator, and constructor. The second level is with the owner.

Modularization in the QA plan

To include modularization, the QA plan should:

- Define quality standards and acceptance criteria in engineering documents.
- Use objective standards instead of subjective standards.
- Carefully define the personnel responsible for quality.
- Provide a thorough definition of QA requirements such as:
 - Programmatic
 - Scope of systems covered and boundaries
 - Documentation needed
- Eliminate duplicate inspections.
- Address ASME stamp on code piping.

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- Describe receipt inspection for potential module damage caused by transportation loads.

Shared QA program

This QA program requires a change in attitude on how those involved deal with one another—more participation is needed to assure quality. One standard QA program is essential for the owner. The vendor or module fabricator programs may be acceptable provided they are compatible with the owner program and can conform to 10CFR52. Vendors, module fabricators, and constructors should use standard paperwork (i.e., the same forms). However, this standardization requires some compromise when the supplier has an acceptable QA program and is working for others.

Vendors and fabricators

QA options for vendors and fabricators

- Work under the owner's QA plan.
- Follow their own acceptable program using standard forms for documentation.
- Follow their own acceptable QA program with its own nonstandard documentation.

Considerations in choosing QA options

- Needed interfaces with suppliers.
- Vendor/fabricator status on ASME qualification.

QA involvement: With the consortium approach likely in the future, the need increases for a common QA program that fabricators, owners, and other project personnel follow. This program would consider these vendor questions:

- Who handles procurement—the owner, A/E, constructor, NSSS vendor, or a combination?
- Who purchases "N" safety equipment?
- Should the purchaser be responsible for ensuring vendors are QA-certified?
- Should contractors be responsible for certifying their subcontractors' QA program?
- At what level of detail does the owner approve or audit vendors' QA programs?

Supporting the QA program

Concern has been raised on the amount of support this standard QA program would receive. Some constructors feel that QA differs little between module and stick-built construction. It has been agreed that achieving quality work may be easier in module manufacturing facilities. The consortium must establish up front the QA plan and resulting QA program. The owner is accountable for quality during the plant's entire life. To provide the owner a quality plant, all personnel, including module fabricators, must contribute to developing and participating in the QA program's implementation.

Global QA program

Concerns with quality may warrant a need for, and support, a global QA program. This program could:

- Help alleviate redundant inspections.
- Provide consistency on quality requirements and inspection criteria.
- Promote standardized documentation.

Quality Control (QC) Inspection

In-shop inspections

The modular approach offers several opportunities to streamline documentation and inspection. Inspection responsibilities would be well-defined in the standard QA program. These inspections could be completed at the module fabricator's shop. The owner should have as much inspection as possible in the shop. However, a fine line exists between owner inspection and acceptance in the shop and owner overview in the shop. This distinction must be clearly defined.

On-site inspections

The QA program should include descriptions of added module inspections caused by transportation-induced loading. Inspections should be "sign as you go" (not going back time after time), including regulators' inspections. When possible, duplication of the owner's inspection at the shop and on-site should be eliminated.

Inspection expertise

Additional inspection expertise may need to be developed. With module inspection, multi-discipline inspection qualifications should be considered.

Codes

Reevaluating codes

Modularization offers a chance to reevaluate codes. Participants in the Design for Constructability Program offered a variety of opinions on how to accomplish this reevaluation:

- To assume current codes would not work in the future may be inaccurate.
- Multiple codes may not be required on one module.
- A modularization or module fabricator code may need to be developed.
- Modularization does not require a separate code—codes are not “masters of our destiny.”
- Codes should guide. A possible error in the past is the approach that “the code does not cover it; therefore it cannot be done.”

The participants agreed that modularization did necessitate an evaluation of code requirements, with at least some revisions and/or additions to sections of current codes.

Issues in code evaluations

ANI: The need for ANI must be considered with one standard QA program for all project participants and the potential for a common, nationwide consortium approach.

Pipe stamping: The cost and risk factors should be determined when evaluating manufacturer and constructor stamping programs for code piping. Manufacturer stamping permits subassembly problems to be determined early, then corrected more cheaply and with superior quality in the shop. However, a second stamp program is then needed because testing and inspection are still required at the interface between adjacent subassemblies before the erection “N” stamp can be applied. Postponing all inspection and testing until the entire system is erected could save money but is an increased risk if fabrication problems needing correction are found during pressurization. Evaluating cost against risk will determine the need for one or two stamping programs.

Mixing code work: Mixing code work on one module is strictly a design, not a QA, concern. This concern should, however, be resolved in advance so that it does not become an issue later.

NF boundary: The NF boundary was determined not to be a QA problem as long as it is resolved early in licensing. In the past, interpretation of NF boundaries has varied from site to site. Standardizing NF interpretation and other code issues would simplify inspection requirements. Inspection and documentation requirements for structural steel modules vary dramatically based on NF interpretation.

Recommendations

- Evaluate current code requirements, with at least some revisions or additions, as necessitated by the modular approach.

Vendors

Vendors' importance

The role of vendors, including the module fabricator, is key to modularization's success in the nuclear industry. A closer team approach must exist between the owner and vendors. The current adversary buyer-seller relationship must be carefully reevaluated while maintaining business discipline. Vendors have to be held more accountable than in the past. The owners may have to give vendors more responsibility, such as in designing elements and components that can be modularized.

Eliminating duplicate QA groups

If vendors are responsive to quality and continue from project to project, some duplicate QA groups (e.g., A/E, owner) could be eliminated. Vendors have problems unless engineering is complete and standard. The concept of complete, standardized design also questions the need for, and the role of, A/Es in the projects.

Standardization and vendor preselection

As already described, standardization has significant implications for the vendors. Materials would be procured from selected vendors with competitive bids during preliminary design. To help achieve the cost/schedule benefits of standardization, utilities would agree up front with regulatory agencies on the process of preselecting vendors. Vendors would then be obligated to maintain the design and produce material based on set cost and schedule contractual agreements.

Adaptability

Vendors must be more adaptable. Those vendors who become module fabricators may find activities outside their normal specialty, such as:

- Component vendors doing piping or electrical work.
- Vendors doing more precision work to meet stringent tolerances.

Module fabricators from non-nuclear industries must adjust to nuclear-grade activities and documentation.

Documentation requirements

Nuclear documentation requirements may be a significant adjustment for some vendors. The module fabricator should coordinate assembly of all documentation before modules are shipped to the owners. Where the module was fabricated before official owner receipt is not important. When organized and shipped by module, documentation should also be accessible by system or another sorting option (e.g., system test boundaries). Accessibility is particularly important during start-up testing and system turnover for pre-operational testing.

Guidelines for selecting module fabricators

- Specify a broad scope of qualification (civil, mechanical, electrical).
- Limit the number of fabricators to centralize owner inspection and shop involvement.
- View involvement as similar to factory operations where construction activities are accomplished.

Considerations

- Those vendors who become module fabricators may find activities outside their normal specialty.

Labor

Limiting union impact

Unions' impact on job sites can be minimized by carefully planning up-front negotiations. For example:

- Agreements should be made to permit use of non-union shop products at the job site to avoid later fee payments to local unions.
- Subcontractor rights should be established up front.
- Project participants should try to establish a project team concept for both site and shop labor.

Agreements

Project Labor Agreement: Must be established to address union jurisdictional issues. This agreement includes module fabricators for their required shop activities. The fabricators would handle their activities independent of the owner or a Site Labor Agreement.

General Precedent Agreement: Primarily differentiates between construction and maintenance activities at a job site. This agreement should not include all activities. A stabilization agreement should, however, be reached at the national level.

Site Labor Agreement: Should be developed and signed between owners and international representatives of unions on the job site. Agreements with the local union level should be avoided. This composite agreement helps address and remove union issues such as jurisdictional disputes. Only on-site activities would be included; the fabricators' work would be independent of the owner or a Site Labor Agreement. When the fabricators' expertise is needed on-site, the fabricators would manage activities using site labor. This involvement becomes an industry trade issue, so some decisions on how and where work is done relate to economics, incentives, and contracts, essentially to subdue risks.

Site trade composition

A site trade composition should be established based on total manpower levels. This composition could then shift for milestone schedules. Meetings with union internationals could establish parameters and an oversight committee. Joint labor/management subcommittees could handle grievances and disputes.

Consortium

Introduction

The next generation of nuclear power plants will probably not be a single company's venture. A consortium of several companies will most likely be joint owners of these projects. (In this report, "owner" refers to the licensee.)

Benefits

A consortium is beneficial because the owners share risks and obligations. They would be able to phase in rate increases at a lower rate, minimizing negative customer relations. Construction also benefits from personnel having different backgrounds and experiences.

NRC licensing

The NRC will license only one operating organization, which must be:

- Clearly established and identified up front.
- Placed in a position to attract and keep top-quality personnel.

This operating organization, which works for the owners, may or may not be one of the owning organizations.

Owner options

The owner (licensee) may have options such as selling to a consortium and buying back the plant over a period of time. Concerns with this option include:

- Independent power producers may not be under the regulatory arm of state.
- For consortiums, regulators may try to deal directly with the licensee.
- License transfers may be handled with independent power producers.

Handling licensee problems

The original design development must have an unusually involved and concerned attitude, concern, and approach toward licensees' problems, including some equity involvement with vendors, module fabricators, or others (e.g., 50% utility, 25% NSSS, 25% A/E). Concerns with this involvement include:

- Regulators trying to deal directly with the licensee in a consortium setup.
- Potential exclusion of bidders not interested in financing as equity involvement.

Section 3.

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Introduction

What this section includes

This part of "Enhancing Constructability Through Design" includes issues to be considered during design, other than plant arrangements and modularization.

Reminder to designers

The industry climate will be very different than the era in which these volumes were written. Much of the information was developed with the understanding that some material could be outdated by the time the next nuclear project is started. While considering this report, particularly the areas on technology, keep in mind that state-of-the-art experiences (e.g., non-nuclear, international nuclear, NASA) will be the best initial resources to consider with the information in these volumes.

General Design Approaches

Introduction

Benefits of Early Standardized Design

- Prefabrication used effectively on civil/structural items, as already demonstrated on rebar cages and structural steel assemblies.
- Underground items designed, installed, inspected, and built up front.
- Standardized and repetitive shapes and, therefore, formwork.
- Innovative approaches, such as automated structural steel welding.

Considerations

- During development of an early standardized design, some issues that should be considered include:
 - Modularization and prefabrication.
 - Standardized and repetitive shapes to help standardize formwork, including uniform column spacing and floor elevations between buildings.
 - Concrete-to-rebar ratio, with studies of international experiences.
 - Trenches covered with grading and embedment of items.
- The following should be optimized:
 - Composite hanging, even across disciplines.
 - Typical designs (e.g., pipe and cable tray support).
 - Alternatives to supports and routings.
 - Embedded plates.
- Accurate bills of materials should be developed for all drawings or tasks.
- A grid system over the entire site may be an effective way to communicate location.
- Before construction begins, construction and operation personnel should review applicable design standards to ensure an overall understanding of actual requirements.

Access

Improving access

Access to the site and to different site locations is crucial to meeting an optimistic construction schedule. Roads and parking lots should be paved early in the construction schedule.

Using jetties

The jetties (elevated roadways), ramps, and roadways over the construction opening, as described in Japanese presentations, would have benefits such as:

- Jetties would allow greater access to the project during construction.
- Access for equipment and subassemblies would be easier.
- A large crane would not be required. Instead, smaller fixed cranes could be located throughout the project along the jetties.

If used, this approach must be incorporated early in the design to ensure supply of the jetty design and materials. The Japanese experience should be studied to determine the cost/benefit ratio.

Computer-Aided Engineering, Design, and Modeling

Benefits

Effectively using computer-aided engineering and design capabilities will achieve many benefits. Modeling provides capabilities such as:

- Configuration control
- As-built data
- Plant life extension data

Computer and plastic modeling has been effective in nuclear plant design and construction. For example, plastic and/or computer modeling of complicated plant areas has helped in:

- Identifying interferences
- Improving construction sequencing
- Making equipment walk-throughs

Computer models have the added benefit of producing 2-dimensional drawings.

Optimizing modeling

To be most advantageous, the relational 3-D data base must be completed at the earliest project phases. The plant model should include:

- All yard structures, such as:
 - Duct banks
 - Buried piping
 - Trenches
 - Catch basins
- The power generator complex, such as these buildings:
 - Reactor
 - Auxiliary
 - Turbine
 - Fuel

In the near future, equipment operations should be automated to "walk-through"-like activities, the simulator, and the sequencer. This technology already exists in grading and compacting. To make any innovations succeed, employees must participate and be motivated as "part of the team."

Modeling at River Bend Nuclear Plant

Plastic and computer models were successfully used in designing and constructing River Bend Nuclear Plant, Gulf States Utilities' first experience in nuclear plant construction. Their methods of using modeling included:

- Two plastic model systems used early in design included:
 - 3/8" scale model for general arrangement and component layout.
 - A 3/4" model and construction drawings to help spot actual interferences.

- During construction, a computerized 3-dimensional modeling and data base:
 - Identified hard interferences (pipe to pipe) and soft interferences (pipe to insulation or envelope space).
 - Allowed craft supervision to walk through component installation.
 - Though cost-effective, would have provided more savings if integrated at the start of construction.

International successes

International nuclear plants have successfully used both plastic and computer models. For instance, West Germany’s Muelheim-Kaerlich Plant extended computer models to small-bore piping and hangers. (In the United States, small-bore piping and hangers are typically field-routed and supported.) At Muelheim-Kaerlich, a dedicated design group used the model to design all piping layouts and subsequent modifications, creating an efficient, near error-free work process that minimized rework.

Study

As part of this program, a study was conducted to investigate and critique current computer model applications. The resulting report, which also comments on the future of computer models, is in Appendix C.

Recommendations

Recommendation	Comments
Use computer models extensively on future nuclear plants to aid in design and construction.	<ul style="list-style-type: none"> • Models will be valuable for: <ul style="list-style-type: none"> ◦ Establishing layout ◦ Identifying interferences ◦ Sequencing construction ◦ Making equipment walk-throughs
Have the modeling done by a multi-discipline team that understands overall plant design and construction.	
Make certain that computer models have built-in modules for computer-aided design (CAD) and computer-aided engineering (CAE).	
Use data processing improvements to permit large numbers of people to rapidly access any segment of the model online.	<ul style="list-style-type: none"> • This development will permit larger computer models that are easier to use.
During construction, make certain that field technicians are aware of multi-discipline use of an area.	<ul style="list-style-type: none"> • With this awareness, decisions on field changes can be made quickly.
Use plastic models to select a location for viewing the detailed 3-dimensional computer model of a small segment of the plant.	<ul style="list-style-type: none"> • The plastic model can be small, less detailed, and not updated except for major items.

Automation

Considerations

- Use of robotics during construction as well as in plant operation can minimize radiation exposure to workers.
- Robotics is expensive initially, so evaluations of cost and benefits are critical.

Construction Tolerances

The need for improvements

Improved construction tolerances are needed to minimize the negative impacts tolerances have on cost and schedule.

Suggested developments

To simplify the area of tolerances while allowing craft personnel additional leeway during construction:

- Allow the use of more liberal tolerances. Additional up-front work will be required to ensure that the performance of an item is not affected.
- Use well-defined tolerances that are effectively communicated and understood by the designer, constructor, and inspector.
- To avoid misinterpretation and misuse, adequately document tolerances and their application.
- Have one overall tolerance that would be used in all applications.
- Provide individual tolerances for each drawing. Though this procedure would require additional work and could confuse craft personnel, it would allow additional tolerances on many items.
- Early in the project, identify the tolerance procedures to be used.

Design Change and Corrective Action

Suggestions

- An effective mechanism for design change and corrective action must be established on future projects. This mechanism should incorporate as many items as possible. All corrective action processes must expedite changes to:
 - Minimize their impact on work progress.
 - Ensure a timely incorporation of the changes.
- Changes and corrective actions should be handled based on the severity of the issue.
- The decision process must consider the cost and benefit of all changes.
- A commitment to design minimizes the number of design changes. Construction personnel should not be authorized to alter established, detailed plans. The goal should be to complete the work correctly the first time and minimize changes.
- Design personnel must also be committed to the plans.
- Increased standardization/replication will assist with commitment to the design plan.
- When used, field routing should be integrated into the related detail design layout, possibly by using a computer model of the plant. Other items, such as construction services routing, should also be considered for inclusion.

Inspection

Recommendations

- During the design, have engineers ensure that documents:
 - Reflect requirements and inspection criteria.
 - Can be accomplished and inspected with reasonable efforts.
- Remember that any interpretations required must be supplied by design.
- Develop a minimal number of inspection documents.

Planning During Design

The importance of planning during design

Experience in nuclear construction shows the importance of planning during the design phase. Insufficient planning has caused increased construction costs and longer schedules. Too frequently, a nuclear plant's designers fail to determine the most effective design. "Layout/Accessibility" discusses both successes and problems of taking constructability into consideration when designing the plant layout.

Japanese experiences

At Tsuruga II, the Japanese handled all design aspects with thorough, detailed planning:

- Construction planning began at the project's preliminary design phase and was fully integrated in the design process.
- Planning was detailed for every aspect of the work—nothing was left to the last minute.
- Detailed planning and a commitment to stay within the designs helped keep the project on schedule.
- Planning, rather than working harder or longer, led to a smooth work flow and reduction in idle time.

Canadian experiences

After studying on schedule and cost reduction, Ontario Hydro recognized the importance of planning. An "up-front" planning team:

- Was integrated within the design effort.
- Included individuals experienced in:
 - Design
 - Construction
 - Licensing
 - Commissioning
 - Operations
- Included experts in:
 - Scheduling
 - Estimating
 - Procurement
- Could plan for problems areas not addressed in design because the team was represented by a cross-section of the plant's design, construction, and operating areas.

Recommendations

Recommendation	Comments
Begin a project's construction planning at the preliminary design phase.	
Make planning for the construction process an integral part of all aspects of the design process.	<ul style="list-style-type: none"> • This integration can best be accomplished by a team that would ensure that adequate planning is included in design. • The planning team should consist of individuals experienced in: <ul style="list-style-type: none"> ○ Design ○ Construction ○ Licensing ○ Operations ○ Scheduling ○ Estimating ○ Procurement
Complete construction work precisely according to the detailed plans.	<ul style="list-style-type: none"> • Field personnel should not have the authority to alter the plans. • Design personnel should be committed to the plans.
<p>Plan for specific areas in design, including contingency planning and ways to optimize:</p> <ul style="list-style-type: none"> • Composite hanging, even across disciplines. • Use of typical designs on areas such as pipe and cable tray supports. • Alternatives to supports and routing difficulties, (e.g., floor troughs, pipe and cable embedment, and armored cable). • Material handling equipment (e.g., monorails and cranes) for construction and operating modes. (Modularization affects crane and monorail layout.) 	

Caution

- Make the most of layout and embedded plates instead of concrete anchor bolts.

Civil Engineering Design

Earthwork

Using technology in earthwork

Laser and computer technology should be used in earthwork applications. Laser measurements are more accurate and, when loaded directly into a field workstation, allow faster interpretation of results. Modeling geophysical conditions and simulating activities in this way:

- Optimizes activities and activity sequencing.
- Makes better use of resources (e.g., personnel, equipment).
- Optimizes material-handling equipment (e.g., fleetings of earth-moving equipment).
- Improves communication.
- Generally creates more accurate prices and schedules.
- Improves credibility.

Improving earthwork

To maximize these benefits in earthwork:

- Be more site-specific—try to use local earthwork contractors' innovations.
- Use the latest technology.
- Consider the soil interaction with the building—minimize seismic backfill and consider materials.
- Keep accurate records of soil type and placement.

Reinforcements

Using nonmetallic reinforcements

Although the reinforcing material could be the traditional steel, nonmetallics should be investigated. The brittle nature of nonmetallic reinforcement would, however, limit application by code committee when personnel safety is a concern. Present applications could be limited to crack control for nonsafety-related concrete. Fibers added in the concrete mix can also provide some reinforcement.

Reinforcement connections

Options on reinforcement connections include lapped, crimped, screwed, and fused. Mechanical splices are currently preferred over exothermic connections. Some of these options are old, but new techniques **are** being developed, such as a new lightweight crimping tool used in Japan.

Installing reinforcements

Lower ratios of rebar-to-concrete would make installing rebar and pouring concrete easier. Prefabricated assemblies should also be used, with the number and size based on crane capacity. Methods should be developed to control alignment tolerances. Designers and constructors can investigate, and learn from, experiences in other countries.

Concrete

Documentation

Quality assurance documentation requirements for ASME Division 2 concrete should be evaluated and, if possible, simplified. Present documentation requirements could be "overkill."

Improving concrete mix

Possibilities for improving concrete mix include:

- A combined effort from design and construction employees to develop additional selection options for concrete mix procedures.
- Using computer technology to control mixing of concrete, reducing batch reject rates and ensuring a more uniform mix design.
- Sampling material as aggregate enters the mixing hopper.

Developments

Developments have occurred in the use of:

- Plasticizers
- High-strength concrete
- Quick-setting concrete

These uses should be expanded to nuclear-grade work—specifically, superplastics should be used:

- In areas of high-rebar density.
- Where vibration techniques are restricted and uniform filling cannot be ensured.

Decreasing wall widths

Higher-strength concrete can be used when possible or practical to decrease wall widths. A combination of high-strength concrete and smaller aggregate will help reduce void formations in decreased wall widths. Plexiglass viewing ports can be used selectively to ensure a lack of void formation. Walls used for radiation shielding may not allow a thickness reduction.

Heat of hydration

Heat of hydration is primarily a concern in mass concrete pours. Fly ash is being used experimentally as a concrete supplement to control this heat. Liquid nitrogen can also be used in mix design when placement temperatures and heat of hydration limit placement rates and times.

Formwork

Developments may permit earlier formwork removal, thereby reducing capital outlay for formwork inventory. These developments include accelerators and improved predictability of concrete strength.

Left-in-place formwork can be used more creatively by:

- Integrating formwork and embedments.
- Minimizing attachments by using left-in-place steel formwork for vertical concrete faces.

Other formwork considerations include:

- Large, strategically located metal forms with attached Nelson studs to facilitate formation of vertical faces with numerous embedded plates.
- A mix of form systems using jump, slip, and stay-in-place forms.
- Welded wire fabric as a form.
- Snap ties to improve productivity.

Pour sizes

Pour sizes should be evaluated to ensure that special requirements necessitated by pour sizes are cost-effective for schedule and plant critical paths.

Concrete pumps

Placement productivity is improved by using concrete pumps with mobile conveyor systems and a superplasticized concrete.

Concrete distribution

A centralized concrete distribution system for the entire site would:

- Speed up concrete placement.
- Eliminate reliance on cranes during concrete pours.

Precast concrete

Precast concrete sections could be substituted for block walls, given variables in cost, accessibility, and design. Precast concrete should still be investigated for optimizing concrete placement.

Generic Issues

Structural steel and Q-decks

- Maximize the use of structural steel and centerlock Q-deck. (The Q-deck's seismic qualifications must allow attachment of "unistrut"-type supports.)

Processes

- Reduce construction complexity to help minimize paperwork and job overhead (e.g., by using left-in-place formwork),
- Evaluate process changes to ensure savings are not offset because the changes increase costs to other groups.
- Implement site-specific methods as appropriate, including:
 - Soil freezing
 - Neatline excavation
 - Reinforced earth construction

Conduit raceways and trenches

- Construct accessible conduit raceways inside concrete pours to accommodate cabling (e.g., lighting, multiplex cables, small-bore piping).
- Make certain the conduit raceway design works with all disciplines to provide greater free space by eliminating support steel.
- Use more trenches with grating covers to increase personnel mobility.

Tolerances

- Establish reasonable tolerances that can be met during plant construction (e.g., eliminating pipe hanger tolerances $\pm 1/16"$).
- Locate pipe hangers at limited stress points, which should allow smaller hangers and larger tolerances.
- Make certain tolerances for hangers match building tolerances to lessen drawing changes.

Considerations

- The following should be considered:
 - Reinforcement options (e.g., metallic, nonmetallic, and concrete additives to provide reinforcing characteristics).
 - Reinforcing connection options (e.g., lapped, crimped, screwed, and fused).
 - Concrete additives (e.g., plasticizers and superplasticizers).
 - Formwork options (e.g., more left-in-place forms and Q-deck).

Welding

Introduction

The need to evaluate current designs

In new construction, designers must evaluate revolutionary developments rather than accepting too quickly old methods. The industry should encourage companies with research and development programs to stimulate new ideas, not wait for problems to force innovation. Increased research and development should be used to improve on the "acceptable": more creative or innovative thinking is needed.

Alternatives to welding

The industry should perhaps question the need for a weld created by the design. Design criteria (e.g., intention, pressure, service condition, flow medium) should be considered. Alternatives could include:

- Pipe bending
- Maximizing spool lengths
- Considering erection plan sequence.

Design Considerations

Modeling

Three-dimensional CAD/CAE design modeling holds great promise. The modeling should include detailed construction activities—even minute tasks should be included to ensure construction is sequenced appropriately. This detailing should not, however, replace constructors' accountability. If enough vendors and suppliers adopt CAD systems, the computer language should be standardized in areas such as welding to facilitate communications between the owner and constructor.

Using CAD/CAE modeling

When modular construction is employed, mechanical joints should be used for module connection. Welding and construction engineers should work with plant designers to improve the design for constructability, taking into consideration:

- Limited number of welds and associated ISI points.
- Optimized use of automatic welding on piping, plate, and structure to reduce rejects and resulting paperwork.
- Robotics, using a creative layout for repetitive item configurations (e.g., hangers).
- New techniques such as laser and fusion welding.
- Compatibility of welding material.
- Shop welding and field bolting rather than field welding.
- Sequencing of erection and welding.
- Clearances for in-place automatic welding machines.
- Early identification of ISI welds and acceptable surface finishes.

ASME pipe weld inspections

Difficulties in the past warrant reduction in the number and type of pipe weld inspections for piping that requires lifetime ISI. Weld inspection and documentations performed under ASME Section III is insufficient for pre-service inspection required by Section XI. Experience shows that a weld acceptable by RT examination of Section III can be rejected by a UT examination performed under the pre-service inspection criteria of Section XI. Inspection requirements between ASME Sections III and XI should therefore be made more compatible, with one weld examination satisfying both sections.

Weld joint design

Weld joint design should be standardized for all plant components. A continuity of joint design should exist among designers and suppliers to eliminate welding problems caused by 2 designs' elements in one weld joint.

Post-weld heat treatment (PWHT)

Materials should be selected and designed to eliminate the need for PWHT in containment vessels. PWHT could:

- Be costly and time-consuming.
- Cause unacceptable dimensional changes or distortion.

Weldment design

To improve weldment design:

- Lay out welds to limit factors such as stress intensification. For example, use joint geometries (e.g., narrow-gap welding on heavy wall weldments) in the design.
- Use simpler welds (e.g., replacing full-penetration welds with fillet welds) when possible.
- Improve designs of skewed weld joints.
- Incorporate 3-sided welding, omitting the acute angle.

Increasing designers' welding knowledge

Historically, the designer has always had a lack of welding knowledge. For example, designs have included:

- Incorrect weld symbols
- Misplaced weld locations
- Increased welding difficulty

To increase welding knowledge:

- Review training, using welding engineers as the mediator between design and craft. This process will help include field concerns in the design.
- Establish weld sequences and publish reasons for the sequencing.
- Compensate for perceived field errors by limiting the conservatism built into the design process.

Recommendations

- Take steps to minimize the number of welds and ISI inspections. Pipe routing and pipe bending used as alternatives to fittings will influence the number of welds.
- Use increased standardization to help minimize welding problems because welders and inspectors would not have to know as many codes.

Piping Design

Introduction

Avoiding past problems

The next generation of nuclear plant designers and constructors must be alerted to several past problems and concerns with piping analysis and S/R design. Needs for the future include:

- After a history of overly conservative requirements, stable regulations and regulation interpretation.
- Avoidance of continual regulatory changes to provide "nice to have" requirements.
- To summarize code issues to be pursued, consolidation of regulatory concerns identified in the Design for Constructability Program.
- For piping and equipment erosion, particular attention to:
 - Water chemistry
 - Layup control
 - Coating
 - Material compatibility

Guidelines for Materials

Standard materials

- Eliminate light schedule pipe in system design. Schedule 10 stainless actually requires more fabrication time per weld joint than standard wall piping.
- Standardize pipe sizes, eliminating some intermediate sizes (e.g., 3" pipe). Pipe inventory is then reduced, and unusual reducers and adapters are eliminated.
- Consider stainless-steel lube oil lines. When compared with maintenance costs, the penalty for material cost is minimal for small diameters.

Alternate materials

- When design conditions permit, use polymer material such as PVC, fiberglass, and plastic. Erection time is reduced for applications using alternate materials (e.g., floor drains, sanitary sewers).
- In slab pours, use plastic for embedded items, such as pipe for:
 - Floor and equipment drains
 - Service water
 - Electrical lines
- Use a hot-bend conduit bender.
- Investigate using plastic casting rather than metal casting.
- "Cryofit" couplings where nitrogen bath shrinks as heated. Use this coupling in the slab and out of free space.
- Study the use of alternate materials for pipe support.

CAD/CAE

Benefits of using CAD/CAE

CAD/CAE should be used extensively to design supports and control fabrication. CAD systems should be developed to detail manufacturing steps in support fabrication. If used effectively on piping and support, CAD/CAE could benefit from visualization of comprehensive, up-to-date composite layouts. These benefits include:

- More efficient routing that limits piping and supports.
- Eliminated reserved space interference.
- Direct input to pipe bending and other prefabrication processes.
- Assistance with solving routing and layout concerns.
- Composite hangers, including multi-discipline.
- Construction sequencing and assembly sizing.
- Streamlined procurement.

Pipe and Hangers

Pipe bending

Initial talks on piping focussed on using pipe bending, as discussed in workshop presentations. As Bechtel has already done, pipe bending can easily be incorporated into current CAD/CAE systems.

Impacts on layout and routing

- Longer spools
- Positive impacts on flow characteristics and ALARA considerations, possibly reducing needs for some vents and drains
- Concerns for physically handling larger assemblies
- Pipe flexibility's effects on analysis
- Compensation for outer edge thinning due to corrosion and erosion concerns

Bends vs. fittings

An integrated cost comparison of bends vs. fittings could provide more justification on specific layout. This comparison should include:

- Installation
- Inspection, including ISI
- Documentation
- Inventory
- Use of resources

Suggestions for Piping, Hanger, and Vendors

Piping

- As a standard design practice, use cold or induction pipe bending with CAD 3-D models to:
 - Enhance pipe constructability.
 - Limit pipe welds and lifetime ISI.
- Use embedded conduit and piping to the greatest possible extent without negatively impacting the constructability of structural components (e.g., walls and slabs).
- Eliminate commodity field routing. (Using a 3-D model will lessen, if not eliminate, the need for field routing.)
- Devote more design attention to fluid and gas dynamics in process piping and routing.

Hangers

- In design, minimize the number of pipe hangers, including a reevaluation of stress analysis and seismic criteria.
- Shift peak of response spectra to reduce seismic loads and snubber requirements.
- Use rigid valves rather than nonrigid valves. Nonrigid valves amplify valve response and could require additional supports on the valve body and operator.
- Standardize cone angles on reducers. Higher pipe stresses on some reducer designs dictate additional pipe hangers or higher schedule pipe.
- Remove excess conservatism from vendor nozzle allowances. Additional pipe hangers have been required to reduce loads at equipment nozzles.
- Design support systems to be more flexible, lowering seismic loads.
- Use multi-discipline composite supports as much as possible, including piping, HVAC, instrumentation, and cabling.
- As much as possible, standardize details of pipe support configurations while using component part size and fabrication details (e.g., not using TS 4 x 4 when TS 3 x 3 works; not welding an entire joint if less weld will qualify).
- Have welding engineers provide input on standard fabrication details.
- Standardize or eliminate NF requirements so interpretation is identical between sites. Many participants feel that supports and restraints should be designed and qualified to AWS rather than ASME NF.
- Develop and standardize more realistic and achievable installation and fabrication tolerances for piping and hangers, including construction guidelines to prevent tolerances from being compounded by worst-case scenarios.
- Explore induction bending of structural shapes for use in pipe hangers.

- Combine personnel access/walks on support systems.
- Consider reducing supports by using more dedicated tunnels and chases for placing piping and cabling.

Vendors

- To assure quality components, send construction personnel to the vendor shops. These personnel should include field engineers who will evaluate the acceptance at different intervals of material selection and fabrication.
- Make certain the engineers inspecting material selection and fabrication understand the vendor's processes.
- Become involved early with the vendor to ensure that the vendor fully understands the expected acceptance criteria.
- Later in fabrication, send QC inspectors to make specific audit inspections.
- If needed, encourage other constructors to establish a global construction schedule to prevent manufacturers from building excess plant capacity to fill cyclical need. The last period of nuclear plant construction saw a number of plants simultaneously under construction across the country. This amount of construction created a short-term scheduling problem for vendors who found many customers competing for the vendors' goods and services.

Recommendations and Considerations

Recommendations

- Pursue continued improvements in piping and supports.
- Because it is practical with current technology, use cold bending for pipe sizes below 6 inches.
- Remember that pipe bending can have significant impacts, including:
 - Use of longer pipe spools.
 - Help with flow characteristics.
 - Benefits in ALARA considerations and seismic analysis.

Considerations

- Alternate piping materials should be considered, including:
 - Hot and cold pipe bending
 - Plastics
 - Polymer materials (e.g., PVC, fiberglass)
 - Alternate material applications (e.g., stainless lube oil lines)
- Every effort should be made to reevaluate and simplify current approaches to stress analysis and pipe support.
- A maintenance-free replacement component for snubbers should be developed.

Electrical Design

Technological Changes

Effects of new electrical technology

Rapid advances in the electrical field make technological changes very difficult to predict. For example: Alternatives to termination and penetration areas will be developed. Multiplexing and fiber optics will significantly impact design, construction, and inspections.

The next generation of constructors must thoroughly evaluate these technologies to assess how the advances apply to their generation. Many feel that this assessment will involve a review of some nonnuclear fields (e.g., petro-chemical, communication), where state-of-the-art technologies will be developed over the next few years.

The need for technology

The nuclear industry must learn from other industries' use of technology. For example, the "elder statesmen" designers should be reeducated to seek new, innovative design techniques.

Cables

Use of electrical cables should be minimized and, if possible, replaced with:

- Fiber optics extensively for control circuitry.
- Multiplexing, which is a proven technology.

Relaying should be modernized with state-of-the-art systems (e.g., microprocessor control logic). In addition to reducing cabling, microprocessors improve termination operation and maintenance because microprocessor controls are self-diagnostic.

Alternate materials

The electrical field is a good area in which to consider using alternate materials, including:

- Armored cable, already used successfully
- Plastics, with caution for PVC concerns
- Alternate jacketing materials

Armored cable: Should save significant costs in conduit and supports. Evaluate using armored cable based on the estimated number of cables in future ALWR (e.g., 40 % reduction in I&C cables). Armored cable:

- May be cost-effective for larger power cables because of inherent rugged characteristics to withstand construction activities.
- Is flexible.

- Can be installed in trays, eliminating unnecessary rigid conduit.

Evaluate armored cable based on:

- Size
- Quantity
- Usage
- Replacement costs

Supports

The concerns and remedies for cable tray supports resemble those for pipe supports:

- Simplification
- Limited welding
- Alternate materials

Structural bending may also be used on tray supports. One innovative approach is to integrate personnel access galleries or walkways with the trays and supports.

CAD/CAE**Using CAD/CAE**

CAD/CAE is another area where up-front design and effective use will reap many benefits, including:

- Optimized cable routing
- Fewer design changes
- Possible use of cable trenches and false floors
- Optimized embedments, including conduits
- Plant life extension data
- Interactive design, to help move electrical tasks off the customary spot on critical path
- Early investigation of fire protection and electrical relationships

Design Considerations

Cables

- Coordinate cable and tray routing so that tray overfilling or significant underfilling is eliminated.
- Evaluate cable sizing based on service requirements rather than ability to withstand construction and maintenance activities.
- Size cable according to real load requirements instead of using standard design assumptions. For example, if load demands #18, use it—do not use a standard #14 because of design consistency.
- Make certain that equipment is properly sized for the cables to which they terminate.
- Enhance cabinet termination design for easier installation and testing.

Local control

- Use programmable controller and electronic devices to lower control voltages and improve local control.
- Evaluate the need for local control stations vs. remote control for equipment operations. Lowering local redundant controls can reduce costs, and many local controls are unnecessary for safe plant operations.

Power sources

- Choose the best power source locations to reduce cable length (e.g., moving closer to the load) and conductor sizes.
- When designing power sources, consider maintenance and modifications. Currently this power is not provided, so plant personnel must locate temporary sources.

Design by area

- Use area terminal cabinets and consolidate tables by area to:
 - Allow cables between electrical equipment to be pulled and terminated sooner.
 - Eliminate waiting period for items such as remote mounted equipment and instrument valves to be installed.
 - Shorten the lengths of most cables.
 - Possibly facilitate use of fiber optic cables.

Large equipment

- To allow electrical work to begin, investigate locating and installing large electrical equipment (control boards) as soon as possible.

Termination blocks and lugs

- Size termination blocks and lugs to be compatible with cabling and equipment. Experience has shown that termination lugs were too small for cabling runs between termination points.
- Limit terminations with plug-in connection because they require more labor. Termination blocks are more cost-effective and reliable.

Supports

- Early in the project, establish cable support requirements that all personnel understand.
- Limit welding on electrical supports—use more bolting clips and threaded-type studs.

Cable trays and separation

- Establish separation requirements early in the project.
- Use cable trays rather than conduits, but keep separation criteria in mind.
- Because cable separation is difficult to maintain and verify during construction, investigate separation requirements using fiber optics and low voltage/low control methods.

Contractors

- Beware of contractor changes to requirements that could increase costs.

Conduit

- Use embedded conduit as much as possible.
- When required, use electric metal tubing instead of rigid steel for exposed conduit.
- Make certain conduit is embedded in concrete pours to eliminate conduit hangers and potential interferences.
- Remember that embedding conduit is more practical when design is completed before construction starts.

Trenches

- Use more underground precast concrete trenches for outside cable routing.
- Design trenches for construction loads to permit flexibility in the yard area, because construction loads are the most severe.

Ground protection circuits

- Optimize ground protection circuits in plant to improve constructability. These circuits may allow use of plastic boxes rather than metal boxes.

Conductors

- Consider using aluminum conductors, rather than copper, for power cables (e.g., #2 or greater). Compression fittings and more effective seals have solved past technical problems with aluminum cables, creep, and poulitice phenomena.

Construction Considerations

Lighting

- In areas with high maintenance costs, use DC circuits for incandescent lighting.
- Use 3-dimensional modeling to help in designing the lighting layout.
- When designing lighting, consider the installation schedule to minimize the use of temporary rope lights.
- Reevaluate field run lighting practices.
- Study concerns posed for generating mercury through the failure of fluorescent lights inside containment.

Mechanical equipment

- Locate mechanical equipment (e.g., valves, motors) to facilitate electrical installation.

Cable trays and conduit supports

- In initial design of cable trays and conduit support, include seismic movement and the potential for adding loads.

Electrical penetrations and embedded conduit

- Locate electrical penetrations and embedded conduit on civil drawings to make certain these items were not overlooked.

Locking fork terminations

- To improve termination time in the field, use locking fork terminations instead of normally expected ring tongue terminations.

Motor-operated valves

- Devote effort to eliminating problems with motor-operated valves.
- Avoid relying on one brand of motor-operated valve.

Access areas

- Identify early the access areas needed for maintenance that must remain clear during construction. These areas would include:
 - Pump maintenance areas
 - Areas for pulling heat exchanger tubes, motors, and pumps
 - Areas around electrical control panels and cabinets

Future Studies

Fiber optics

Fiber optics manufacturers should be asked to develop a training program to educate designers in that area. This training will help change established mindsets within the design organizations.

Recommendations, Considerations, and Cautions

Recommendations

- Use fiber optics and multiplexing to benefit future plant construction. Advances in these areas, which may reduce cable amount, should be pursued.

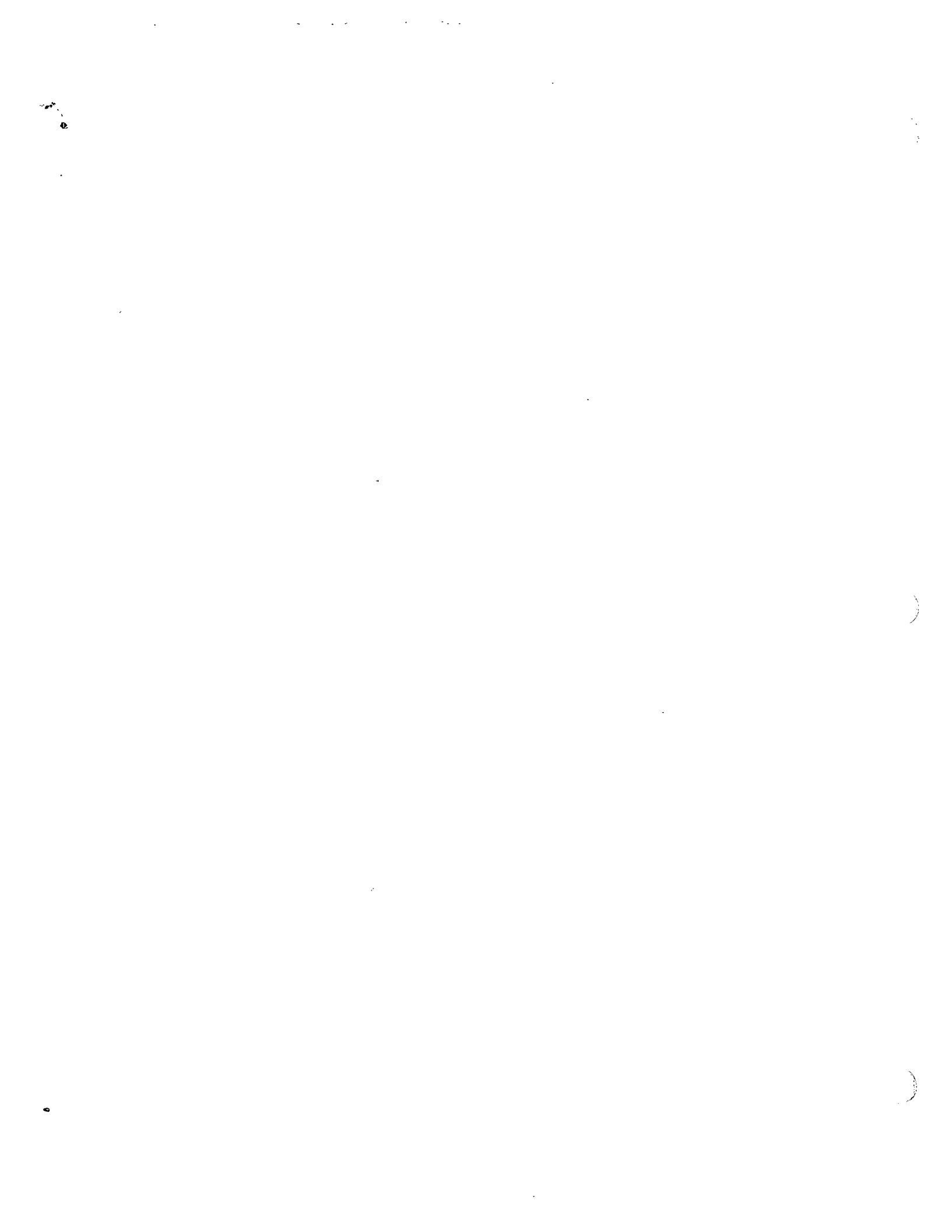
Considerations

- The electrical area is prime for alternate materials such as:
 - Armored cable
 - Plastics
 - Support materials, possibly including structural bending
 - Fiber optics
 - Aluminum vs. copper conductors
- Cable tray supports should be considered.
- Integrating walkways with cable trays and supports improves access.
- Using more sensitive electronic components will require improved protection to avoid impact of climate control and housekeeping during construction.
- Use of CAD/CAE can have many benefits, including investigation of train separation and fire protection.

Cautions

- Fewer local redundant controls (the "nice to have" approach of the past) may be possible with reevaluation of requirements for safe plant operation.
- Standardized cable specifications could prevent problems with differences between vendor requirements (e.g., bend radius, pull tension), which can be overly conservative.

Appendix A. Excerpts From Initial Bechtel Arrangements



EPRI ADVANCED LWR PROGRAM

CONCEPTUAL PWR GENERAL ARRANGEMENT STUDY

RP 2660-15

Progress Status Report, February 12, 1988

Prepared For: Electric Research Power Institute

By: Bechtel Group, Inc.

CONCEPTUAL PWR GENERAL ARRANGEMENT STUDY

CONTENTS

SECTION 1	Alternate Containment Types
SECTION 2	Bases For Plant Arrangement Selection
	2A - Nuclear Island
	2B - Turbine Island
SECTION 3	Reference Plant Arrangement Options
SECTION 4	Study Conclusions
	4A - General Arrangement Drawings
	4B - Site Arrangement Drawings
	4C - Divisional Separation Drawings
	4D - Personnel Access Drawings
	4E - Equipment Removal Drawings
APPENDIX A	Equipment List

SECTION 1

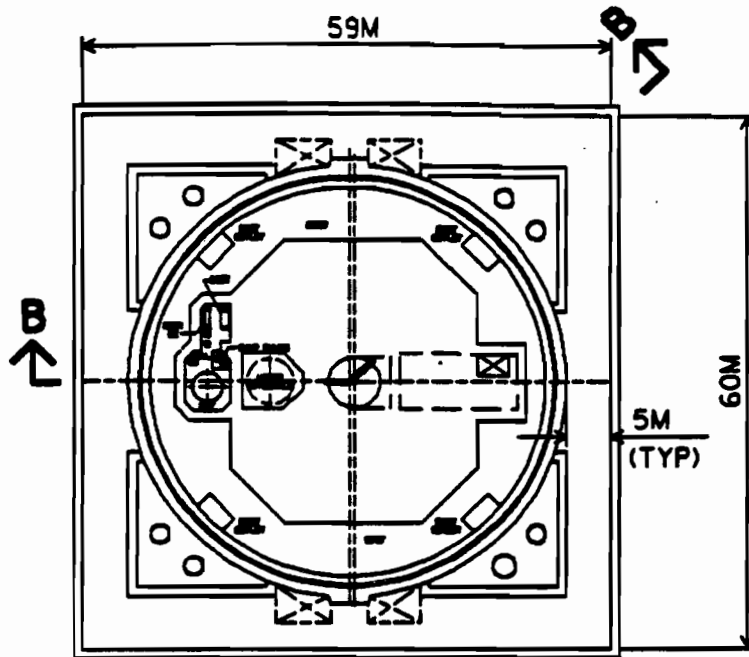
ALTERNATE CONTAINMENT TYPES

Figures 1-1 through 1-6 illustrate selected containment types and their interface with support systems and structure. They also show a comparison of the effect of containment type on basemat dimensions assuming a nominal 5M access corridor around the building.

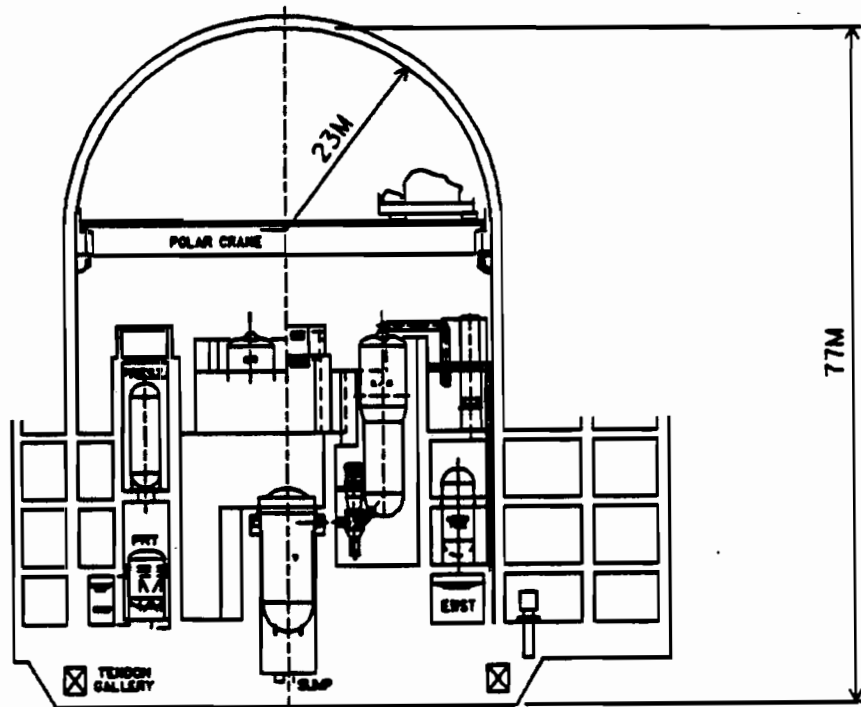
These sketches are for information purposes only and are not intended to prejudge the relative merits of the building configuration shown.

PRESTRESSED CONCRETE CONTAINMENT VESSEL

PCCV



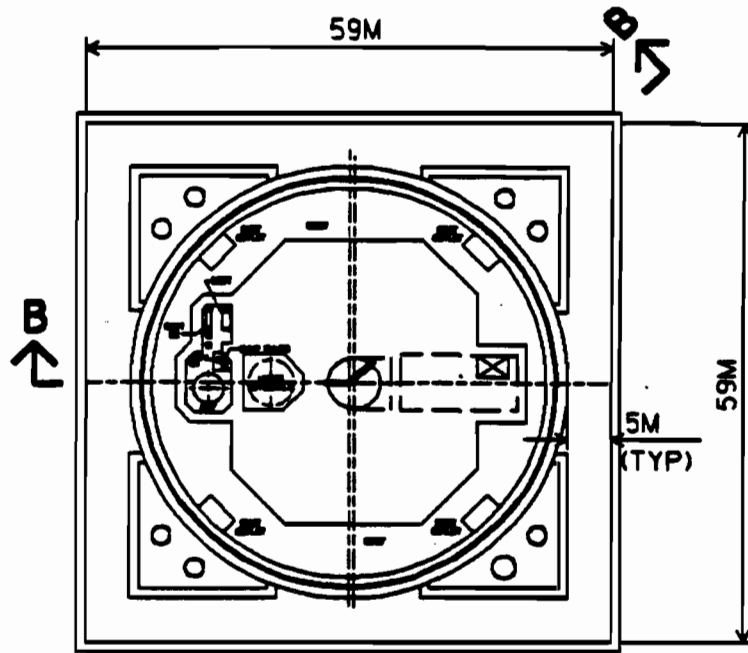
BASE LEVEL PLAN



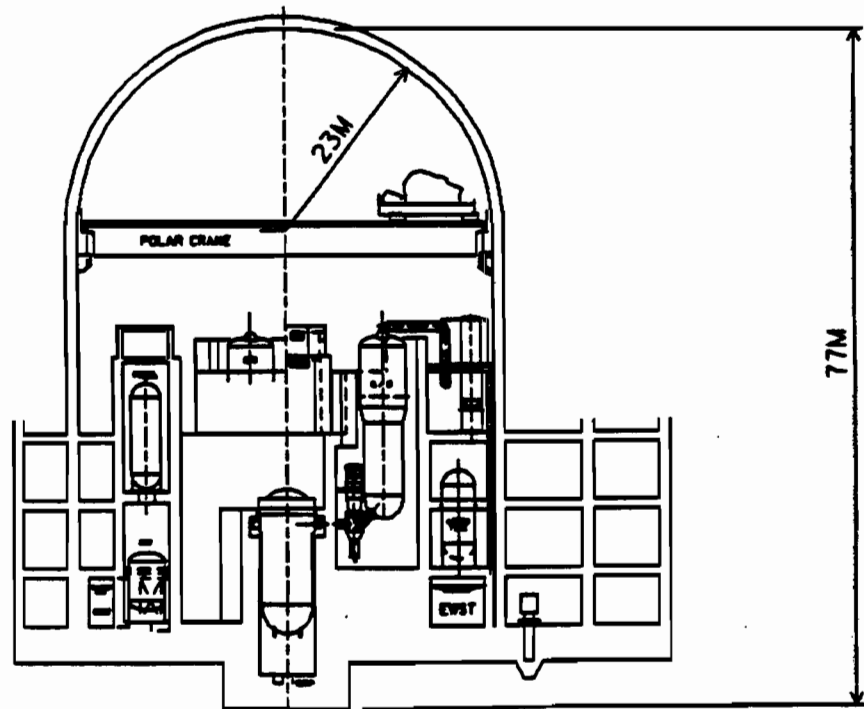
SECTION B-B

REINFORCED CONCRETE CONTAINMENT VESSEL

RCCV



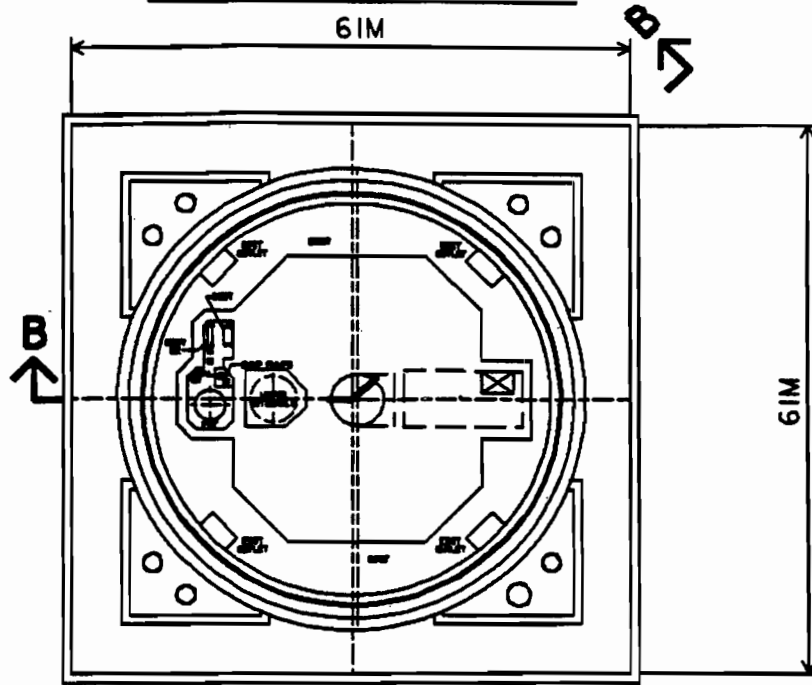
BASE LEVEL PLAN



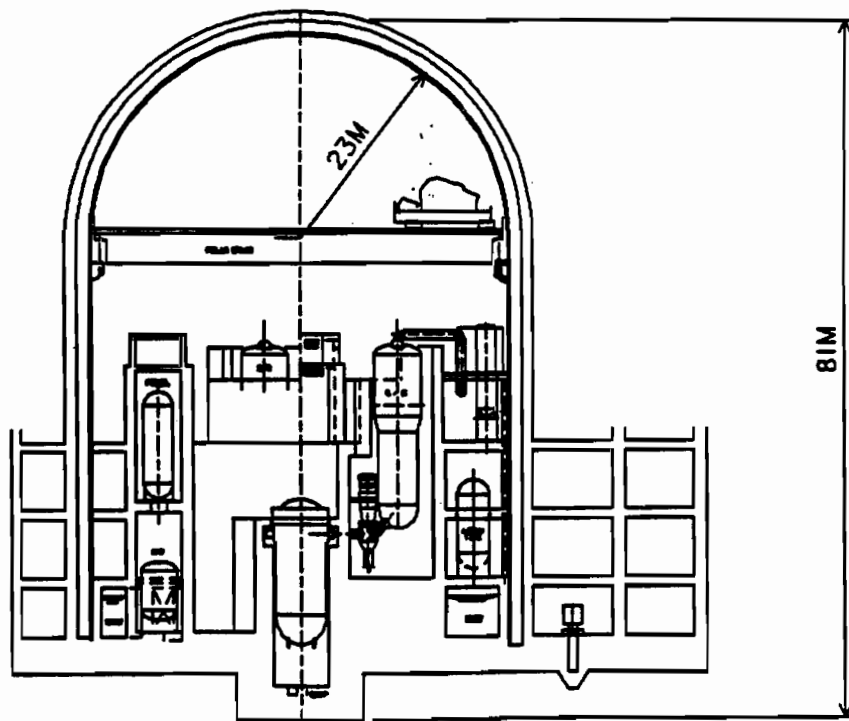
SECTION B-B

CYLINDRICAL STEEL CONTAINMENT VESSEL

CSCV - FLAT BOTTOM



BASE LEVEL PLAN

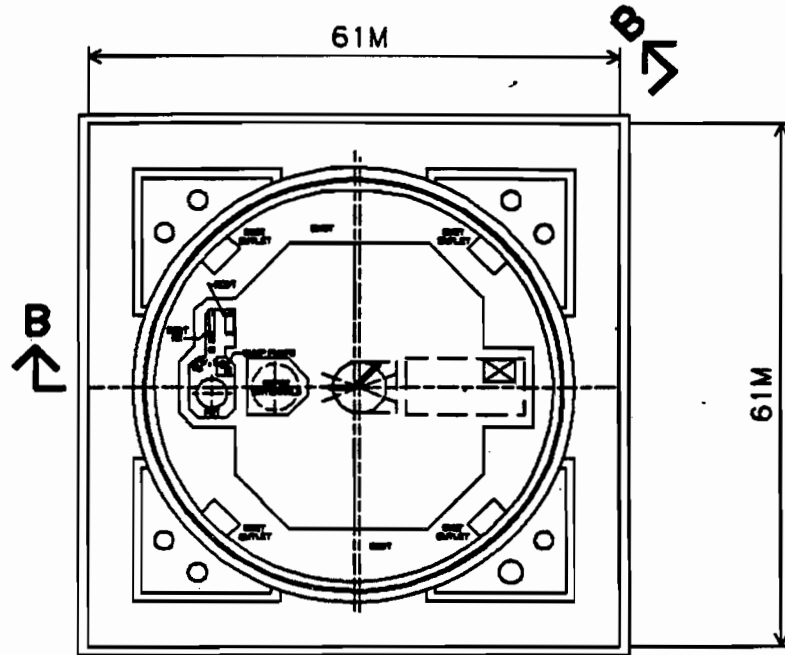


SECTION B-B

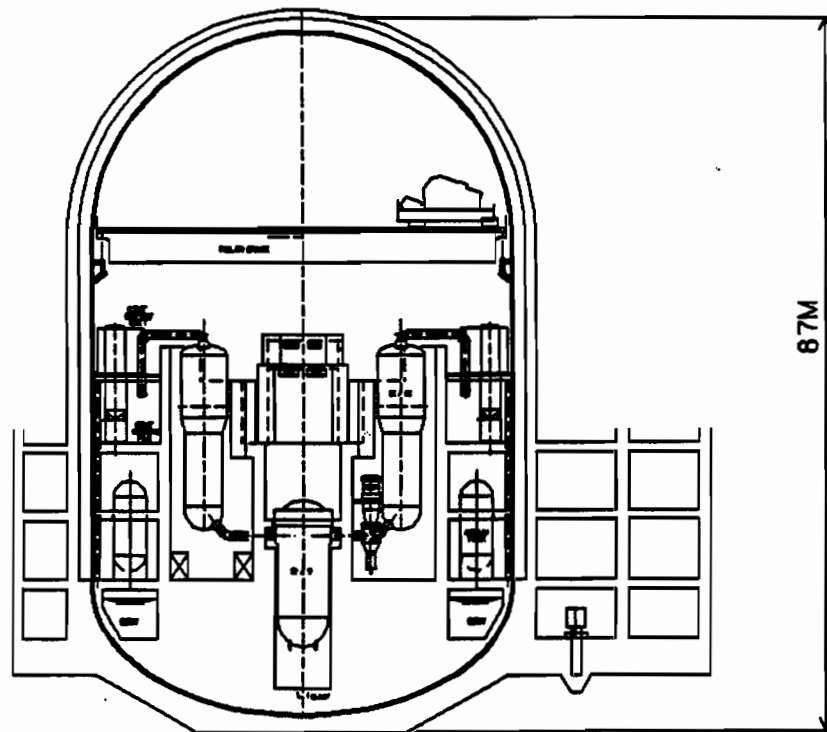
1957A DCM 10-19-87 VAL VTP-6.6667

SPROUC

CYLINDRICAL STEEL CONTAINMENT VESSEL
CSCV - DISHED BOTTOM



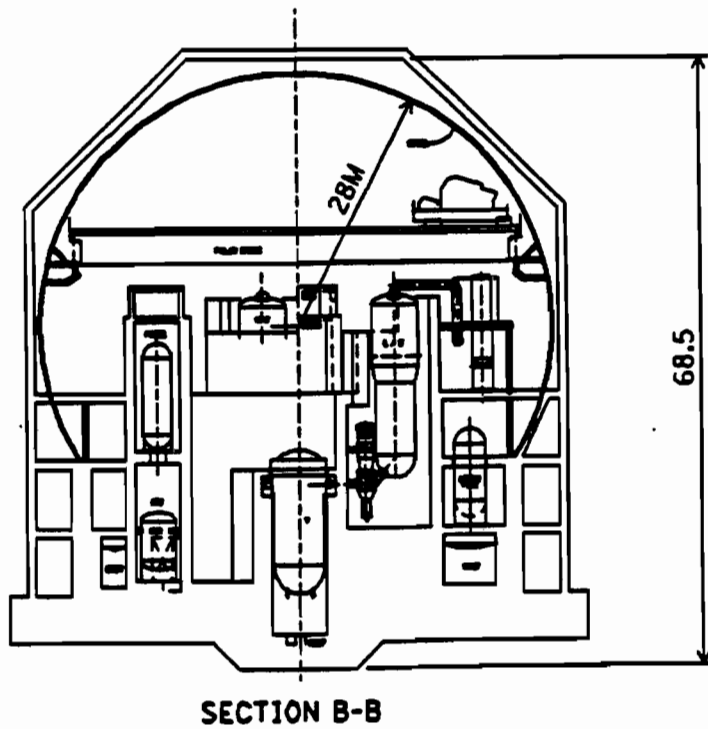
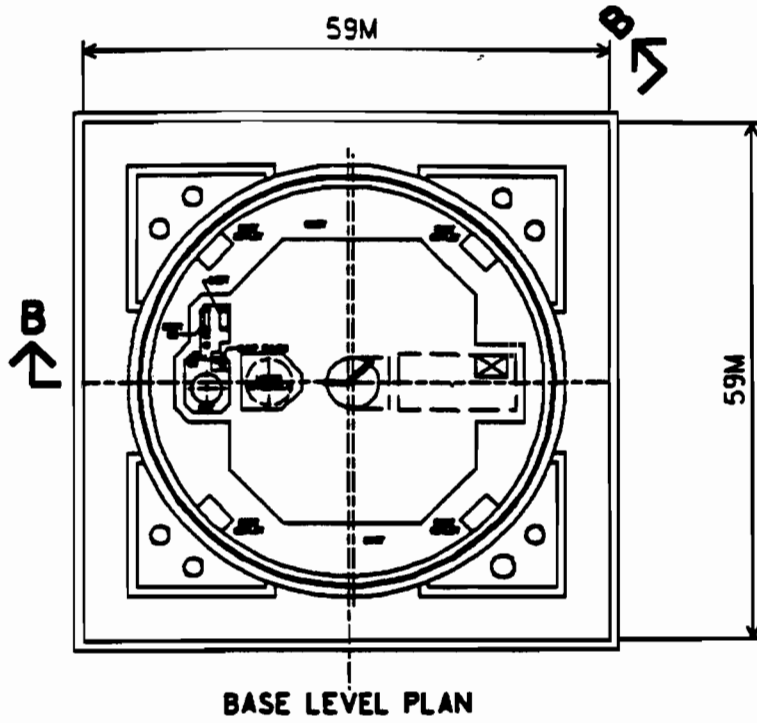
BASE LEVEL PLAN



SECTION B-B

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HYBRID SSCV & RCCV



57000001 000 10-19-07 V4

FIG 1-6

SECTION 2

BASES FOR PLANT ARRANGEMENT SELECTION

Section 2 outlines what is considered to be general requirements for an efficient plant arrangement and the layout preferences thought to be applicable to each system, particularly those affected by the Advanced PWR system changes. Also included is an evaluation of location options taken from a cross section of existing designs.

LAYOUT GENERAL REQUIREMENTS

1. PLANT ARRANGEMENT MUST BE CONDUCTIVE TO SHORTENING CONSTRUCTION COSTS AND SCHEDULE.
2. EMBEDMENT DEPTH SHOULD BE MINIMIZED BUT THE ARRANGEMENT SHOULD ALLOW FLEXIBILITY TO SUIT VARIATION IN SOIL CONDITIONS.
3. MAINTENANCE AND REMOVAL OF EQUIPMENT MUST BE PROVIDED FOR.
4. SEPARATED ACCESS ROUTES SHALL BE PROVIDED TO BOTH CONTROLLED AND UNCONTROLLED ACCESS AREAS.
5. SAFETY RELATED COMPONENTS SHALL HAVE PHYSICAL BARRIERS BETWEEN DIVISIONS.
6. SPENT FUEL STORAGE CAPACITY IS 3 FULL CORES.
7. MAIN ACCESS AND EQUIPMENT REMOVAL AISLES WILL GENERALLY PROVIDE A MINIMUM CLEAR SPACE OF 12FT (3.6M) WIDE BY 8FT (2.4M) HIGH.
8. DIRECT ACCESS TO CONTAINMENT OVER AT LEAST A 90 DEGREE SECTOR, FOR EASIER CONSTRUCTION AND MAINTENANCE ACCESS.
9. THE TURBINE BUILDING ORIENTATION RELATIVE TO THE REACTOR BUILDING SHALL BE INLINE WITH THE MAIN STEAM LINE - FUEL POOL AXIS. (I-TYPE)

SUB-SECTION 2A

NUCLEAR ISLAND

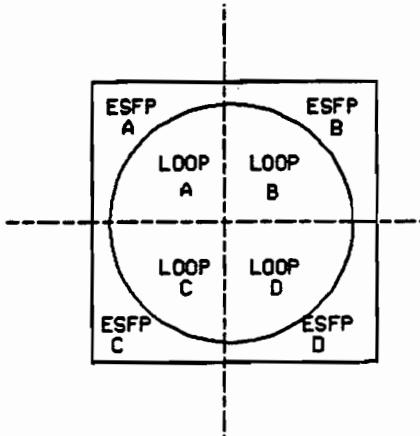
LAYOUT PREFERENCES

ESF PUMPS

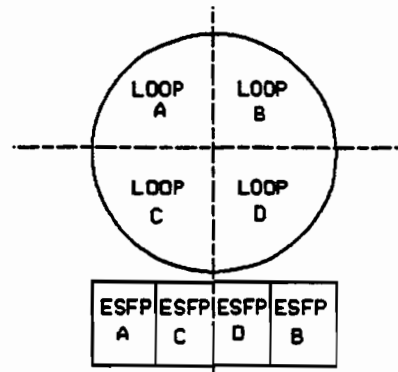
PREFERENCE	REASON
1. LOCATION SHOULD BE DIRECTLY ADJACENT TO EACH PRIMARY LOOP	BECAUSE THE PWR HAS 4 DIVISIONS OF PRIMARY SAFETY PUMPS IT IS DESIRABLE TO KEEP THE PRIMARY PIPING AS SHORT AS POSSIBLE AND IDENTICAL FOR EACH LOOP.
2. VERTICAL ESF PUMPS	PROVIDE NPSH REQUIREMENTS WITHOUT DEPRESSING THE BASEMAT
3. ESF ROOMS SHOULD BE ON THE SAME BASEMAT AS THE CONTAINMENT	AVOID RISK OF SETTLEMENT AND PROVIDE SEISMIC STABILITY FOR ROOMS THAT ARE AWAY FROM ADJACENT CAT 1 BUILDINGS

LOCATION OPTIONS

ESF PUMPS



OPTION "A"
*



OPTION "B"

- SHORT PIPING RUNS BETWEEN PRIMARY LOOP, PUMPS AND RHR HX.
- ALLOWS SIMILAR PIPE ROUTING FOR EACH DIVISION.
- LONGER ELECTRICAL CABLE AND COOLING WATER PIPING

- DIFFICULT PIPE ROUTING FROM "A" AND "B" LOOPS.
- SHORTER ELECTRICAL CONNECTIONS

* BEST MEETS LAYOUT PREFERENCE

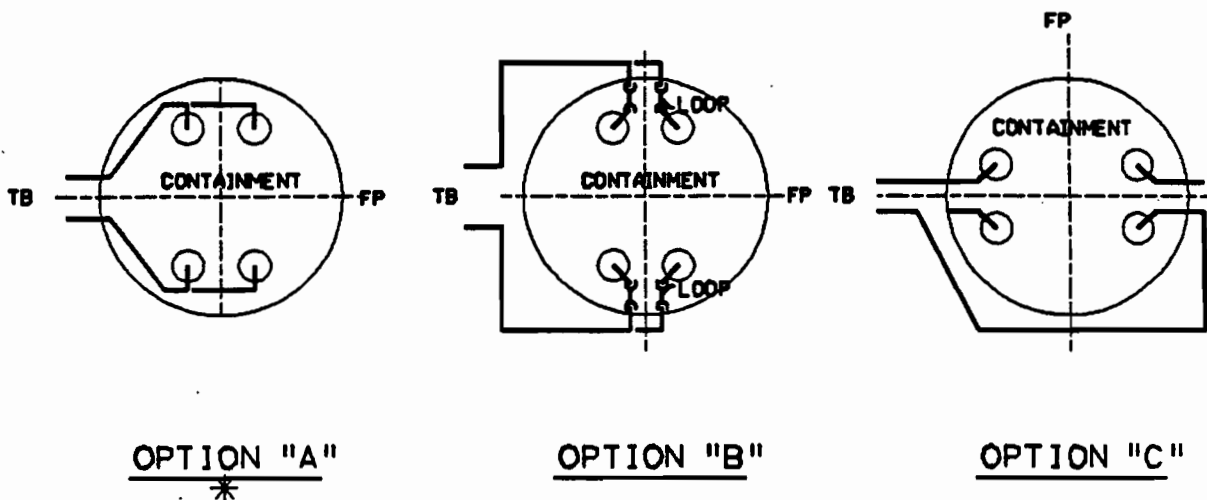
LAYOUT PREFERENCES

MAIN STEAM TUNNEL

PREFERENCE -----	REASON -----
1. A SINGLE TUNNEL SHOULD BE USED FOR THE 4 MSL AND 4 MFWL	PROVIDE SUFFICIENT TUNNEL AIR SPACE TO AVOID EXCESSIVE PIPE BREAK COMPARTMENT PRESSURIZATION WHILE MINIMIZING COST
2. TUNNEL SHOULD BE LOCATED ON THE CONTAINMENT REFUELING CAVITY AXIS	PERMIT SYMETRICAL ROUTING OF THE MSL AND MFWL INSIDE CONTAINMENT AND FACILITATE ACCESS FROM THE CLEAN SIDE OF THE PLANT

LOCATION OPTIONS

MAIN STEAM LINE ROUTING PATH



- DIRECT ROUTING TO TURBINE BUILDING
- NO ADDITIONAL PIPE REQUIRED FOR THERMAL STRESS.
- MSIV \square AND MFIV \square ARE LOCATED IN THE SAME AREA.

- LONGER PIPING TO TURBINE BUILDING.
- MAY REQUIRE STRESS LOOP INSIDE CONTAINMENT.
- REDUCES MSL AND MFL LENGTH INSIDE CONTAINMENT.

- LONGER PIPING TO TURBINE BUILDING.
- UNBALANCED FLOW CONDITIONS

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

EMERGENCY FEED WATER SYSTEM

PREFERENCE

REASON

1. EFWS LOCATION SHOULD BE CLOSE
TO THE MAIN STEAM TUNNEL

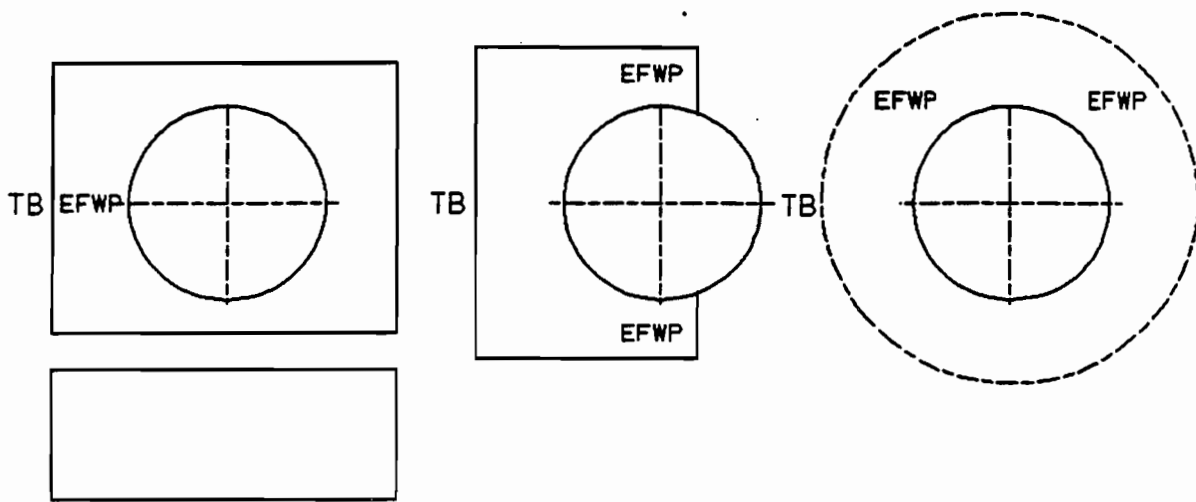
TO MINIMIZE PIPING LENGTH FOR
EMERGENCY FEED WATER SUPPLY
AND EFWS TURBINE STEAM SUPPLY.
THIS LOCATION IS IN THE NON-
CONTAMINATED SIDE OF THE PLANT
SIMPLIFYING ACCESS

2. SPACE IS REQUIRED FOR PUMP AND
TURBINE LAYDOWN

PROVIDE FOR MAINTENANCE

LOCATION OPTIONS

EMERGENCY FEEDWATER PUMPS



OPTION "A"

*

o NEAR MS AND FW LINES

OPTION "B"

o NEAR MS AND FW LINES

OPTION "C"

o LONGER CONNECTION TO MS AND FW LINES.

* BEST MEETS LAYOUT PREFERENCE

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LAYOUT PREFERENCES

FUEL POOL

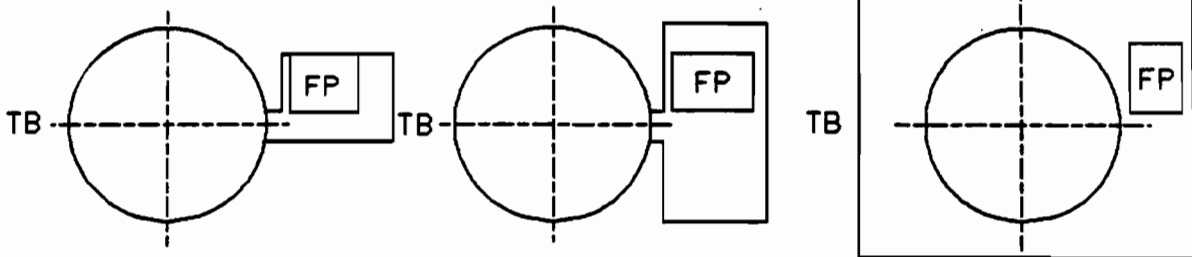
PREFERENCES

REASON

- | | |
|---|--|
| 1. THE FUEL POOL SHALL BE LOCATED AS CLOSE AS POSSIBLE TO THE REFUELING CAVITY INSIDE CONTAINMENT | TO MINIMIZE THE LENGTH OF SPENT FUEL TRANSFER AND RELATED SHIELDING REQUIREMENTS AND COSTS |
| 2. THE CASK REMOVAL CRANE PATH SHALL NOT PASS OVER THE POOL | TO MINIMIZE THE RISK OF FUEL DAMAGE |
| 3. THE CASK HANDLING LIFT HEIGHT SHALL BE MINIMIZED | TO MINIMIZE THE RISK OF SPENT FUEL CASK DAMAGE |
| 4. THE POOL SHALL BE LOCATED AT THE FUEL BUILDING BASEMAT LEVEL | TO SIMPLIFY STRUCTURAL DESIGN AND REDUCE QUANTITIES |
| 5. FUEL POOL SYSTEMS SHALL BE LOCATED NEAR OTHER CONTROLLED ACCESS AREAS OF THE PLANT | TO SIMPLIFY PERSONNEL TRAFFIC AND REDUCE PIPING LENGTH |

LOCATION OPTIONS

FUEL POOL



OPTION "A"
*

OPTION "B"
*

OPTION "C"

○ FUEL POOL LOCATED
AT BASEMAT LEVEL.

○ FUEL POOL LOCATED
AT BASEMAT LEVEL.

○ ELEVATED FUEL POOL

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

CVCS SYSTEM

PREFERENCES

REASONS

- | | |
|--|---|
| 1. LOCATION AS CLOSE TO CONTAINMENT PENETRATION AS POSSIBLE | TO MINIMIZE ROUTING OF PRIMARY COOLANT PIPING |
| 2. FILTERS AND DEMINERALIZERS TO BE PROVIDED WITH VALVE ROOMS | TO MEET ALARA REQUIREMENTS |
| 3. FILTERS AND DEMINERALIZERS SHOULD BE LOCATED CLOSE TO RADWASTE SYSTEM AREAS | TO MINIMIZE WASTE TRANSFER PIPING LENGTH |

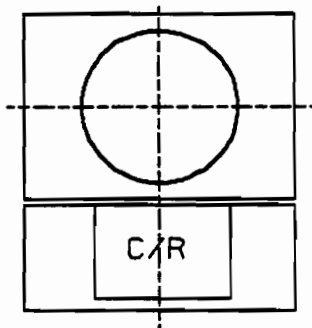
LAYOUT PREFERENCES

CONTROL/ELECTRICAL FACILITY

<u>PREFERENCES</u>	<u>REASONS</u>
1. LOCATION CLOSE TO CG OF POWER BLOCK AND ON OR NEAR ONE CONTAINMENT/ESF DIVISIONAL AXIS OF SYMETRY	MINIMIZE LENGTH OF CABLE FROM R/B, T/B AND A/B AND FACILITATE DIVISIONAL SEPARATION
2. ELEVATION SUCH THAT C/S ROOM APPROXIMATES CONTAINMENT PENETRATION ROOMS AND BULK ROUTING LEVELS.	MINIMIZE CABLE AND AVOID SCHEDULE IMPACT.
3. UNLESS A MAJOR ADVANTAGE RESULTS THE C/R SHOULD NOT BE LOCATED NEXT TO HIGH ENERGY PIPING	ALTHOUGH NOT CRITERIA THIS IS EXPECTED TO BE AN NRC PREFERENCE
4. HABITABILITY, OFFICE SPACE AND COMPUTER ROOM AT THE SAME LEVEL AS THE C/R	TO HELP OPERATORS STAY AT OR NEAR THEIR CONTROL ROOM WORK STATION
5. A TECHNICAL SUPPORT CENTER OF APPROXIMATELY 1200 SQ.FT. AT THE SAME FLOOR LEVEL AS THE C/R	TO IMPROVE COMMUNICATION WITH PLANT OPERATORS
6. A SINGLE COMBINED FIELD CABLE TERMINATION CABINET AND CABLE ROOM	ADVANCED CONTROL SYSTEMS DO NOT REQUIRE AN UPPER AND LOWER CABLE SPREADING ROOM

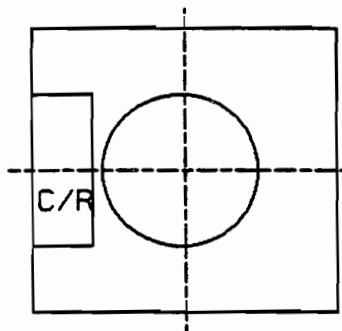
LOCATION OPTIONS

CONTROL ROOM

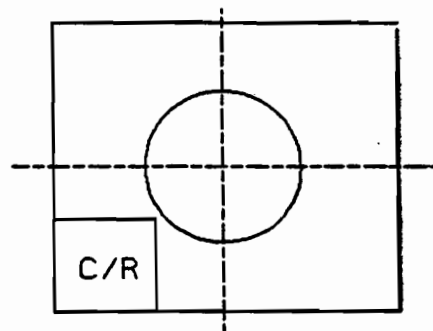


OPTION "A"

*



OPTION "B"



OPTION "C"

- ◻ ELEVATION IS NOT AFFECTED BY OTHER SYSTEMS.
- ◻ CONSTRUCTION IS INDEPENDENT OF R/B.

- ◻ CENTRALIZED PLANT LOCATION.
- ◻ PROXIMITY TO MS & FW LINES.

- ◻ MS TUNNEL AND CONTAINMENT RESTRICT ACCESS.
- ◻ PROXIMITY TO MS & FW LINES.

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

COMPONENT COOLING WATER

PREFERENCES -----	REASONS -----
1. SHOULD BE LOCATED NEAR MAIN COOLING LOADS, PARTICULARLY RHR AND LETDOWN HX	TO REDUCE PIPING LENGTH AND PUMPING POWER
2. SHOULD BE LOCATED AT OR NEAR CLEAN/CONTROLLED ACCESS BOUNDARY	TO FACILITATE OPERATION IN THE EVENT OF ACCIDENTAL CONTAMINATION
3. SHOULD BE LOCATED AT OR NEAR DIVISION AXIS OF SYMETRY	TO FACILITATE DIVISIONAL SEPARATION AND MINIMIZE PIPING LENGTH
4. DIRECT HX TUBE REMOVAL TO OUTSIDE OF BUILDING	ECONOMY OF SPACE UTILIZATION

LAYOUT PREFERENCES

DIESEL GENERATORS

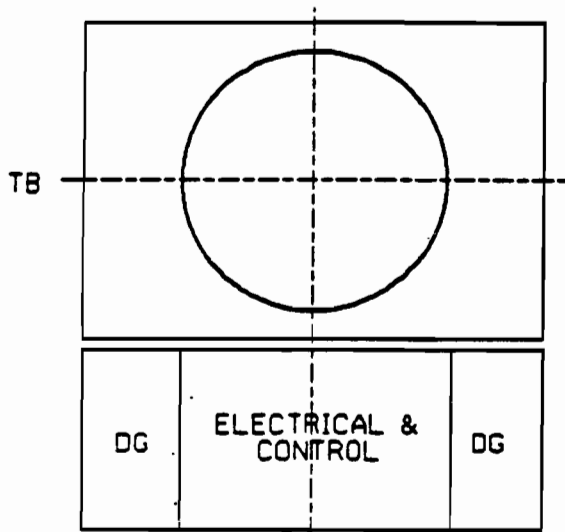
PREFERENCES

REASONS

- | | |
|---|---|
| 1. LOCATED OUTSIDE OF NORMALLY HABITATED OR SENSITIVE INSTRUMENTATION BUILDINGS | TO MINIMIZE POTENTIAL NOISE AND VIBRATION |
| 2. LOCATED AT GRADE LEVEL | TO SIMPLIFY INSTALLATION AND MAJOR OVERHAUL MAINTENANCE |
| 3. BASEMAT FOUNDATION | TO SIMPLIFY STRUCTURAL DESIGN |
| 4. LOCATED IN SAME AREA | TO SIMPLIFY FUEL ROUTING FROM STORAGE TANKS |
| 5. EXHAUST LOCATED AWAY FROM VENTILATION INLETS | TO PREVENT EXHAUST FUMES FROM ENTERING BUILDINGS |

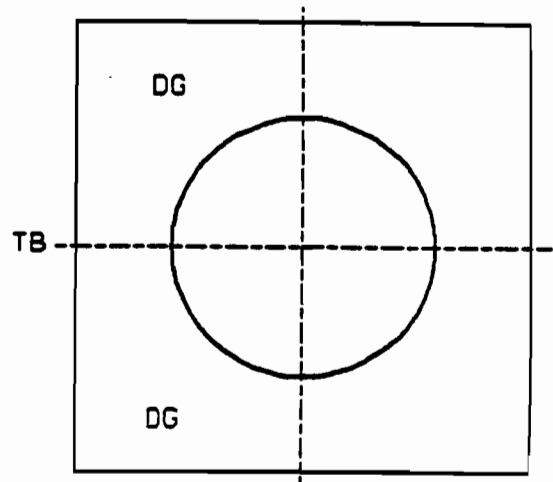
LOCATION OPTIONS

DIESEL GENERATORS (SHARED BUILDING)



OPTION "A"

- MAY PRESENT VIBRATION PROBLEMS TO CONTROL ROOM.
- DIFFICULT EXHAUST PATH

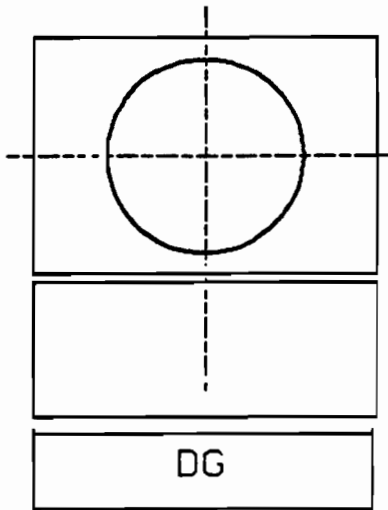


OPTION "B"

- MAY PRESENT VIBRATION PROBLEMS TO CONTROL ROOM.
- DIFFICULT EXHAUST PATH
- DIFFICULT FUEL SUPPLY ROUTING AND PERSONNEL ACCESS.

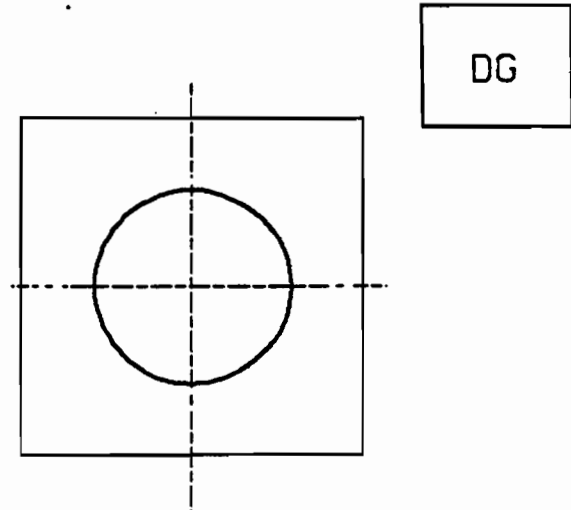
LOCATION OPTIONS

DIESEL GENERATORS (SEPARATE BUILDING)



OPTION "C"

*



OPTION "D"

- o NO EFFECT ON OTHER SYSTEMS
- o POTENTIAL FOR IMPROVED EXHAUST RELEASE.

- o NO EFFECT ON OTHER SYSTEMS
- o POTENTIAL FOR IMPROVED EXHAUST RELEASE.
- o LONGER COMMUNICATION TO CONTROL ROOM.
- o PERSONNEL AND SECURITY ACCESS IS REMOTE.

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

RADWASTE

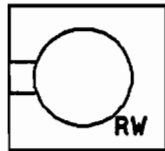
PREFERENCES

REASONS

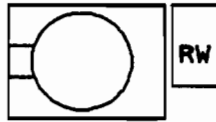
- | | |
|---|---|
| 1. SHOULD NOT IMPACT CONSTRUCTION OF BUILDING ON CRITICAL PATH | TO MINIMIZE CONSTRUCTION SCHEDULE |
| 2. SHOULD BE LOCATED NEAR OTHER CONTROLLED ACCESS AREAS, CVCS AND FUEL POOL SUPPORT SYSTEMS | TO FACILITATE PERSONNEL TRAFFIC AND REDUCE CONTAMINATED PIPING LENGTH |
| 3. SHOULD HAVE SOME FLEXIBILITY IN BUILDING LOCATION | TO ACCOMODATE POSSIBLE SITE LIMITATIONS AND MULTI UNIT CONFIGURATIONS |
| 4. SHOULD HAVE FREE SPACE AVAILABLE ADJACENT TO THE RADWASTE BUILDING | TO ACCOMODATE POSSIBLE SYSTEM EXPANSION AND MODIFICATION |
| 5. SHOULD BE NEAR A DEDICATED SITE STORAGE AREA | TO PERMIT EASY TRANSFER TO AND FROM ON SITE STORAGE FACILITY |

LOCATION OPTIONS

RADWASTE BUILDING

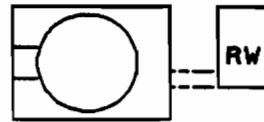


OPTION 'A'



OPTION 'B'

*



OPTION 'C'

*

NO SYSTEM MODIFICATION/
EXPANSION FLEXIBILITY

MAJOR IMPACT ON
CONSTRUCTION

SHORT PIPING LENGTHS

MINIMAL CONSTRUCTION IMPACT

SHORT PIPING LENGTHS

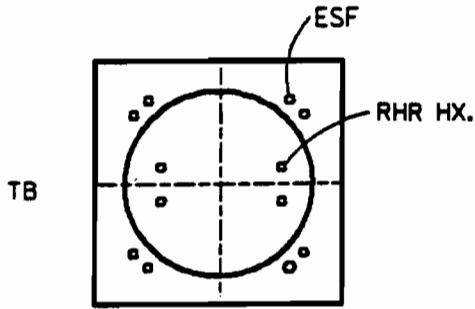
LONG PIPING LENGTHS AND
PERSONNEL ACCESS PATHS

NO IMPACT ON MAJN
POWER BLOCK CONSTRUCTION

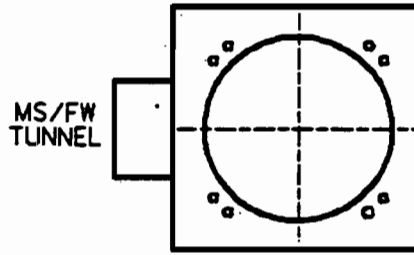
FLEXIBILITY TO ADJUST TO
SPECIFIC SITE LIMITATIONS
OR MULTI UNIT CONFIGURATIONS

*BEST MEETS LAYOUT PREFERENCE

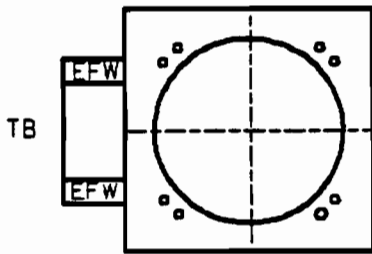
NUCLEAR ISLAND-PREFERRED ARRANGEMENTS



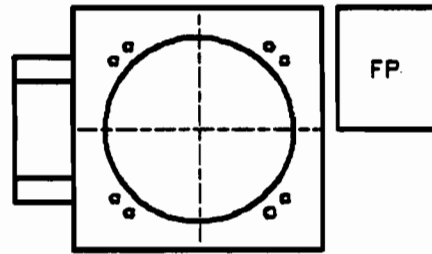
1.
ESSENTIAL SAFETY FUNCTION
SYSTEM



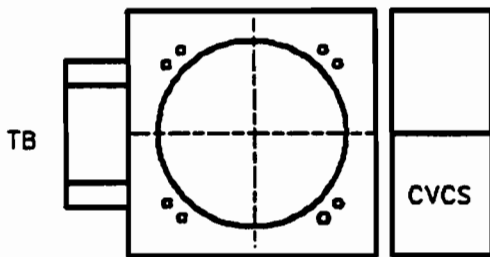
2.
MAINSTEAM/FEEDWATER
SYSTEM



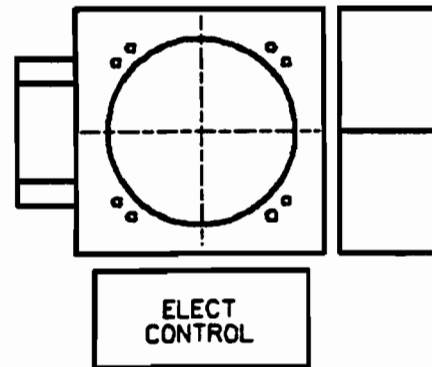
3.
EMERGENCY FEEDWATER
SYSTEM



4.
FUEL POOL SYSTEM



5.
CHEMICAL & VOLUME CONTROL
SYSTEM



6.
ELECTRICAL POWER SUPPLY
AND CONTROL SYSTEMS

SUB-SECTION 2B

TURBINE ISLAND

LAYOUT PREFERENCES

MAIN TURBINE GENERATOR SYSTEM

PREFERENCE -----	REASON -----
1. THE PLANT LAYOUT SHOULD ACCOM- MODATE 100% TURBINE LAYDOWN PROVIDED THE BUILDING SIZE IS NOT INCREASED	TO FACILITATE TURBINE OVERHAUL WITHOUT MAJOR ADDITIONAL INITIAL COST
2. THE MOISTURE SEPARATOR REHEATERS SHOULD BE LOCATED ON THE TURBINE DECK	TO PROVIDE SPACE FOR REHEATER TUBE REMOVAL AT THE MINIMUM COST
3. A MINIMUM CLEAR ACCESS SPACE OF 8FT (2.4M) IS REQUIRED AROUND THE TURBINE GENERATOR	TO ALLOW USE OF MOBILE LIFTING EQUIPMENT DURING OVERHAUL

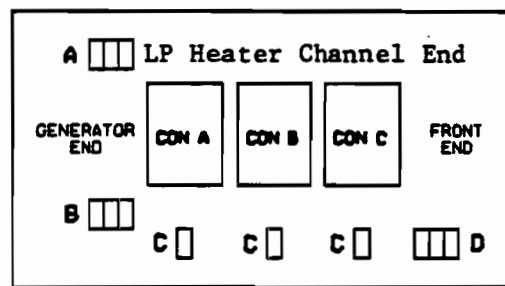
LAYOUT PREFERENCES

CONDENSATE PUMPS

PREFERENCE -----	REASON -----
1. LOCATION SHOULD ALLOW SHORT AND SIMPLE SUCTION PIPE ROUTING FROM THE MAIN CONDENSER	TO MINIMIZE PIPING LENGTH AND PRESSURE LOSS
2. THE PUMP SUCTION NOZZLE ELEVATION MUST BE LOWER THAN THE PIPING CONNECTION AT THE CONDENSER	CONTINUOUSLY SLOPED PIPING IS REQUIRED IN ORDER TO PROVIDE VENTING FROM THE PUMP TO THE CONDENSER
3. SPACE MUST BE PROVIDED FOR INSTALLATION OF A SUCTION STRAINER IN A STRAIGHT RUN OF PIPE AT THE PUMP SUCTION	THE STRAINER SHOULD BE LOCATED CLOSE TO THE NOZZLE TO AVOID DAMAGE TO THE PUMP
4. A CLEAR SPACE ABOVE THE PUMP TO THE OPERATING FLOOR IS REQUIRED	TO ALLOW REMOVAL OF THE PUMP AND MOTOR

LOCATION OPTIONS

CONDENSATE PUMPS



TURBINE BUILDING

OPTION 'A'

*

SHORT PIPING TO LP HEATERS

SPACE AVAILABLE FOR OPERATING
DECK REMOVAL

OPTION 'B'

LONG PIPING TO LP HEATERS

SPACE AVAILABLE FOR OPERATING
DECK REMOVAL

OPTION 'C'

DIRECT SUCTION PIPING

REMOVAL SPACE EXCESSIVE

OPTION 'D'

LONG PIPING TO LP HEATERS

POTENTIAL CONFLICT WITH HP
EQUIPMENT

* BEST MEETS LAYOUT PREFERENCE

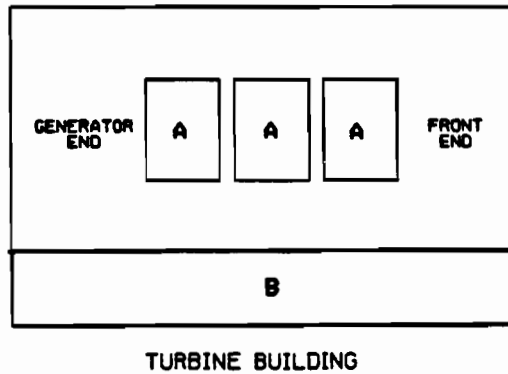
LAYOUT PREFERENCES

LOW PRESSURE FEEDWATER SYSTEM

PREFERENCE -----	REASON -----
1. THE 4 LOW PRESSURE FEEDWATER HEATERS ARE LOCATED IN THE CONDENSER NECK	TO MINIMIZE EXTRACTION STEAM PIPING (CHAPTER 2 CRITERIA)
2. THE DEAERATOR IS LOCATED ON OR ABOVE THE OPERATING FLOOR LEVEL OUTSIDE OF THE TURBINE HALL	TO SATISFY NPSH OF THE FEED-WATER BOOSTER PUMPS AND MINIMIZE IMPACT ON THE TURBINE BUILDING ARRANGEMENT
3. THE BOOSTER FEEDWATER PUMPS ARE LOCATED AT BASEMAT LEVEL BELOW THE DEAERATOR STORAGE TANK	TO PROVIDE NPSH AND MINIMIZE SUCTION PIPING LENGTH

LOCATION OPTIONS

LOW PRESSURE FW HEATERS



OPTION 'A'

*

(CONDENSER NECK)

SHORT EXTRACTION PIPING

INCREASES PEDESTAL HEIGHT

SHORT DRAIN PIPING TO
THE CONDENSER

OPTION 'B'

(HEATER BAY)

LONG EXTRACTION PIPING

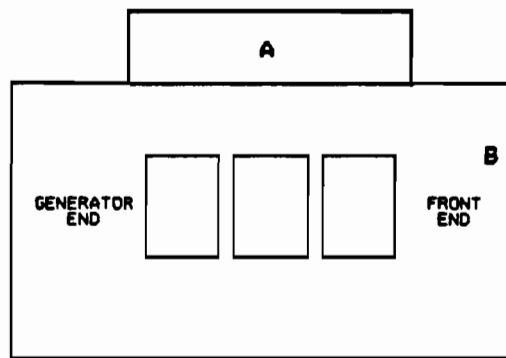
REDUCES PEDESTAL HEIGHT

LONGER DRAIN LINES TO
THE CONDENSER

* BEST MEETS LAYOUT PREFERENCE

LOCATION OPTIONS

DEAERATOR



TURBINE BUILDING

OPTION 'A'

*

DOES NOT IMPACT THE MAIN
BUILDING

OPTION 'B'

SHORTER EXTRACTION STEAM LINE

*BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

GLAND STEAM SYSTEM

PREFERENCE -----	REASON -----
1. THE GLAND STEAM CONDENSER SHOULD BE ON THE SAME SIDE OF THE BUILDING AS THE CONDENSATE PUMPS	TO MINIMIZE THE CONDENSATE PIPING
2. THE GLAND STEAM CONDENSER SHOULD BE AT AN ELEVATED LEVEL	TO ALLOW FOR THE LOOP SEAL IN THE EXHAUST LINE TO THE MAIN CONDENSER

LAYOUT PREFERENCES

SIDESTREAM CONDENSATE POLISHING SYSTEM

PREFERENCES

REASONS

1. THE SIDESTREAM PUMP(S) SHOULD BE NEAR TO THE CONDENSATE PUMP DISCHARGE HEADER

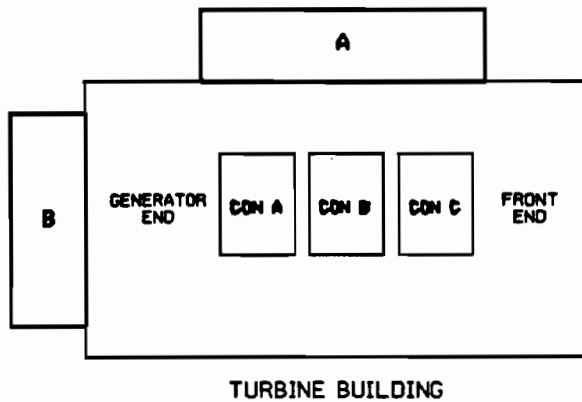
TO AVOID EXCESSIVE PIPE LENGTH

2. THE DEMINERALIZERS SHOULD BE LOCATED IN AN OUTSIDE BUILDING ADJACENT TO THE MAIN TURBINE BUILDING

TO ALLOW FLEXIBILITY IN THE SYSTEM DESIGN WITHOUT AFFECTING THE STANDARDIZED TURBINE BUILDING

LOCATION OPTIONS

SIDE STREAM CONDENSATE DEMINERALIZERS



OPTION 'A'

*

SHORTER PIPING CONNECTIONS

GOOD UTILIZATION OF SPAN
BELOW DEAERATOR

OPTION 'B'

MAXIMUM DESIGN FLEXIBILITY

*BEST MEETS LAYOUT PREFERENCE

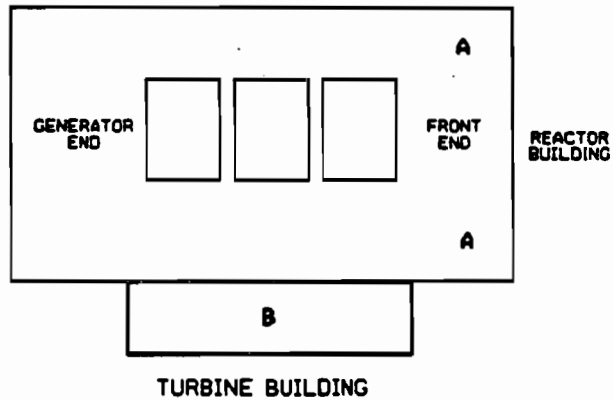
LAYOUT PREFERENCES

HIGH PRESSURE FEEDWATER SYSTEM

PREFERENCES -----	REASON -----
1. THE FEEDWATER PUMPS (MOTOR DRIVEN) SHOULD BE LOCATED CLOSE TO THE HIGH PRESSURE FEEDWATER HEATERS	TO MINIMIZE HIGH PRESSURE PIPING QUANTITIES
2. THE HP FEEDWATER HEATERS SHOULD BE LOCATED CLOSE TO THE MAIN STEAM TUNNEL	TO MINIMIZE HIGH PRESSURE PIPING QUANTITIES
3. SPACE SHOULD BE DESIGNATED FOR THE FEEDWATER CONTROL VALVES	SO THAT PROPER MAINTENANCE ACCESS CAN BE PROVIDED

LOCATION OPTIONS

HP FEEDWATER HEATERS



OPTION 'A'

*

SHORT FEEDWATER LINE TO THE REACTOR BUILDING

SHORTER DRAIN LINES TO THE CONDENSER

CONGESTED AREA OF THE BUILDING

POTENTIAL FOR DIFFICULTY IN TUBE REMOVAL

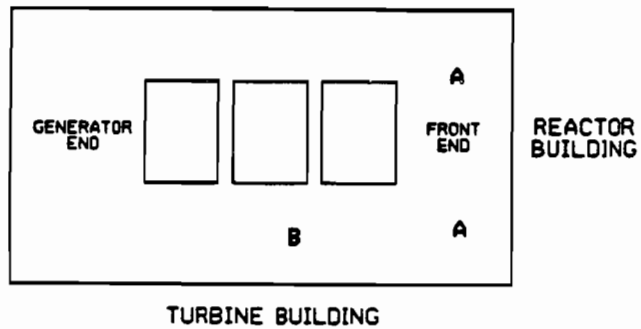
OPTION 'B'

LONG FEEDWATER, EXTRACTION STEAM AND DRAIN PIPING

LESS POTENTIAL CONFLICT WITH OTHER SYSTEMS

*BEST MEETS LAYOUT PREFERENCE

LOCATION OPTIONS
HP FEEDWATER PUMPS
(MOTOR DRIVEN)



OPTION 'A'

*

SHORTER DISCHARGE LINES TO
THE REACTOR ON I-TYPE
ARRANGEMENT

OPTION 'B'

LONGER HIGH PRESSURE PIPING
TO REACTOR BUILDING

PROBABLE CONFLICT WITH FW
BOOSTER PUMP LOCATION

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

MAIN TURBINE LUBE OIL SYSTEM

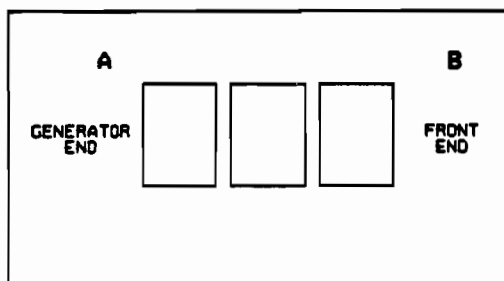
PREFERENCE

REASON

- | | |
|---|--|
| 1. SHOULD BE LOCATED AT THE FRONT
END OF THE TURBINE | TO MINIMIZE THE PIPING TO
THE HIGH PRESSURE JOURNAL |
| 2. SHOULD BE CONFINED TO ONE LOC-
ATION | TO SIMPLIFY DRAINAGE AND
FIRE PROTECTION |

LOCATION OPTIONS

MAIN TURBINE LUBE OIL SYSTEM



TURBINE BUILDING

OPTION 'A'

REQUIRES TURBINE SUPPLIER APPROVAL
FOR LONGER LINES TO AND FROM THE
HIGH PRESSURE JOURNAL

LOCATION IS LESS CONGESTED THAN
THE FRONT END OF THE TURBINE

OPTION 'B'

*

STANDARD LUBE OIL SYSTEM
LOCATION

MAY CONFLICT WITH OPTIMUM
LOCATION OF HP FEEDWATER

* BEST MEETS LAYOUT PREFERENCE

LAYOUT PREFERENCES

TURBINE COMPONENT COOLING SYSTEM

PREFERENCES

REASON

- | | |
|---|--|
| 1. LOCATION SHOULD BE AS CLOSE AS POSSIBLE TO MAJOR COOLING LOADS | TO MINIMIZE PIPE LENGTHS |
| 2. THE HEAT EXCHANGERS SHOULD BE ON THE SAME SIDE OF THE BUILDING AS THE SERVICE WATER SUPPLY | TO SIMPLIFY SERVICE WATER PIPE ROUTING |

LAYOUT PREFERENCES

ELECTRICAL POWER SUPPLY SYSTEM

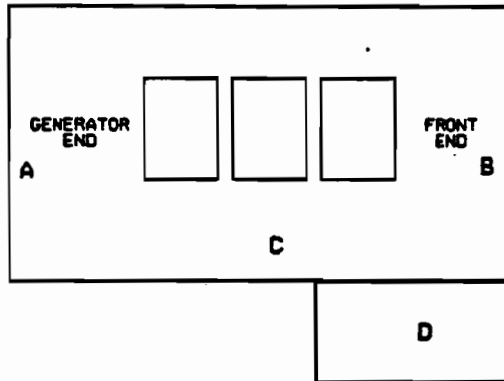
PREFERENCES

REASON

- | | |
|---|--|
| 1. SWITCHGEAR SHOULD BE LOCATED CLOSE TO THE AUXILIARY AND STARTUP TRANSFORMERS | TO SHORTEN THE LENGTH OF HIGH VOLTAGE CABLE |
| 2. LOAD CENTERS AND MOTOR CONTROL CENTERS SHOULD BE LOCATED AS CLOSE AS POSSIBLE TO THE COMPONENTS THEY SUPPLY | TO MINIMIZE CABLING |

LOCATION OPTIONS

ELECTRICAL POWER SUPPLY (SWITCHGEAR)



OPTION 'A'

LONG CABLING LENGTH TO
THE CONTROL ROOM

SHORT POWER CABLE LENGTH
FROM THE TRANSFORMERS

OPTION 'C'

SHORT POWER CABLE LENGTH

OPTION 'B'

CONGESTION WITH HIGH PRESSURE
PIPING

OPTION 'D'

*

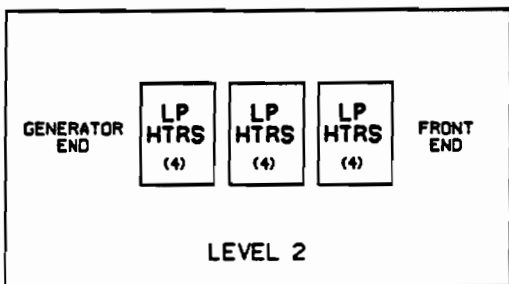
SHORT POWER CABLE LENGTH
FROM THE TRANSFORMERS

SHORT CABLE LENGTH TO
THE CONTROL ROOM

DOES NOT IMPACT TURBINE
BUILDING CONSTRUCTION AND
MAINTENANCE ACCESS

*BEST MEETS LAYOUT PREFERENCE

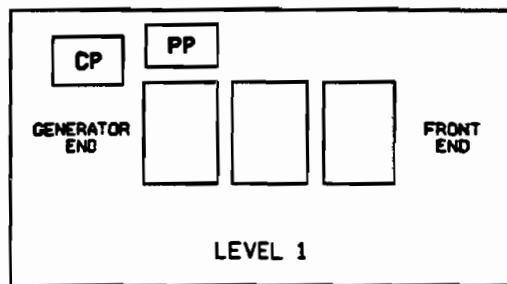
TURBINE ISLAND - PREFERRED ARRANGEMENTS



LEVEL 2

1.

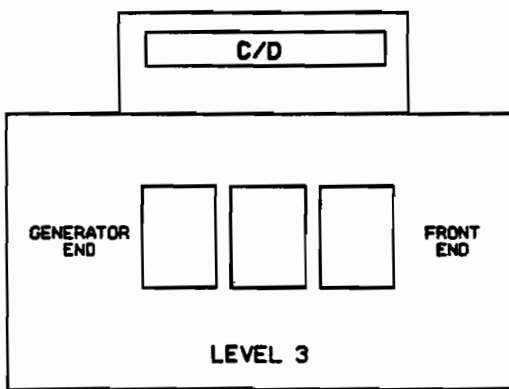
LOW PRESSURE FEEDWATER HEATERS
(GIVEN)



LEVEL 1

2.

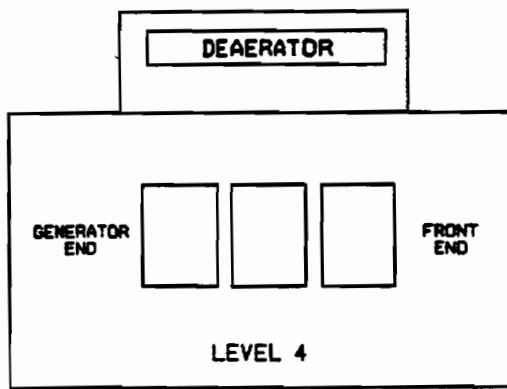
CONDENSATE PUMPS
POLISHING PUMPS



LEVEL 3

3.

CONDENSATE DEMINERALIZERS

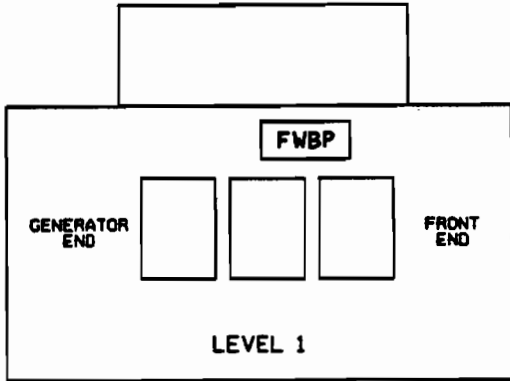


LEVEL 4

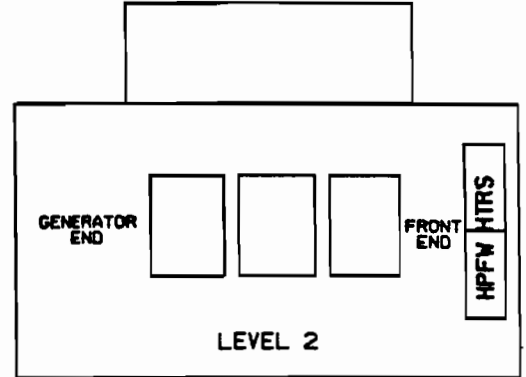
4.

DEAEATOR

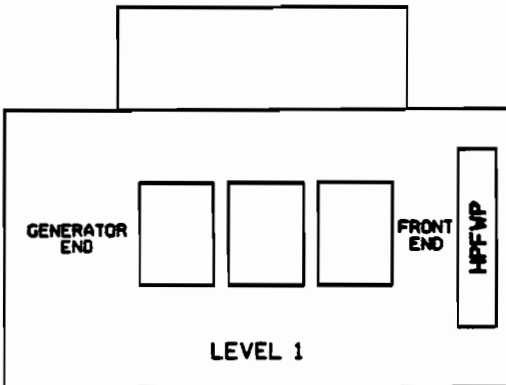
TURBINE ISLAND - PREFERRED ARRANGEMENTS



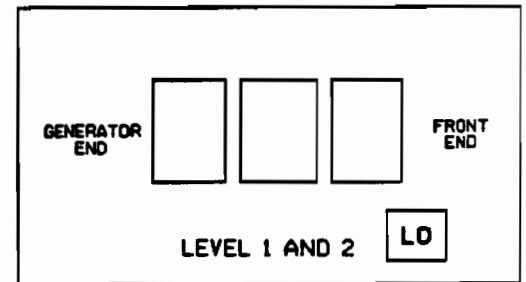
5.
FEEDWATER BOOSTER PUMPS



6.
HIGH PRESSURE FEEDWATER HEATERS



7.
HIGH PRESSURE FEEDWATER PUMPS



8.
TURBINE LUBE OIL SYSTEM

SECTION 3

REVIEW OF REFERENCE PLANT ARRANGEMENTS

Section 3 consists of a review of selected Reference Plants and an evaluation on which features of the arrangement meet or do not meet the requirements and preferences outlined in Section 2.



SECTION 4

STUDY CONCLUSIONS

This Section illustrates a recommended PWR plant arrangement concept based on the conclusions for preferred locations identified in Sections 2 and 3.

Figure 4-1 and 4-2 show conceptual power block arrangements for the four loop and two loop NSSS plants respectively.

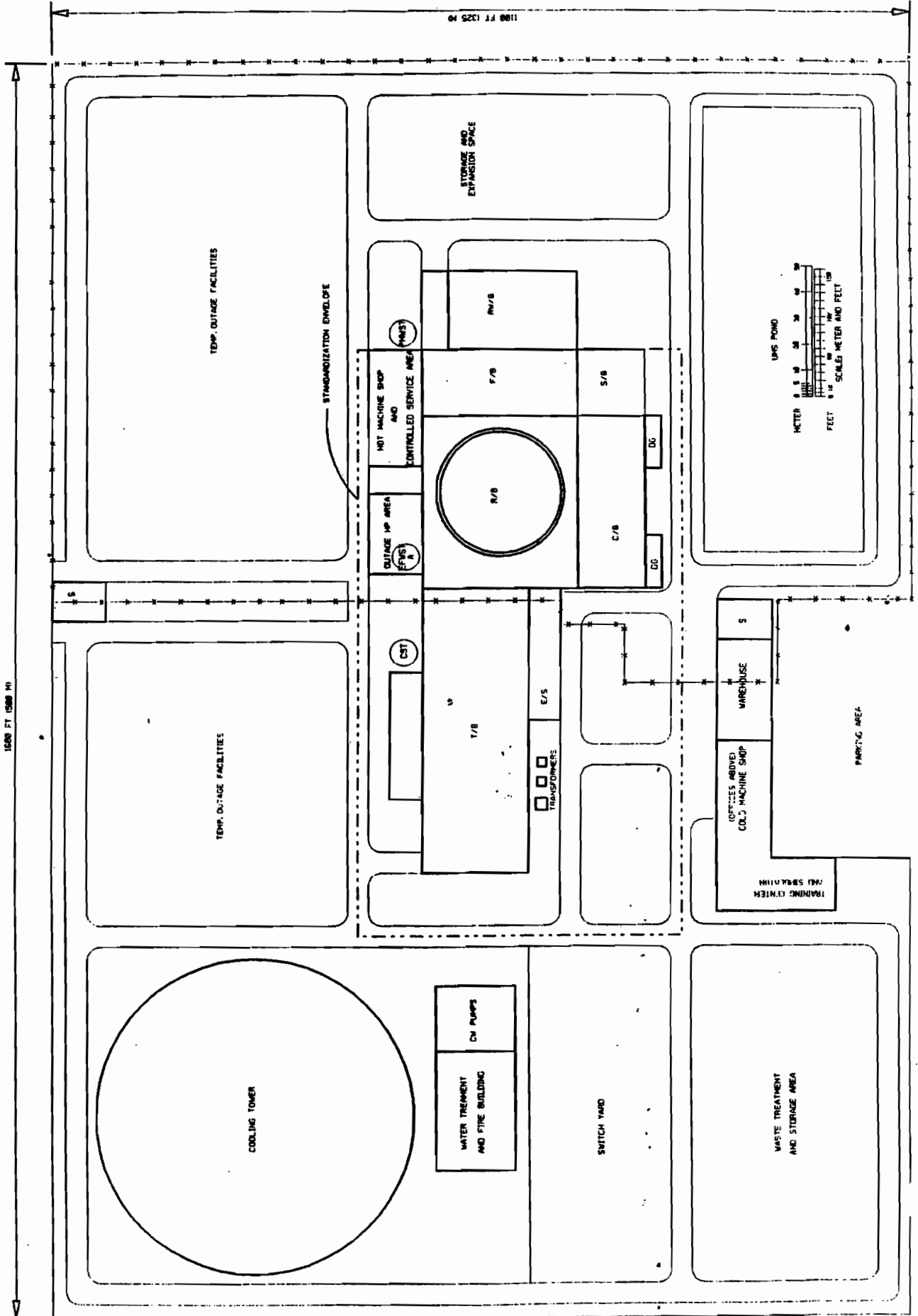
Figure 4-3 presents a typical plot plan illustrating the key requirements of building interface. The effect of site specific features on the plot plan are not taken into consideration.

Figure 4-4, 4-5 and 4-6 illustrate, using a two loop plant as reference the arrangement divisional separation, personnel access and equipment removal paths respectively.

LWR PROGRAM CHAPTER 6 REFERENCE PWR SITE PLOT PLAN

FEB. 12, 1968

1600 FT (500 M)



Appendix B. Comparative Constructability Evaluation of PWR Containments

**Comparative Constructability
Evaluation of PWR Containments**

Prepared By

**Duke Power Company and
Bechtel North American Power Corporation**

January, 1990

EXECUTIVE SUMMARY

This study is a result of a recommendation made by participants of the DOE/DPCo DFC program. Participants recommended that standardization of a containment type for a future ALWR would be a first step towards standardization of a nuclear plant design. Participants also felt standardization of containment type would subsequently reduce the cost and schedule of the next generation ALWR. A multitude of factors impact a standardized design therefore, a comparative constructability evaluation was developed for containment type selection. This evaluation was to provide ALWR designers and prospective utility owners with the significant parameters that impact constructability of the various containment types used in the US. The evaluation was also to provide current and future ALWR participants with a mechanism to evaluate different containment types and select a type based on the most important parameters defined by this study. These parameters include but are not limited to cost, schedule, maintainability and licensability. The containment types considered in this study were:

- o PCCV (Prestressed Concrete)
- o RCCV (Reinforced Concrete)
- o SSCV (Spherical Steel)
- o CSCV (Flat bottom Cylindrical Steel)
- o CSCV (Ellipsoidal bottom)

Duke, Bechtel and other leaders in the nuclear industry were instrumental in developing this report. A total of nine meetings were held addressing the study which consisted of three Phases:

Phase 1. Determine what parameters should be used in the comparative evaluation.

Phase 2. Develop a Decision Matrix that compares the selected alternatives based on the selected parameters found from Phase 1. The evaluation criteria include:

- o Finished Product

- o Construction Impact
- o Investment Protection

Phase 3. Demonstrate the use of the Decision Matrix based on the current experience base and knowledge.

Containment selection for an ALWR is a complex decision with multiple and diverse impacts on the plant design and performance. The objective of the study was not to recommend a containment type based on today's experiences and ideas. This report was to identify major parameters for containment selection and provide a means for evaluation of containment type by use of a Decision Matrix. Subjectivity of the evaluation criteria is a drawback of the Decision Matrix Methodology. Results of Phase 3 (Section 9.0) show participants had a tendency to select containment types they were most familiar with. Inspection of the results show the matrix evaluation criteria was weighted and subsequently rated to reflect this. This subjectivity must be recognized and minimized before the methodology can be applied to an ALWR.

Products of the study include:

1. A uniform size and general arrangement for each containment type.
2. A means to select a containment type by use of the Matrix.
3. Cost and schedules for each alternative based on historical data and Bechtel experience.
4. Future technological improvements that will play a significant role in the selection process in the future.
5. Recognition that a reduction in the plant critical path with or without an increase in capital cost will save significant dollars to the future owners of an ALWR.
6. Demonstration of the subjectivity of the evaluation based on evaluators' experience base.

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2.3.3 All Steel Containments (CSCV, SSCV)

2.4 Distinctive Features of Containments

3.0 DESIGN BASIS

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5.0 FINISHED PRODUCT

5.0.1 Operability/Maintainability

5.0.2 Reliability/Availability (Lifetime)

5.0.3 Upset (Safety Margins and Accident Recoverability)

5.1 PCCV

5.1.1 Advantages

5.1.2 Disadvantages

5.2 RCCV

5.2.1 Advantages

5.2.2 Disadvantages

5.3 CSCV (F/B)

5.3.1 Advantages

5.3.2 Disadvantages

5.4 CSCV (E/B)

5.5 SSCV

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-
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-
- 7-1 PCCV - Construction Schedule Extract
 - 7-2 RCCV - Construction Schedule Extract
 - 7-3 CSCV-F/B - Construction Schedule Extract
 - 7-4 CSCV-E/B - Construction Schedule Extract
 - 7-5 SSCV - Construction Schedule Extract
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1.0 INTRODUCTION

This study is part of the Department of Energy (DOE)/Duke Power Company Design for Constructability Program. The Design for Constructability Program is part of the DOE Technology Programs in Support of Advanced Light Water Reactors.

The objective of this study was to develop a comparative constructability methodology of established containment designs for possible applications to large U.S. Advanced Pressurized Water Reactor Plants in the mid to late 1990's.

1.1 Workscope

The scope of the study was defined by the following tasks:

- o Define the main parameters of proven, established PWR containment alternatives, as they might apply to Large U.S. Advanced PWR plants of about 1300 MWe.
- o Develop a comparative evaluation of these containment alternatives with primary emphasis on constructability.
- o Prepare recommendations for use by others in selecting the standardized containment type (or types) to be used in the Large U.S. Advanced PWR plants of the mid to late 1990's.

This study consisted of three phases.

Phase 1 - Determine what parameters would be used in the comparative evaluation. The parameters selected and defined in this study were based on the cumulative experience of Bechtel, Duke, and industry representatives. (Reference Appendix A for industry representatives.)

Phase 2 - Develop a methodology that compares selected alternatives based on selected parameters found from Phase 1. This comparative evaluation should satisfy the Advance Light Water Reactor (ALWR) requirements contained in the

Electric Power Research Institute's Utility Requirements Document. The product of this evaluation was a Decision Matrix that could be used by a future owner when selecting a containment type.

Phase 3 - Demonstrate the use of the Decision Matrix developed in Phase 2 based on current experience base and knowledge.

Postulated plant designs were developed based on the overall ALWR Program objective of high plant safety, high owner's investment protection, and low power generation cost.

The five types of containment vessels and two types of nuclear systems evaluated were listed below:

Types of Containment Vessels (CV)

- o Prestressed Concrete - PCCV
- o Reinforced Concrete - RCCV
- o Cylindrical Steel Flat Bottom - CSCV (F/B)
- o Cylindrical Steel Ellipsoidal Bottom - CSCV (E/B)
- o Spherical Steel - SSCV

Types of Nuclear Systems

- o Combustion Engineering 2 Loop System 80+ - CE
- o Westinghouse 4 Loop APWR System - W

During the course of the study, Duke Power Co., Bechtel and other leaders in the nuclear industry held nine meetings, as recorded in Appendix A. Comments and other technical inputs received during the course of these reviews were incorporated in the study and greatly contributed to the results presented.

The remainder of the report is organized as follows:

1. Containment Alternative Evaluation

2. Design Basis for Containment type
3. Development of Decision Matrix
4. Discussion of Evaluation Criteria Contained in the Matrix
 - A. Finished Product
 - o Operability/Maintainability (Everyday)
 - o Reliability/Availability (Lifetime)
 - o Upset (Safety Margins and Accident Recoverability)
 - B. Construction Impact - Costs (Features/Designs which results in least capital investment.)
 - o Overnight cost
 - o AFUDC (construction schedule)
 - C. Investment Protection
 - o Schedule Controllability/Brevity
 - o Proven Technology
 - o Licensability
 - o New Technology
5. Examples of use of the Decision Matrix
6. Conclusion

2.0 CONTAINMENT ALTERNATIVES EVALUATION

The initial work reviewed the containment design requirements provided by Combustion Engineering and Westinghouse, particularly, as they relate to the arrangement of NSSS equipment. Typical "Balance of Plant" space requirements were also identified to adequately provide for such design controlling functions as; containment air cooling, piping, duct and cable tray routing, personnel access, and process equipment inspection, removal, laydown and decontamination. The following power block building arrangements were identified to further establish the technical base, for consistency in defining and evaluating the containment alternatives:

- o PCCV - Palo Verde, SNUPPS
- o RCCV - Diablo Canyon
- o CSCV - Davis Besse
- o SSCV - Japanese 1300 MWe APWR

Figures 2-1 through 2-5 show configurations of various containment alternatives evaluated in this study.

2.1 Evaluation Approach

- o Evaluate the Base Case containment alternatives based on today's technology and the perception of how it will be in the early 1990's.
- o Evaluate the Improved containment alternatives based on today's technology and with assumed technological improvements.
- o Considered containment size and design duty to accommodate current 1300 MWe NSSS package by Westinghouse and Combustion Engineering. The study was focused on the 4-loop NSSS for consistency.
- o Coordinated containment size and arrangement with EPRI's APWR layout study.
- o Focused on distinctive features of containment candidates.

2.2 Layout General Requirements for Cylindrical and Spherical Containments

Following is a list of the general layout requirements considered in developing the containment configuration.

- o Plant arrangement must be conducive to enhancing constructability.
- o Embedment depth should be minimized but the arrangement should allow flexibility.
- o Maintenance and removal of equipment must be provided. (Steam generators can be removed/reinstalled in one piece.)
- o Direct access to the containment must be provided over at least a 90 degree sector, for easier construction and maintenance.

2.3 Common Features of Containments

2.3.1 All Containments

- o Internal arrangement permitting one-piece removal of steam generators.

2.3.2 All Cylindrical Containments (PCCV, RCCV, CSCV)

- o Identical internal arrangement (above flat bottom base) based on 1988 arrangement studies for EPRI. Height and diameter of the cylindrical containments are identical.
- o Identical external plant arrangements for CSCV, PCCV, and RCCV except minimal modifications made to accommodate the external shield wall of the CSCV.

2.3.3 All Steel Containments (CSCV, SSCV)

- o External shield wall and dome provide gamma shielding equivalent to the PCCV/RCCV wall and dome.
- o A five foot inspection space provided between the steel shell and the external shield structure. (Annulus)

2.4 Distinctive Features of Containments

PCCV

- o Two buttress anchorage for horizontal tendons.
- o Cylindrical wall is 4 feet thick.

RCCV

- o In-plane seismic shears are resisted by vertical and hoop reinforcing assuming the diagonal reinforcing will be deleted per proposed ASME code revisions.
- o Cylindrical wall is 5.25 feet thick to accommodate the more complex reinforcing patterns than the PCCV.

CSCV

- o Cylindrical plate thickness based on the assumption that present ASME Code PWHT requirements have been relaxed for materials thicker than present code permits.
- o Flat bottom CSCV shell is anchored by welded steel assemblies embedded into the base slab rather than using anchor bolts. Base slab thickness would be more than 10 feet to permit this type anchorage system.

SSCV

- o Containment size, internal and external arrangement are based on 1984 study for MHI - Japan.

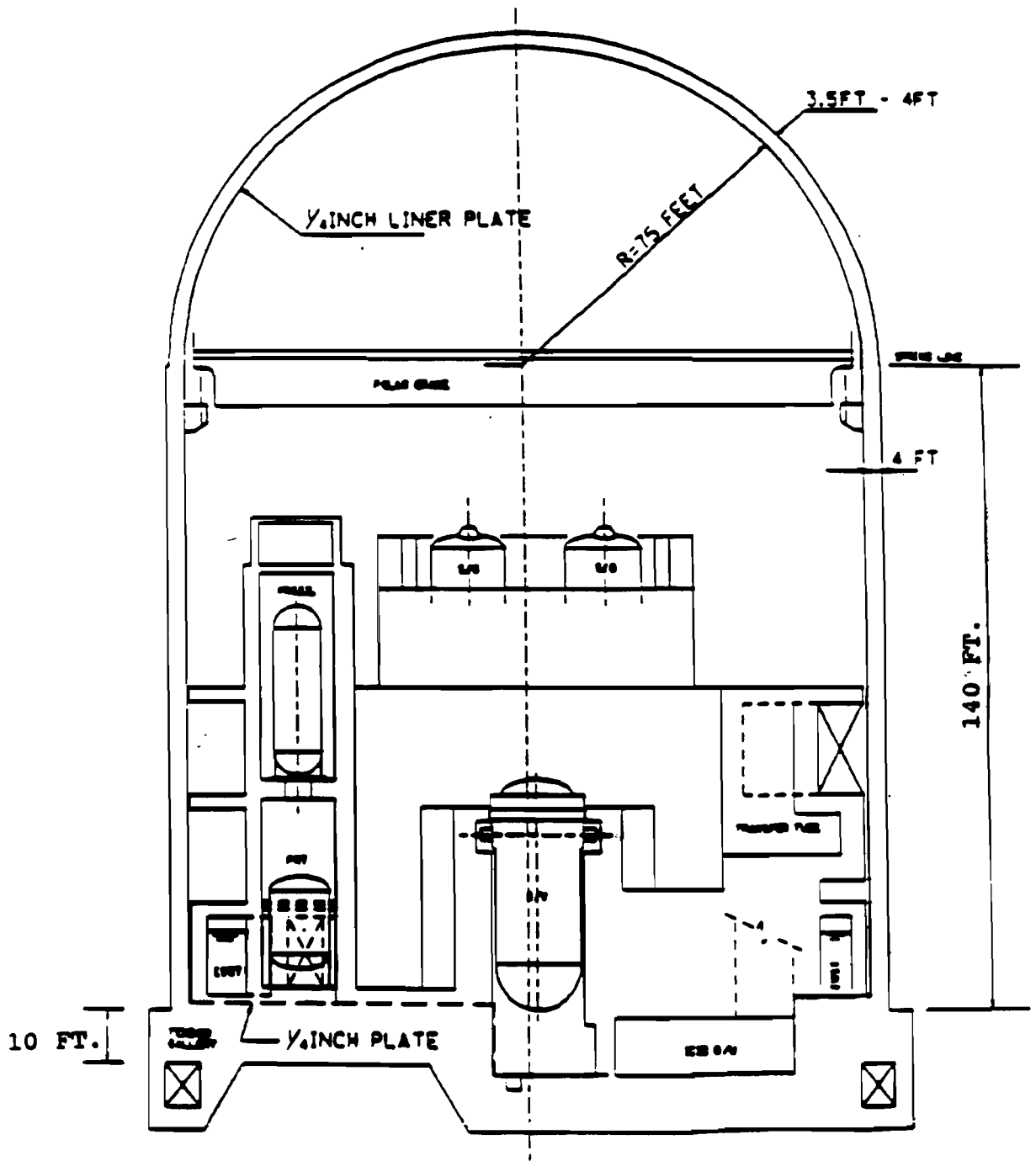


FIGURE 2-1: PRESTRESSED CONCRETE CONTAINMENT VESSEL (PCCV)

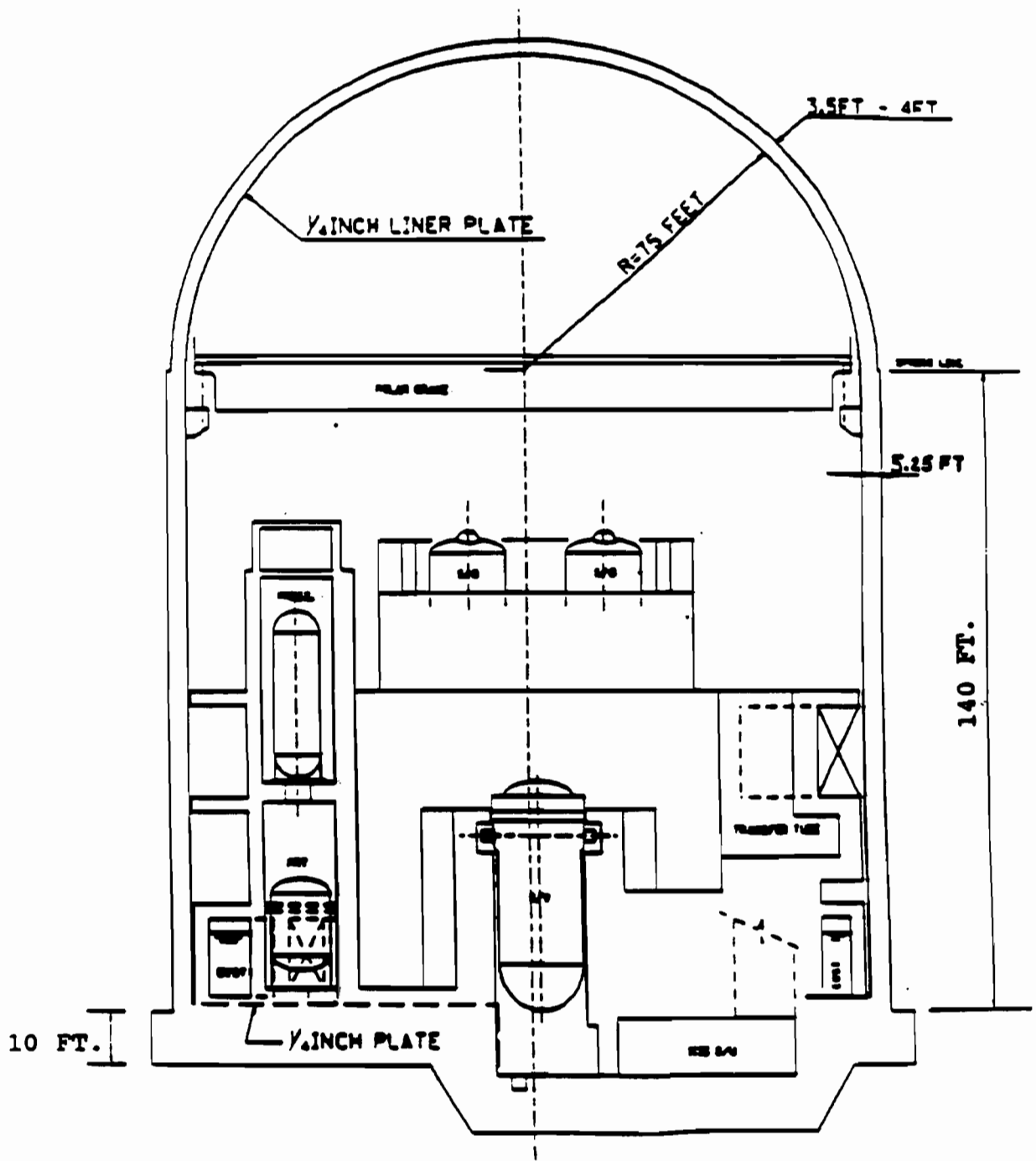


FIGURE 2-2: REINFORCED CONCRETE CONTAINMENT VESSEL (RCCV)

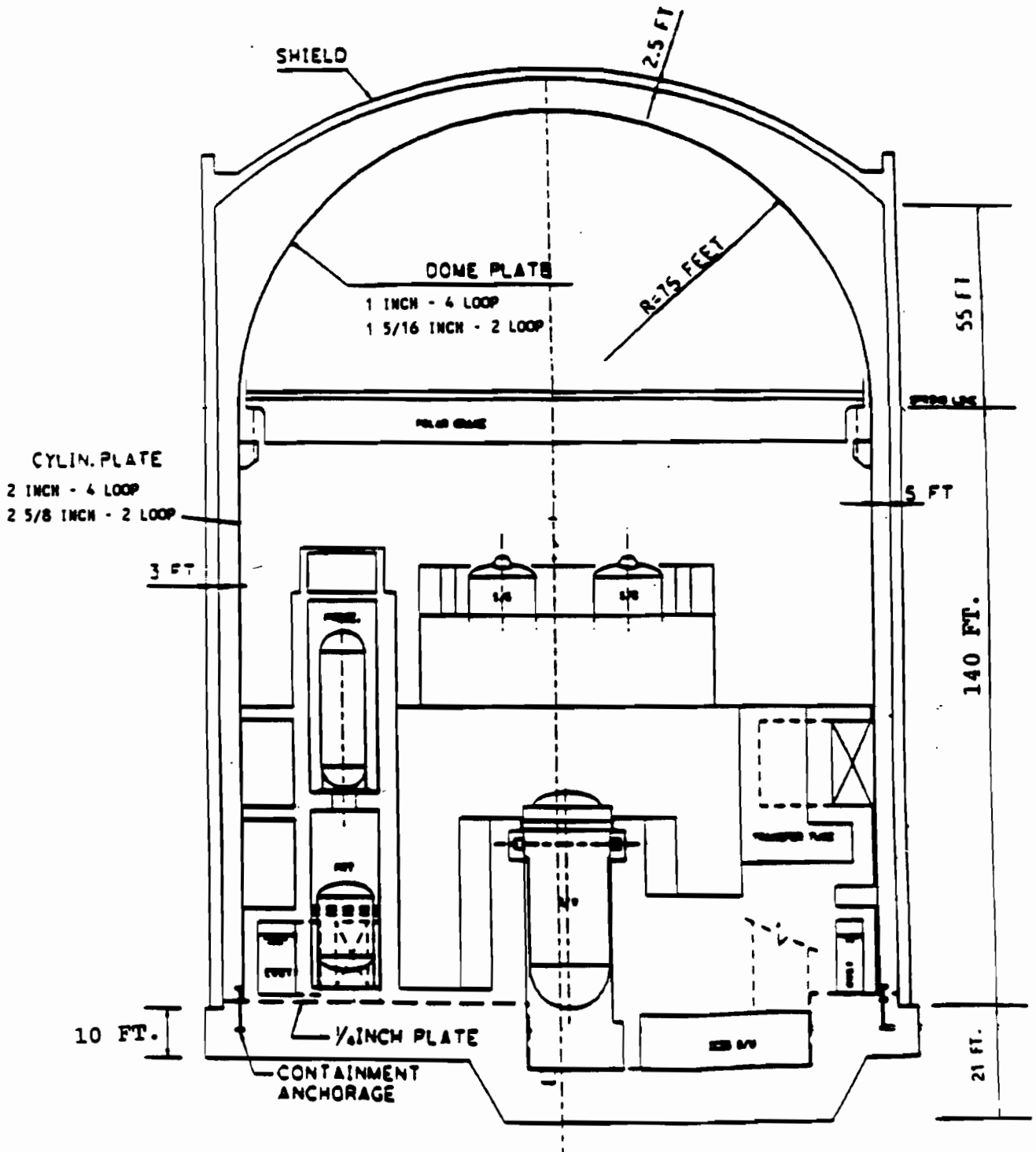


FIGURE 2-3: CYLINDRICAL STEEL CONTAINMENT VESSEL (CSCV)
FLAT BOTTOM

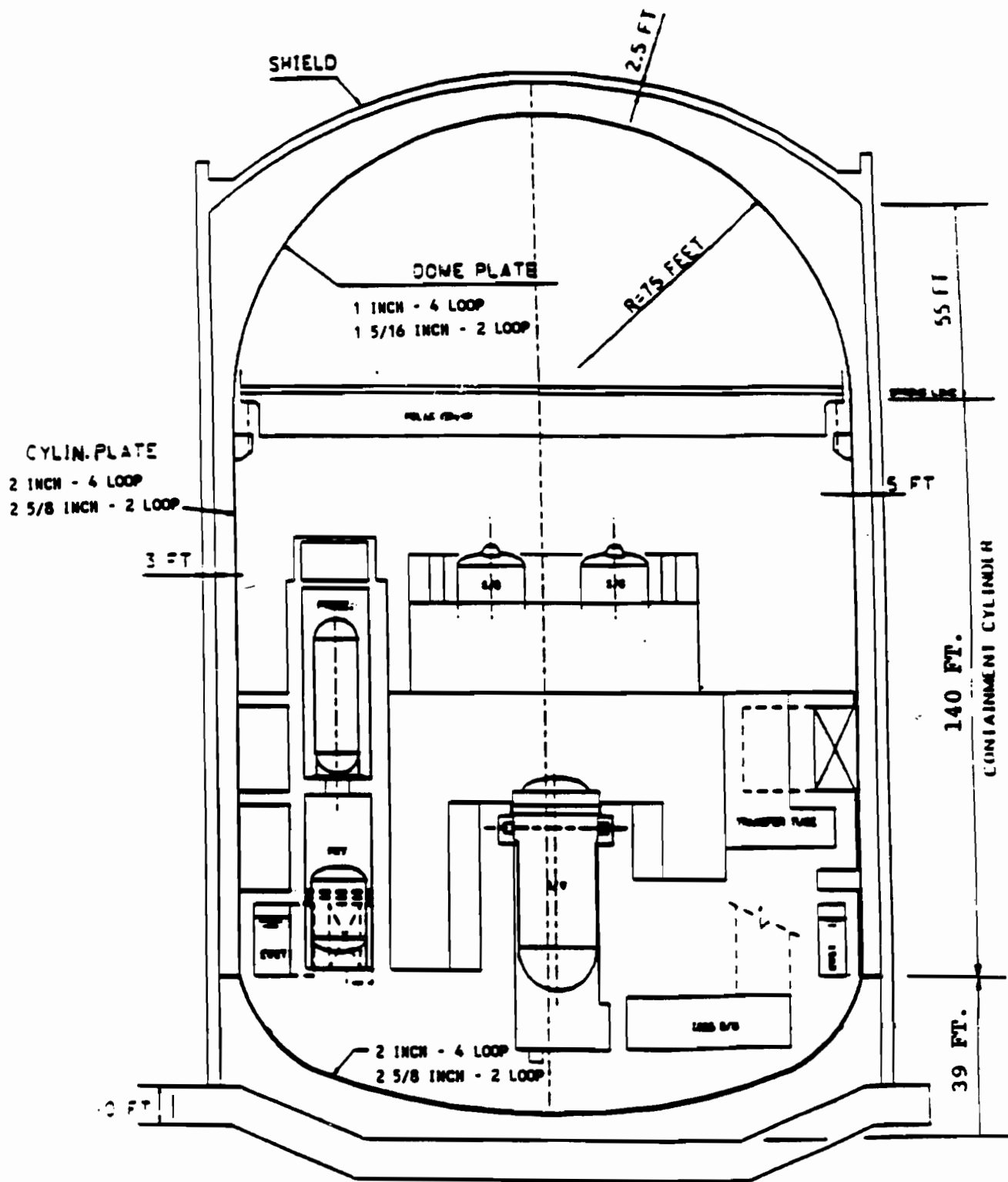


FIGURE 2-4: CYLINDRICAL STEEL CONTAINMENT VESSEL (CSCV)
ELLIPSOIDAL BOTTOM

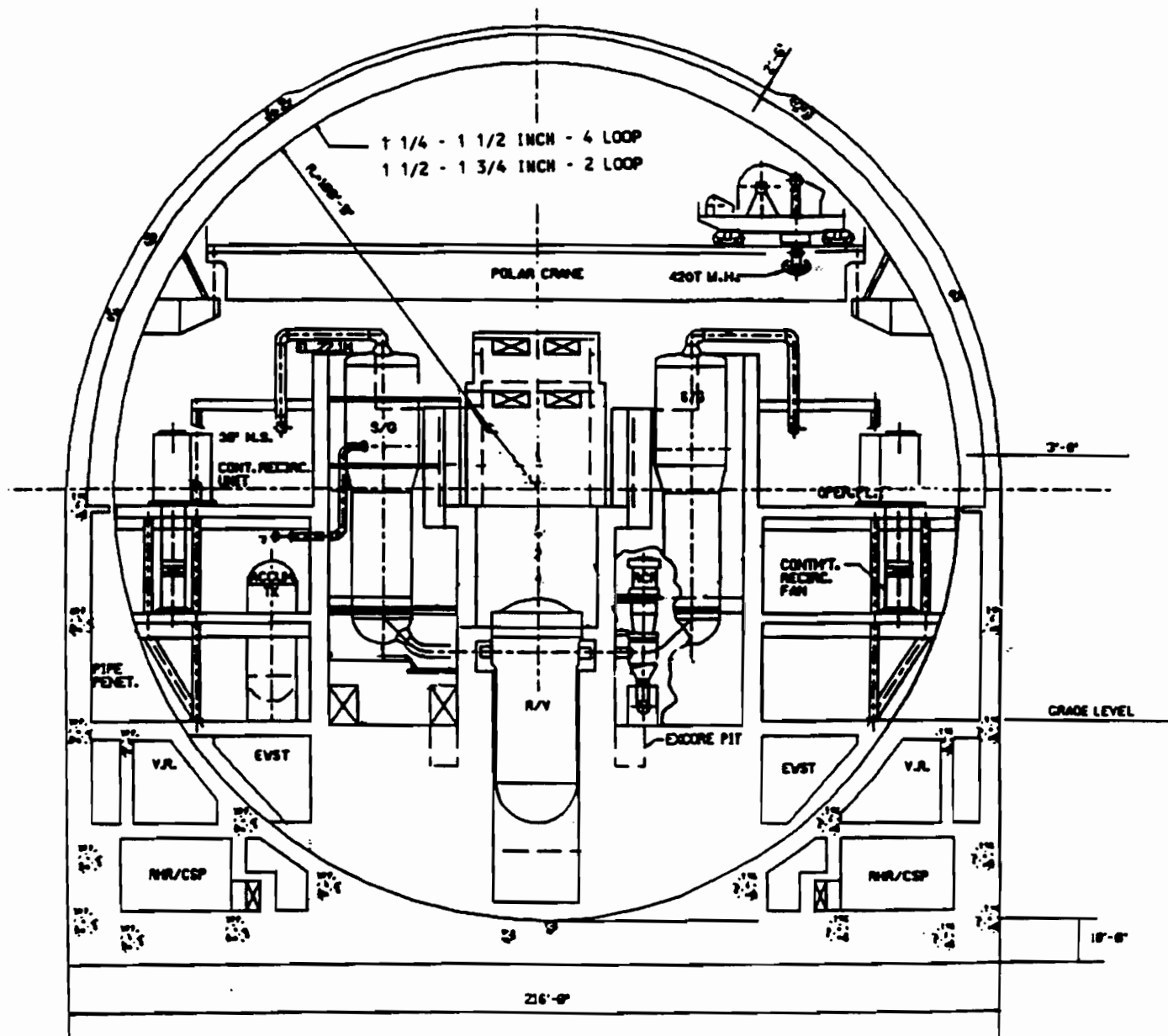


FIGURE 2-5: SPHERICAL STEEL CONTAINMENT VESSEL (SSCV)

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3.0 DESIGN BASIS

For each of the alternatives, global containment parameters such as; height, diameter, pressure rating, were based on the following:

- o Mass and energy release data for licensing basis events and severe accident hydrogen generation.
- o General arrangement criteria. (Example: One piece steam generator removal.)

Layout sketches were prepared and generic differences between containment types evaluated. Differences were defined in terms of general attributes such as operating floor area, constructability, experience base and licensability. Major categories of construction quantities, such as concrete and rebar quantities were estimated and evaluated in terms of approximate overnight cost and schedule. The study concentrated on areas which were judged to result in significant differences between containment types.

Table 3-1 gives design pressure for various containment types. These are derived for various configurations from the pressure-volume relationships provided by Westinghouse and Combustion Engineering. Seismic loads were based on SSE = 0.30g as specified in the Electric Power Research Institute's Utility Requirements Document.

Table 3-1 shows the design codes and properties of materials used for construction.

Table 3-2 lists selected containment design data.

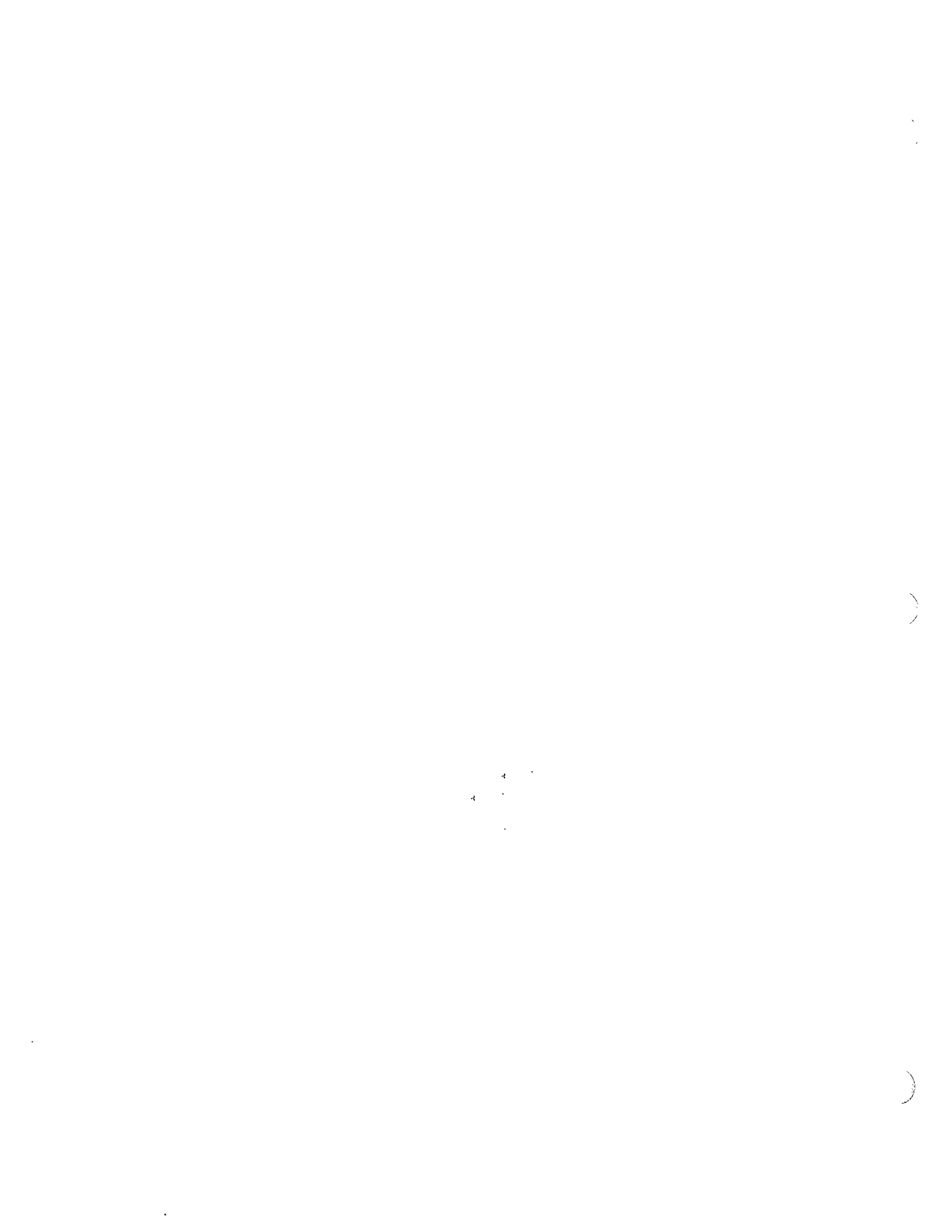


TABLE 3-1

DESIGN BASIS FOR ADVANCED PMR
CONTAINMENT VESSELS

ITEM	PCCV		RCCV		CSCV		SSCV
	Flat Bottom	Ellipsoidal	Flat Bottom	Ellipsoidal	Flat Bottom	Ellipsoidal	
DESIGN CODE							
ASME SECTION III, DIV. 1				X		X	
ASME SECTION III, DIV. 2	X		X		X		
CONTAINMENT VOLUMES (FT ³)							
GROSS VOLUME	3.3 x 10 ⁶		3.3 x 10 ⁶		3.3 x 10 ⁶	3.7 x 10 ⁶	4.2 x 10 ⁶
FREE VOLUME	2.9 x 10 ⁶		2.9 x 10 ⁶		2.9 x 10 ⁶	2.9 x 10 ⁶	3.6 x 10 ⁶
DESIGN PRESSURE (psig)*							
4 - Loop	47		47		43	43	38
2 - Loop	59		59		55	55	47
MATERIALS							
CONCRETE: BASEMAT	f'c = 4000 psi		f'c = 4000 psi		f'c = 4000 psi	f'c = 4000 psi	f'c = 4000 psi
WALL AND DOME	f'c = 6000 psi		f'c = 4000 psi		N/A	N/A	N/A
SHIELD BUILDING	N/A		N/A		f'c = 4000 psi	f'c = 4000 psi	f'c = 4000 psi
STEEL PLATE	N/A		N/A		SA 516, GRADE 70	SA 516, GRADE 70	SA 516, GRADE 70
REBAR:	A615, GRADE 60		A 615, GRADE 60		A 615, GRADE 60	A 615, GRADE 60	A 615, GRADE 60
POST-TENSIONING SYSTEM	(1000 TON TENDON)		N/A		N/A	N/A	N/A
LINER PLATE	SA 516, GRADE 60		SA 516, GRADE 60		SA 516, GRADE 60	SA 516, GRADE 60	N/A

* APPROXIMATE VALUE

TABLE 3-2

SELECTED CONTAINMENT DATA

ITEM	PCCV	RCCV	CSCV		SSCV
			Flat Bottom	Ellipsoidal Bottom	
o INSIDE RADIUS	75 FT	75 FT	75 FT	75 FT	100 FT
o HEIGHT BOTTOM LEVEL TO SPRINGLINE	140 FT	140 FT	140 FT	140 FT	N/A
o CONCRETE SHELL					
- Cylinder Thickness	4 FT	5.25 FT	N/A	N/A	N/A
- Dome Thickness	3.5 - 4 FT	3.5 - 4 FT	N/A	N/A	N/A
- Base Mat Thickness	10 FT	10 FT	10 FT	N/A	N/A
o STEEL SHELL	N/A	N/A			
- Cylinder 4 Loop			2.0 IN	2.0 IN	N/A
- 2 Loop			2.6 IN	2.6 IN	N/A
- Dome 4 Loop			1.0 IN	1.0 IN	1.25 - 1.5 IN
- 2 Loop			1.3 IN	1.3 IN	1.25 - 1.5 IN
- Bottom 4 Loop			.25 IN	2.0 IN	N/A
- 2 Loop			.25 IN	2.6 IN	N/A
o SHIELD BUILDING	N/A	N/A			
- Cylinder			3 FT	3 FT	3 FT
- Dome			2.5 FT	2.5 FT	2.5 FT
o POLAR CRANE RUNWAY SUPPORT					
			STEEL BRACKET	STEEL BRACKET	STEEL TRUSS

4.0 DECISION MATRIX

Duke, Bechtel and other leaders in the nuclear industry held nine meetings addressing this study. Through the course of these working meetings, the following parameters were developed to be used in the comparative evaluation.

- o Cost
 - o Overnight Containment Cost
 - o Relative Impact on the BOP Arrangement
- o Schedule
 - o Elapsed time from first structural containment concrete to NSSS installation (critical path as established from review of past experience and study work)
- o Licensing
 - o Governing Design Codes
 - o NRC Acceptance (previous licensing experience)
- o Design
 - o Relative Cost of Analysis and Design for Certification
 - o Cost/Schedule Impact of increased design duty (internal pressure, seismic, internal missiles, pipe whip, tornado, fire)
- o Safety
 - o Ultimate Capacity for Severe Accident or Severe External Phenomena
 - o Potential for Secondary Containment

- o Operations and Maintenance
 - o Operation and Refueling
 - o In-Service Inspection (ISI)
 - o Corrosion Protection

A means of evaluating this criteria for selection of a containment type is the Decision Matrix. The Decision Matrix list seven containment alternatives to be evaluated. There are four basic types of containments with three that include significant future technological improvements. Below is a description of each:

- A. RCCV (base) - Adjusted to include impact of Code changes not requiring ASME III, Div. 2 concrete. This has proved to be more of a nuisance than a major cost when compared to the overall plant cost. A memo to file dated April 28, 1989 by D.A. Kelley addressed this issue in more detail. (Reference Appendix D.)
- B. RCCV (improved) - In-plane seismic shears are resisted by vertical and hoop reinforcing assuming the diagonal reinforcing will be deleted per proposed ASME code revisions.
 - o Improved reinforcing steel couplings
 - o Code change not requiring ASME III, Div. 2 concrete
- C. PCCV (improved) - Code change not requiring ASME III, Div. 2 concrete.
- D. CSCV F/B (base) - CSCV F/B (base) and CSCV F/B (improved) consider impacts of ASME III, Div. 2 concrete while the CSCV E/B and the SSCV do not. Flat bottom steel containments necessitate consideration of ASME Div. 2 concrete because the flat bottom serves as the pressure retaining component. The steel liner in flat bottom containments serve only as a leak tight membrane. The elliptical bottom and spherical steel containment shells serve as the pressure retaining component and do not require Div. 2 concrete. (Reference Table 3-1.)

- E. CSCV F/B (improved) - Cylindrical plate thickness based on the assumption that present ASME code PWHT requirements have been relaxed for materials thicker than what the present code permits.
- F. CSCV E/B (improved) - Cylindrical plate thickness based on the assumption that present ASME code PWHT requirements have been relaxed for materials thicker than what the present code permits.
- G. SSCV (base)

Use of the matrix is described below. (Reference Table 4.0 for a blank Decision Matrix.)

1. Place a weighting factor on each evaluation criteria. The sum of the weighting factors must equal 100.
2. Rate on a scale of 1 to 10, each criteria for each containment type to be considered.
3. Multiply each weighting factor by the applicable rating factor and sum for each containment type. The summation for each containment type will be compared.
4. The containment type with the highest numerical value is the most favorable of the candidates evaluated for use.

A description of the Evaluation Criteria and its advantages/disadvantages of each containment type are discussed in the following sections.

TABLE 4-0

**DUKE / DOE DESIGN FOR CONSTRUCTIBILITY PROGRAM
ADVANCED PWR CONTAINMENT CONSTRUCTIBILITY
CONTAINMENT TYPE DECISION MATRIX**

EVALUATION CRITERIA

WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)						
	CASE A	CASE B	CASE C	CASE D	CASE E	CASE F	CASE G
I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH) (OPERABILITY)							
A. OPERABILITY / MAINTAINABILITY (EVERDAY)							
B. RELIABILITY / AVAILABILITY (LIFETIME) • ISI • CORROSION RESISTANCE • S / G REMOVAL							
C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY) • RESISTANCE TO FIRE, FLOOD, SABOTAGE • PRESSURE MARGIN • SA COPING							
II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT) (OVERNIGHT COSTS)							
OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.)							
TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)							
III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS) (SCHEDULE)							
A. SCHEDULE CONTROLLABILITY / BREVITY							
B. PROVEN TECHNOLOGY							
C. LICENSABILITY (NPC / PUC) (LICENSABILITY)							
TOTAL	100						

CANDIDATE DESCRIPTIONS

- A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)
- B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)
- C. PCCV (IMPROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2

D. CSCV F/B (BASE)

E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT

F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT

G. SSCV (BASE)

RATING SCALE R
10 - EXCELLENT
1 - MARGINAL

WEIGHTING FACTOR W
TOTAL = 100

5.0 FINISHED PRODUCT

The finished product addresses the serviceability of the containment. Serviceability are features and design which make the plant easier to operate and maintain. The categories that address this topic are:

5.0.1 Operability/Maintainability (Everyday)

- o Access for Operation and Maintenance
- o Polar Crane Access
- o Containment Layout
- o Unique Maintenance Items

5.0.2 Reliability/Availability (Lifetime)

- o In-Service Inspection (ISI)
- o Corrosion Resistance
- o Steam Generator Removal

5.0.3 Upset (Safety Margins and Accident Recoverability)

- o Resistance to Fire, Flood, Sabotage
- o Pressure Margin (The difference between the operation pressure and the ultimate pressure before rupture.)
- o Severe Accident Coping Capability
- o Hydrogen Dilution (The amount of free volume required to dilute hydrogen generated from fuel assemblies during a core melt.)

Advantages and disadvantages of the finished product for each type containment are listed below.

5.1 PCCV

5.1.1 Advantages

A. Operability/Maintainability (Everyday)

- o 150 feet ID cylinder provides improved access for operation and maintenance.
- o Does not require a crane wall providing more usable laydown area at the operating deck.

B. Reliability/Availability (Lifetime)

- o Steam generator can be removed in one piece through a concrete plug in the containment cylinder without necessitating a larger equipment hatch. Reference Sargent & Lundy feasibility study in Appendix N of Volume 2.

C. Upset Conditions (Safety Margins and Accident Recoverability)

- o Rugged containment; resistance against internal missiles, high energy pipe penetrations and flooding.
- o Flexibility; can add wall height to accommodate volume increase. Severe accident scenarios may dictate additional containment volume to dilute hydrogen concentration levels (severe accident criteria may increase from 75% Zirconium reaction and 13% hydrogen concentration to 100% Zirconium reaction and 10% hydrogen concentration).
- o Containment will demonstrate Leak-before-Break behavior during severe accident conditions.

5.1.2 Disadvantages

A. Operability/Maintainability

- o Butress (2) reduce the flexibility and space available for arranging penetrations.
- o Auxiliary Building requires space for tendon inspection at the vertical butress.
- o Implementation of a shallow common basemat requires vertical pumps. Vertical pumps are difficult to access, therefore hindering maintenance. These pumps do not have historical performance in the US in high pressure applications (> 40psi).

B. Reliability/Availability (Lifetime)

- o Requires ISI of tendons. Leaking tendon grease problems and accessibility makes this difficult.
- o ISI requirements for ASME Section XI (exterior concrete surface inspection).
- o Repeated full-pressure leakage testing of the containment may cause exterior cracking of the containment allowing migration of water to the reinforcing steel.

C. Upset (Safety Margins and Accident Recoverability)

- o Does not allow for potential exterior cooling during a severe accident. This function can be performed by the addition of new heat exchangers, however, this would increase cost and require maintenance.

5.2 RCCV

5.2.1 Advantages

A. Operability/Maintainability

- o The 150 feet ID cylinder provides improved access for operation and maintenance.
- o Does not require a crane wall providing more usable laydown area at the operating deck.

B. Reliability/Availability

- o The steam generator can be removed through the equipment hatch in one piece.

C. Upset Conditions (Safety Margins and Accident Recoverability)

- o Rugged containment; resistance against internal missiles, high energy pipe penetrations and flooding.
- o Flexibility; can add wall height to accommodate volume increase. Severe accident scenarios may dictate additional containment volume to dilute hydrogen concentration levels (severe accident criteria may increase from 75% Zirconium reaction and 13% hydrogen concentration to 100% Zirconium reaction and 10% hydrogen concentration).
- o The containment will demonstrate Leak-before-Break behavior during severe accident conditions.

5.2.2 Disadvantages

A. Operability/Maintainability

- o Implementation of a shallow common basemat requires vertical pumps. Vertical pumps are difficult to access, therefore hindering maintenance. These pumps do not have historical performance in the US in high pressure applications (> 40psi).
- o There are two options to allow one-piece Steam Generator removal. The steel liner plate can be cut/removed and concrete rebar cut/demolished when the need arises, or a larger equipment hatch can be provided. The larger hatch will somewhat increase complexity during construction. More important, are increased difficulties in operation and maintenance.

B. Reliability/Availability (Lifetime)

- o ISI requirements for ASME Section XI (exterior concrete surface inspection).
- o Repeated full-pressure leakage testing of the containment might cause exterior cracking of the containment allowing migration of water to the reinforcing steel.

C. Upset (Safety Margins and Accident Recoverability)

- o Does not allow for potential exterior cooling during a severe accident. This function can be performed by the addition of new heat exchangers, however, this would increase cost and require maintenance.

5.3 CSCV (F/B)

5.3.1 Advantages

A. Operability/Maintainability

- o The 150 feet ID Cylinder provides improved access for operation and maintenance.

B. Reliability/Availability

- o The steam generators can be removed in one piece through a pre-engineered section of the steel containment and concrete shield walls. This permits a small equipment hatch.

C. Upset (Safety Margins)

- o Annulus and shield building allows for installation of a ventilation system for accident conditions providing a secondary containment. This creates favorable public perception in populace areas.
- o Flexibility; can add wall height to accommodate volume increase. Severe accident scenarios may dictate additional containment volume to dilute hydrogen concentration levels (severe accident criteria may increase from 75% Zirconium reaction and 13% hydrogen concentration to 100% Zirconium reaction and 10% hydrogen concentration).
- o Potential exterior cooling for severe accident. Cooling function can be provided by installation of an outside shell spray system supplied by portable self contained pumps.

5.3.2 Disadvantages

A. Operability/Maintainability

- o A Crane wall may be used to support the Polar Crane but this would reduce access and maintenance areas at all levels of containment. Another alternative to the crane wall would be a ring girder supported by columns extending to the operating floor area.
- o Bellows are required at penetrations in containment. Bellows are fragile and difficult to access for maintenance. They also have a history of leaking.

B. Reliability/Availability

- o The steel containment is susceptible to corrosion.
- o ISI is required on the steel containment and the bellows. Provisions must be made for access to all exterior areas of the vessel and mechanical penetrations.
- o Anchorage of the steel cylinder to basemat at pressures of 40 to 60 psi have not been tested. An upper limit of 15 psi has been used on CSCV (F/B) in the US. This will require additional design and construction time to install.

C. Upset (Safety Margins/Accident Recoverability)

- o Potential for catastrophic ultimate failure mode. Tests on prototype steel containments ruptured when pressurized to ultimate capacity. Prototypes have not been tested with the equipment hatch or other penetrations modeled in to determine if they leak to relieve pressure.

5.4 CSCV (E/B)

Same as the CSCV (F/B) except it eliminates the concern for the anchorage to the basemat. It has a better geometry and smoother transition between the cylindrical shell and bottom head requiring only seismic anchorage. Two drawbacks to the E/B are; it is harder to detect corrosion on the bottom surface and the NSSS needs to be artificially raised such that the ICI chase does not interfere with the lower head.

5.5 SSCV

5.5.1 Advantages

A. Operation and Maintenances

- o The SSCV has three support configurations for the Polar Crane. Advantages of each are described below:
 - o Crane Wall (internal ringwall support)
 - o Allows for steam generator removal in one piece.
 - o Provides shielding for maintenance operations and the operating deck during outages.
 - o Hanging Brackets off the Dome/Gantry Crane
 - o Has access to larger floor space.
 - o Lifting equipment to maintenance areas is a one step process.
 - o 200 ft. inside diameter sphere provides improved access for operation and maintenance.

C. Upset (Safety Margins)

- o Annulus and shield building allows for installation of a ventilation system for accident conditions providing a secondary containment. This creates favorable public perception in populace areas.
- o Potential exterior cooling for a severe accident. Cooling function can be provided by installing an outside shell spray system supplied by portable self contained pumps.
- o Larger volume for hydrogen dilution during a core melt without artificially increasing containment height.

5.5.2 Disadvantages

A. Operation and Maintenances

- o Disadvantages of the three polar crane support configurations are:
 - o Crane Wall (Internal ringwall support)
 - o Requires multiple handling of equipment to place outside the ringwall.
 - o Hanging Brackets off the dome
 - o One piece steam generator replacement may not be feasible.

- o Gantry Crane
 - o There are concerns with removal of Steam Generator in one piece (i.e., size dimensionally of crane required, clearance for vertical SG lift) due to lack of industry experience.
 - o Support trucks for trolley are very large and occupy large areas of the operating floor.
- o Equipment hatch access opening is feasible at only the operating floor.
- o Bellows are required at penetrations in the containment. Bellows are fragile and difficult to access for maintenance. They also have a history of leaking at the seals during testing.

B. Reliability

- o The steel containment is susceptible to corrosion.
- o ISI is required on the steel containment and the bellows. Provisions must be made for access to all exterior areas of the vessel and mechanical penetrations.

C. Upset

- o Potential for catastrophic ultimate failure mode. Tests on prototype cylindrical steel containments rupture when pressurized to ultimate capacity. Prototypes have not been tested with the equipment hatch or other penetrations modeled in to determine if they leak to relieve pressure.

6.0 CONSTRUCTION IMPACT COST

Construction impact cost are features and designs which result in least overnight capital investment. Two aspects of cost were considered when comparing containments:

1. Overnight Costs - Costs associated with engineering, and direct cost in today's dollars.
2. Time Related Cost - Indirect Cost and Allowance for Funds Used During Construction. (AFUDC)

6.1 Overnight Costs

Overnight construction cost were used for the containment cost evaluation. Costs are based on 1987 technology and labor conditions. Unit rates were based on Bechtel experience except for the steel containment shell. The steel containment costs were estimated based on input received from DPCo, Catawba; FP&L, St. Lucie; and WPPSS, WNP-3. Evaluations included allowance for field indirect costs, but no AFUDC. Future escalation and owner's costs were not included.

The following operations were assumed to be subcontracted:

- o Steel containment vessel design and construction
- o Tendon installation and stressing

Costs are based on standard 40 hour work week and include impact of threaded rebar couplers in lieu of "Cadwelds".

For the containment cost evaluation, the following components were included:

- o Containment Shell
- o Interior Structure

- o External Shield Building for Steel Containments
- o Containment Basemat
- o Fill Concrete for Steel Containments
- o External Structure under SSCV "Shadow Area"
- o Structure outside cylindrical containments including basemat that enclose components corresponding to those in SSCV "Shadow Area".
- o Indirects or Distributables

6.1.1 Bases for Cost Evaluation

The following commodities were included in the cost evaluation:

- o Excavation
- o Concrete including:
 - Forms
 - Rebar
 - Cadwelds
 - Embedded Metal
- o Tendons and Accessories
- o Containment Vessel and Polar Crane Supports
- o Non-Structural Liner Plate and Polar Crane Supports
- o Structural Steel

Differences between excavation, internal structure, mechanical, piping and electrical work of the selected alternatives were considered insignificant.

6.1.2 Identification of Cost Components

Cost components of various containment types are identified in Figures 6-1 through 6-5.

6.1.3 Summary of Costs

The summary of cost was developed for various containment types with the Westinghouse "NSSS" and the C-E "NSSS", respectively. These detailed cost breakdown are provided in Appendix B.

6.1.4 Secondary Containment for RCCV and PCCV

To reduce the potential leakage impact and subsequent offsite dose and improve public acceptance of the plant, a secondary containment could be provided around the PCCV and RCCV (similar to a shield building around a steel containment). This would increase the cost of the containment approximately 13 million dollars. (See Appendix B, External Concrete for a CSCV F/B.) This cost addition would negate much of the cost advantage of the RCCV and PCCV.

6.2 Time Related Cost - (Indirects, AFUDC, etc.)

One of the most important factors of long term construction projects is AFUDC. AFUDC is the cost associated with funds used to finance a project during construction. A study was performed to illustrate the relationship between cash flow, and AFUDC with respect to change or shortening of the construction schedule that permits an equal reduction in the total construction schedule. This study demonstrates that a reduction in construction critical path with or without an increase in cost will save significant dollars to the future owner of an ALWR. See Appendix C for study and results.

6.3 Advantages and Disadvantages of Containment Types with Respect to Cost and Schedule

Advantages and disadvantages of containment types with respect to schedules are addressed in this section since schedule has a significant impact on cost.

6.3.1 Advantages

PCCV and RCCV

- o Lower overnight cost than either of steel alternatives.
- o Potential ASME Section III, Division 2 Code change would eliminate requirements for inclined reinforcing steel. Probability of Code change is high and will have a positive impact on both cost and schedule of construction.

CSCV (F/B) and CSCV (E/B)

- o Steel Vessel constructed quickly; assemble plates on site and erect in five (5) segments via Transi-Lift mobile crane.
- o CSCV (E/B) the ellipsoidal bottom eliminates the need for substantial anchorage to the basemat.

SSCV

- o Steel vessel constructed quickly; assemble plates on site and erect in four segments via Transi-Lift mobile crane.
- o Safety systems outside the primary containment are located in the subsphere region under the containment, reducing the footprint of the safety-grade auxiliary building. This allows the control building and other plant structures to be closer to the containment reducing the amount of HVAC, Cables and Piping.
- o Commodity installations in the subsphere would parallel other activities allowing more potential to shorten critical path by multiple paths.
- o The spherical containment has a thinner shell eliminating the need for PWHT based on present code.

6.3.2 Disadvantages

PCCV/RCCV

- o Regulations require containment be built to ASME, DIV 2.

CSCV (F/B) and CSCV (E/B)

- o Schedule/Cost is dependent upon relief from Post Weld Heat Treatment (PWHT) limits for present ASME materials. This could be accomplished by an ASME Code case for application of higher strength steels or increasing PWHT thickness limit. Present ASME Code requirements and materials can add a year to the construction schedule by requiring PWHT. Shipbuilding industry welds steel with thickness up to five inches without PWHT. The ASME Code Committee is not receptive to increasing PWHT thickness requirements.
- o Bellows are required for piping penetrations on the containment vessel. Bellows are fragile and are susceptible to damage during construction. They require ISI and have a history of high maintenance.
- o Higher overnight cost than concrete options without secondary containment. Increased overnight cost could be justified if construction critical path were shortened. (Reference Appendix C, Scheduling Impacts on AFUDC.)
- o Anchorage of steel containment to basemat for flat bottom containment has proved difficult. Increased pressure will require additional design and increase construction costs. F/B containment would dictate ASME, Div. 2 concrete.

SSCV

- o Highest overnight cost.

- o Complex foundation constructability in "shadow" area.
- o Construction duration to NSSS vessel set is the longest of alternatives considered.

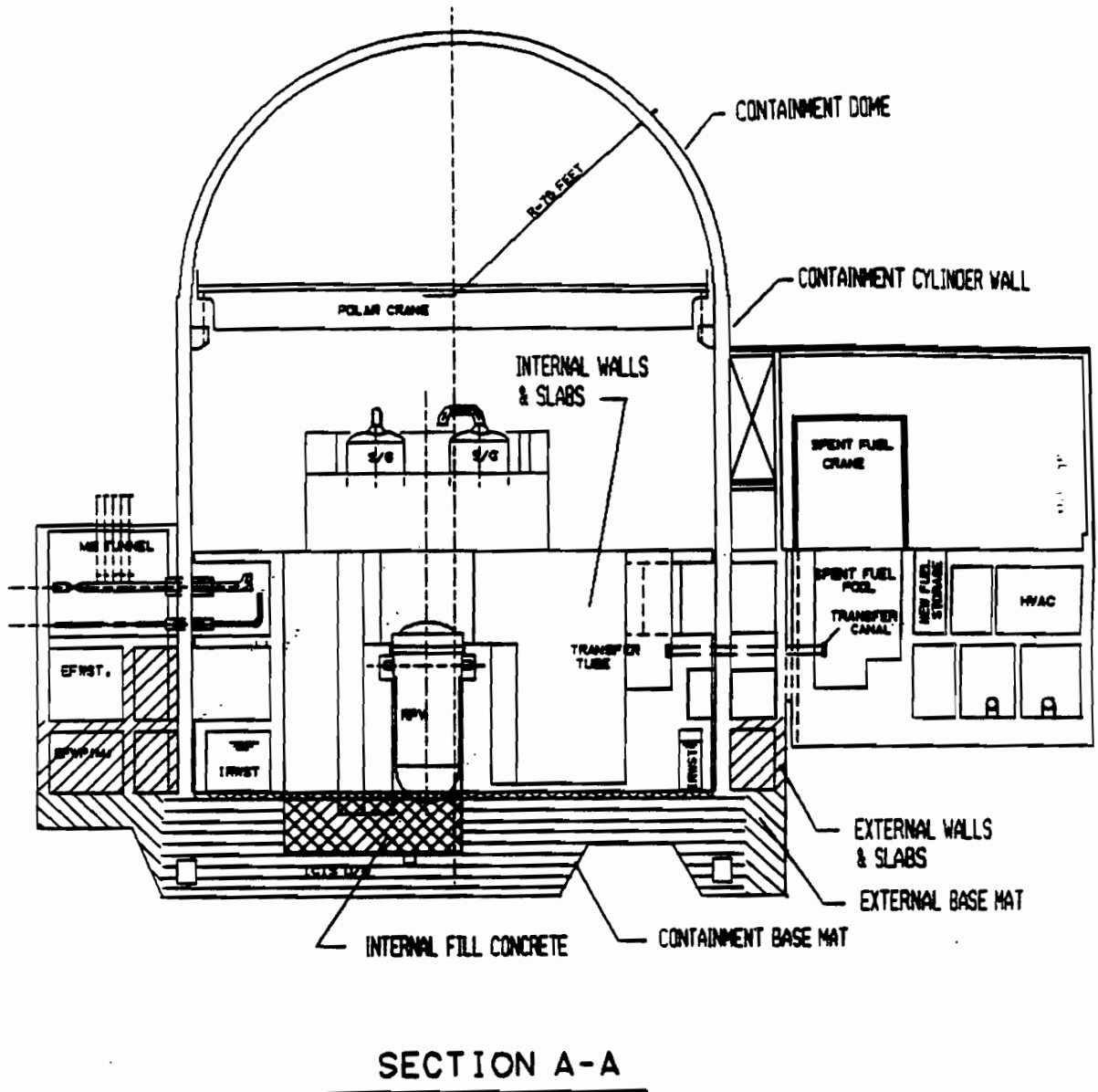
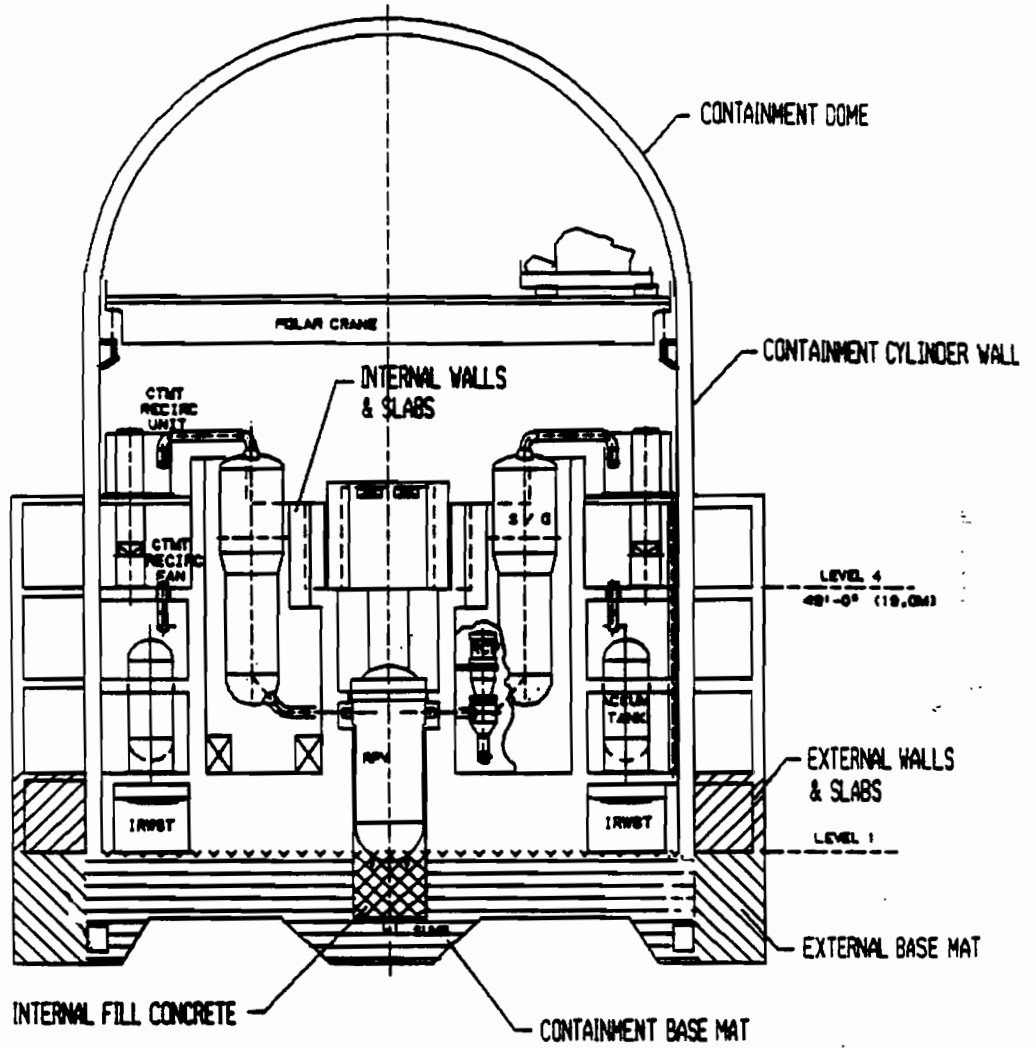


FIGURE 6-1:(a): IDENTIFICATION OF COST COMPONENTS (PCCV)



SECTION B-B

FIGURE 6-2: (b): IDENTIFICATION OF COST COMPONENTS (PCCV)

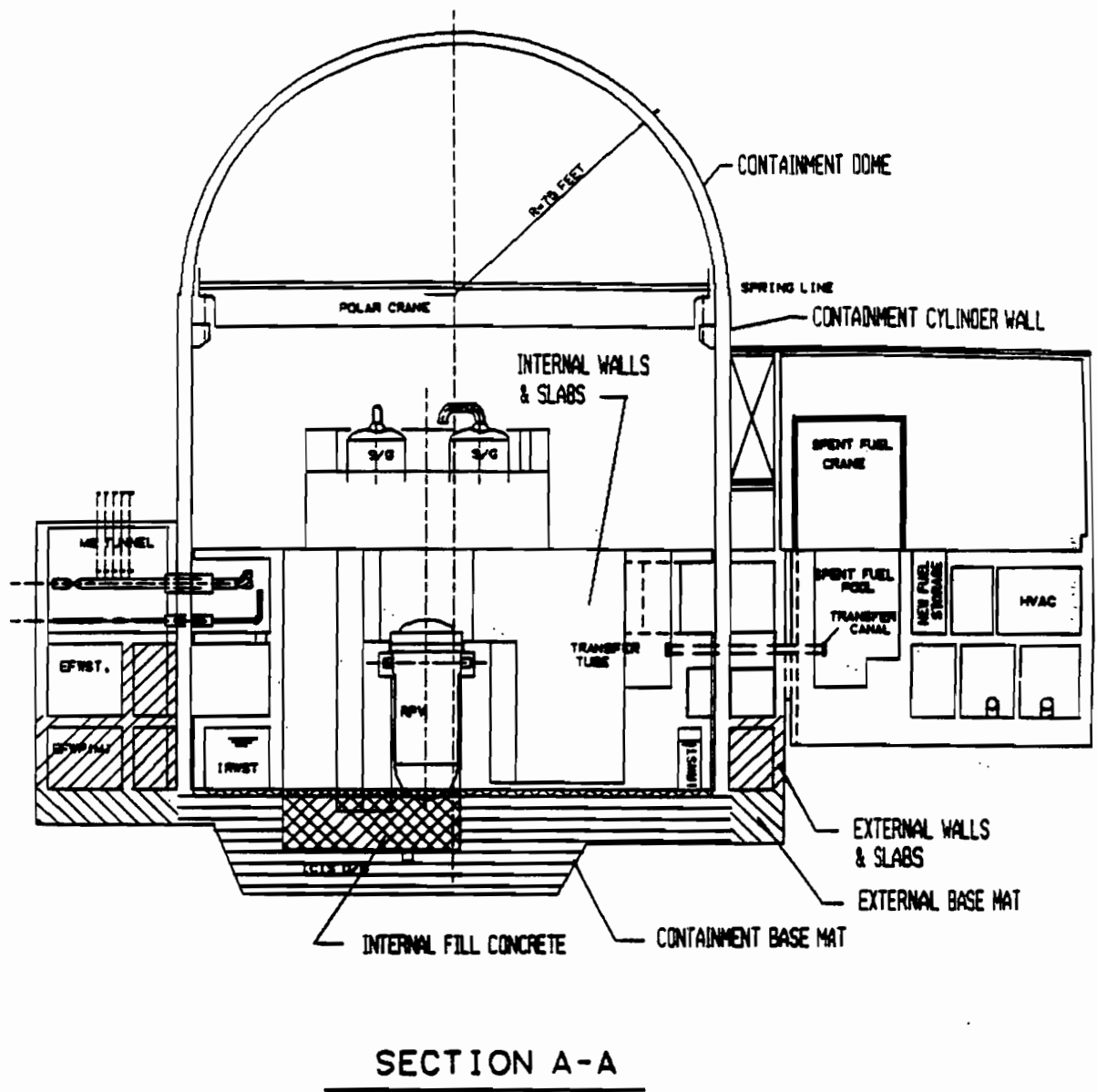
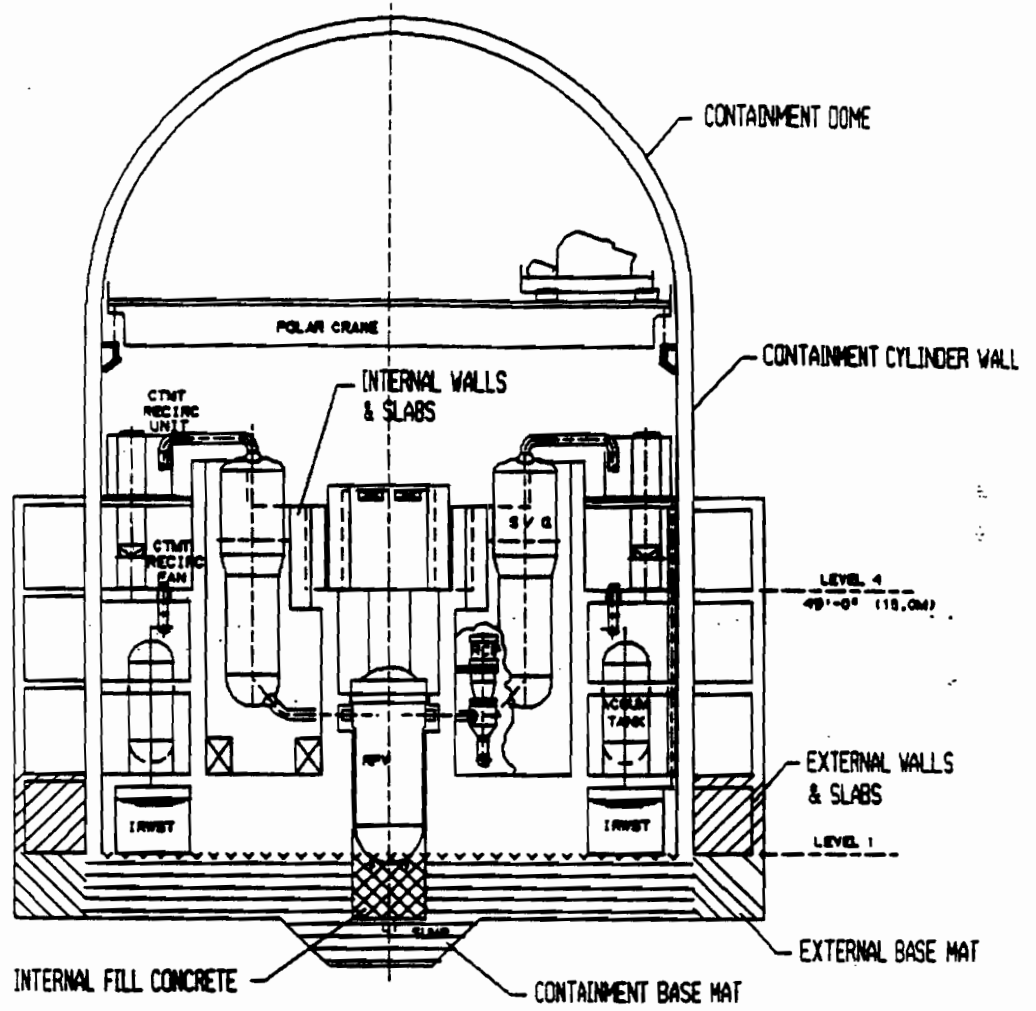
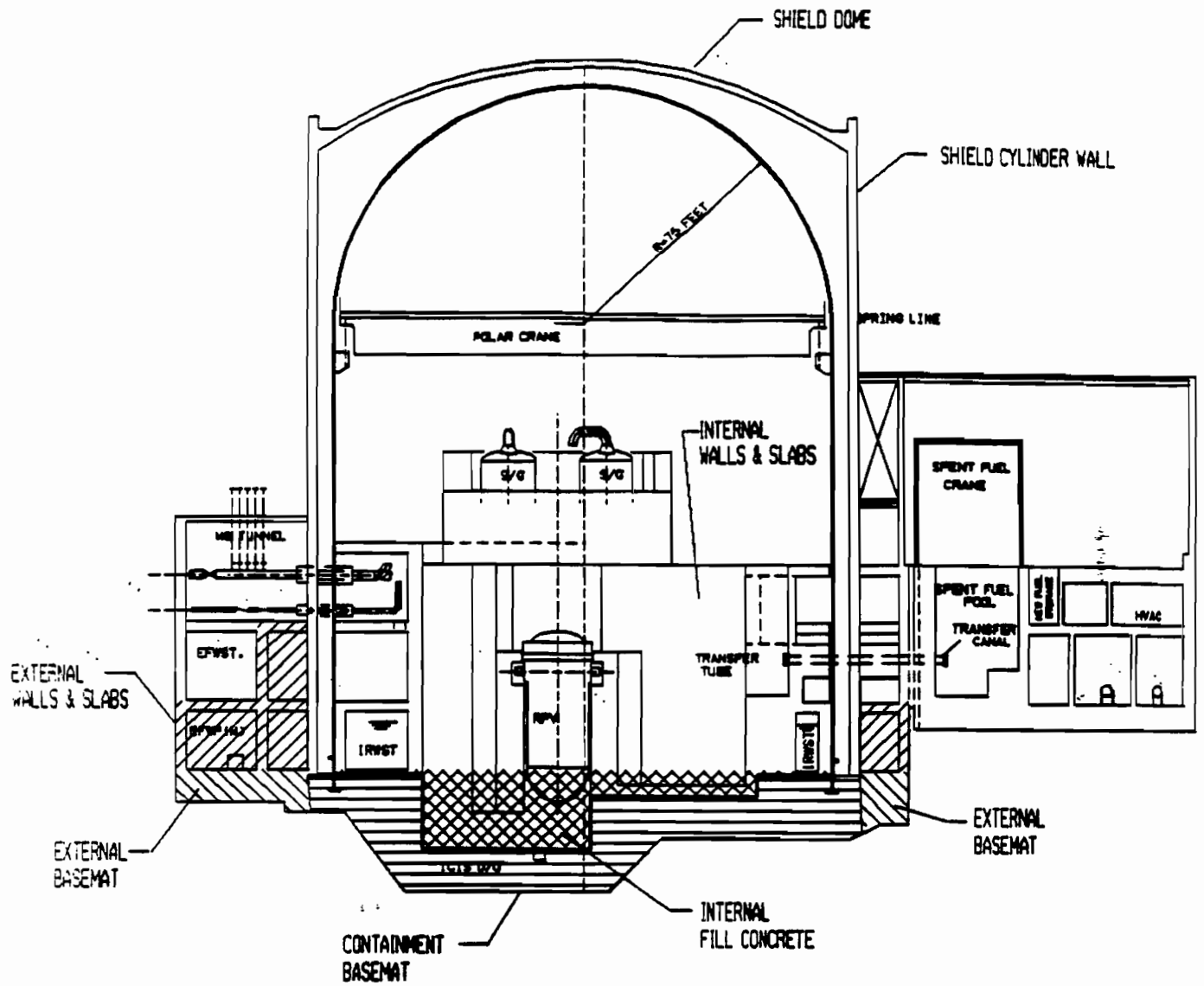


FIGURE 6-2: (a): IDENTIFICATION OF COST COMPONENTS (RCCV)



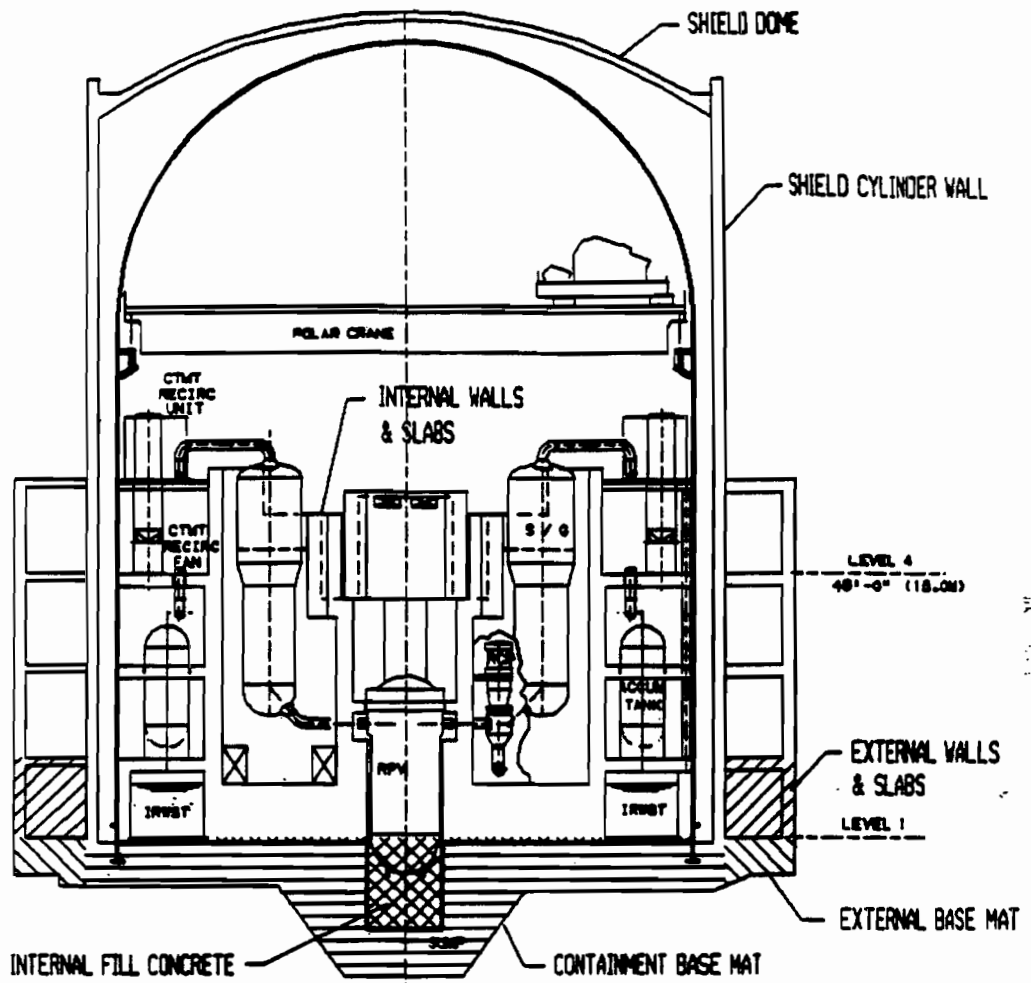
SECTION B-B

FIGURE 6-2:(b): IDENTIFICATION OF COST COMPONENTS (RCCV)



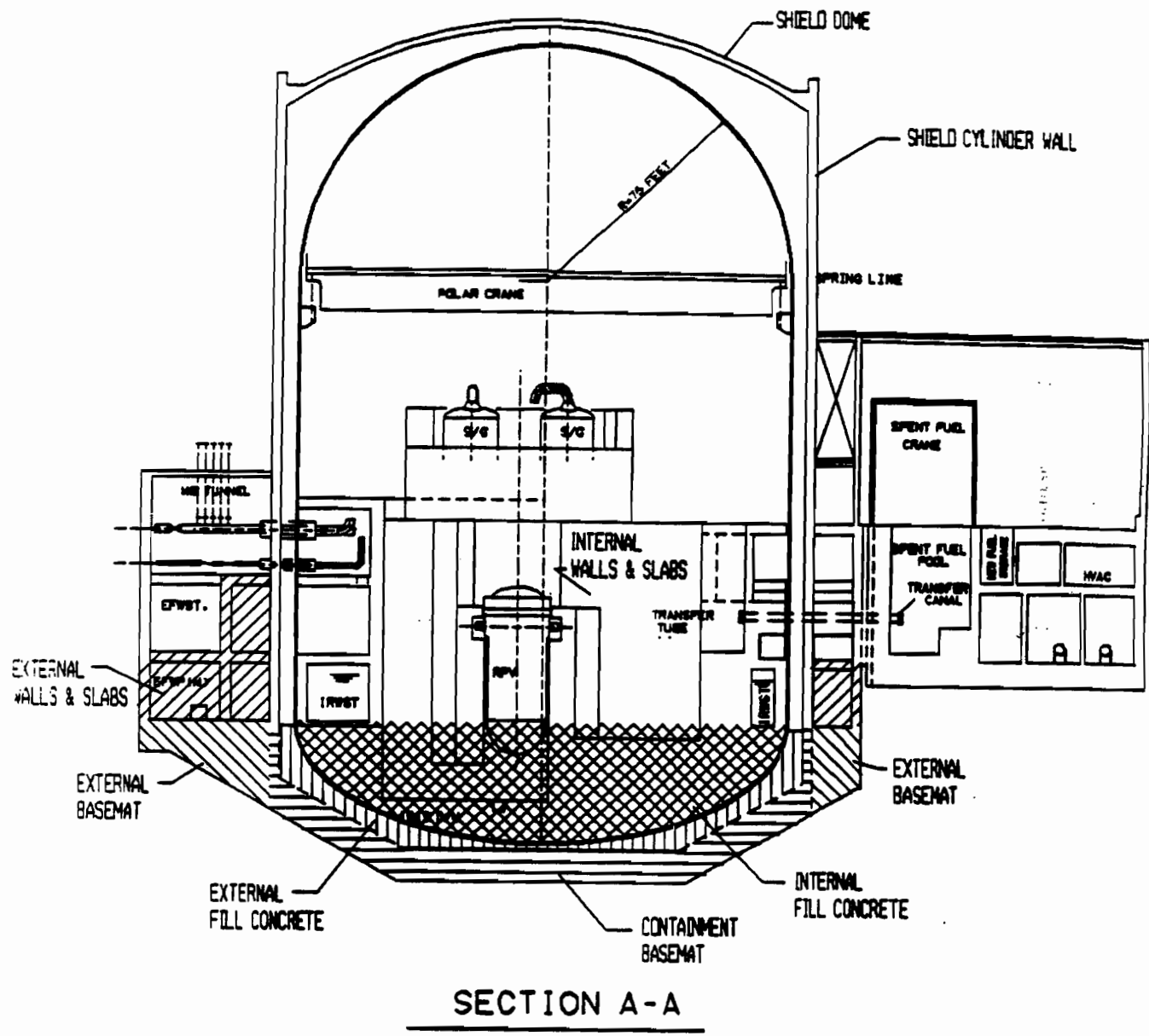
SECTION A-A

**FIGURE 6-3: (a): IDENTIFICATION OF COST COMPONENTS (CSCV)
FLAT BOTTOM**

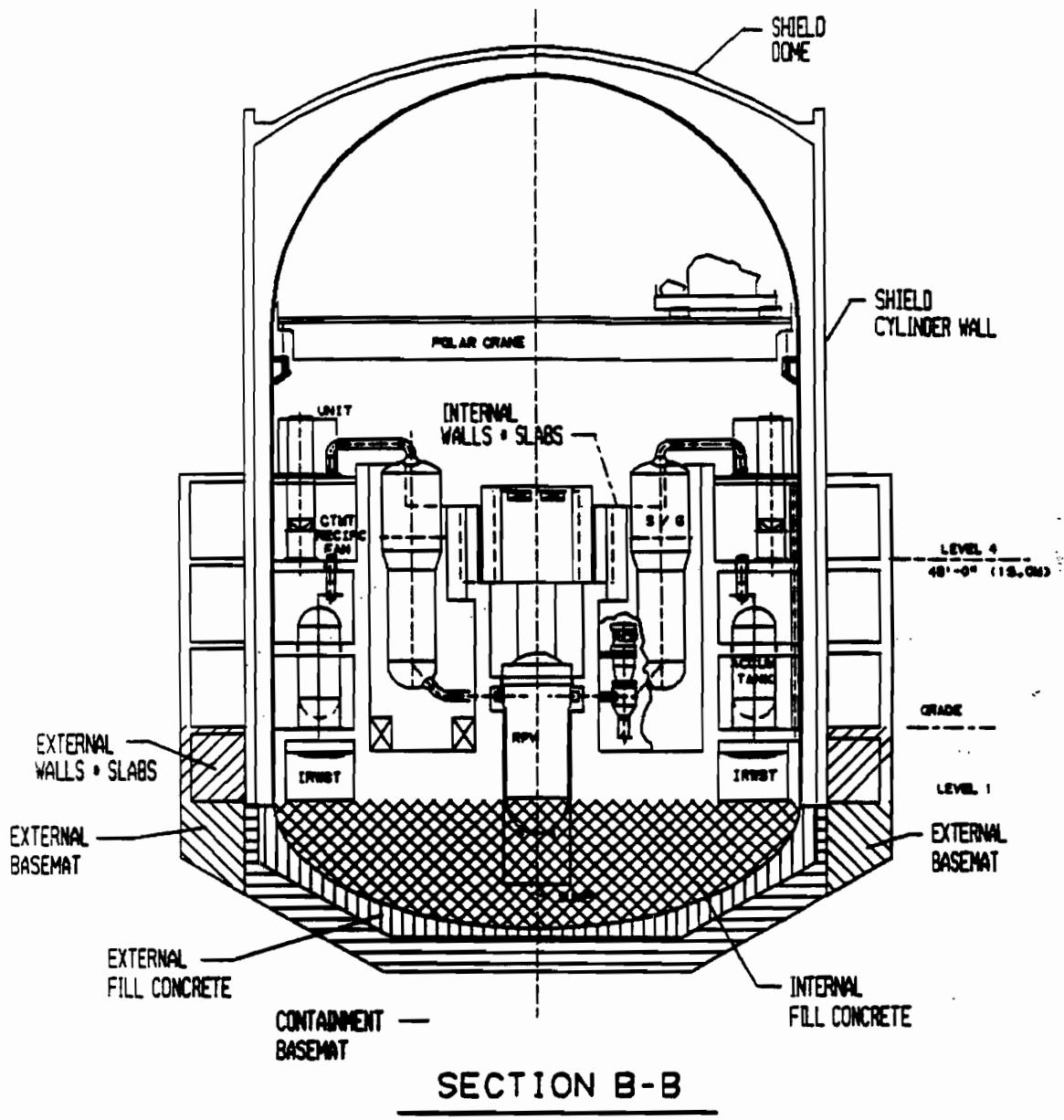


SECTION B-B

**FIGURE 6-3: (b): IDENTIFICATION OF COST COMPONENTS (CSCV)
FLAT BOTTOM**



**FIGURE 6-4: (a): IDENTIFICATION OF COST COMPONENTS (CSCV)
ELLIPSOIDAL BOTTOM**



**FIGURE 6-4: (b): IDENTIFICATION OF COST COMPONENTS (CSCV)
ELLIPSOIDAL BOTTOM**

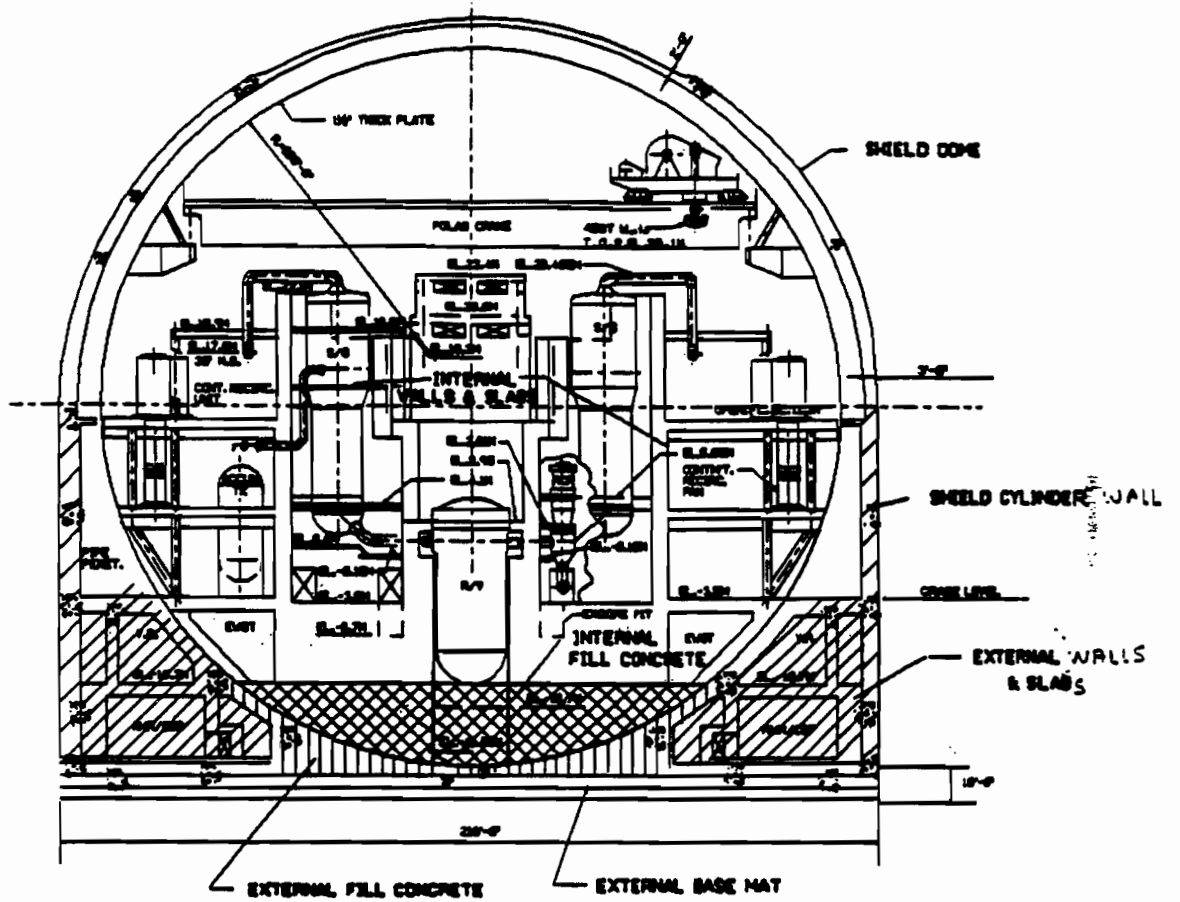


FIGURE 6-5: IDENTIFICATION OF COST COMPONENTS (SSCV)

7.0 INVESTMENT PROTECTION

Investment Protection are features which minimize investor's vulnerability to major loss. These features are addressed in three major categories.

- A. Schedule Controllability/Brevity
- B. Proven Technology
- C. Licensability/Optimization

7.1 Construction Schedule Evaluation

The schedules were discussed in Chicago meeting on June 13-14, 1988 (See Appendix A for list of attendees).

The contribution of containment construction duration on the overall construction schedule was assessed for each alternative. The objective was to quantify schedule differences using consistent assumptions including installation rate of commodities. Schedules are based on 4-loop plant.

7.1.1 Construction Schedule Assumptions

Time span between NSSS vessel set to commercial operation for all concepts (this assumption cannot be confirmed as yet due to minimal design in mechanical and electrical areas).

- o Conventional construction techniques.
- o 40 hour craft work week.
- o Use of Cadwelds.
- o No Post Weld Heat Treatment requirement for steel plates.
- o Bechtel's best craft rates from Palo Verde and Pilgram Unit 2.

- o Basemat concrete under the containment and concrete inside containment are placed in parallel.
- o Prefabrication of complete spherical base (900T) is lifted as one piece.
- o Polar crane is not required to set NSSS and is not on containment critical path.
- o Concrete containments constructed to ASME Section III, Division 2 requirements.

7.1.2 Substructure Schedule - From first structural concrete to start of containment internal structures

Figures 7-1 through 7-5 show schedule details of the various containment alternatives. Durations between first structural concrete to start of containment internal structures can be summarized as follows:

- o PCCV - 12 months
- o RCCV - 9 3/4 months
- o CSCV-F/B - 10 months
- o CSCV-E/B - 10 1/2 months
- o SSCV - 14 months

7.1.3 Overall Construction Schedule - From first structure concrete to fuel load

Figures 7-6 through 7-10 show the major activities and their duration for the various containment alternatives. The schedule durations are summarized below:

- o PCCV - 60 months
- o RCCV - 58 months
- o CSCV-F/B - 58 months

- o CSCV-E/B - 58 1/2 months
- o SSCV - 62 months

Given the scheduling assumptions made, none of the alternatives meet the EPRI ALWR objective of a 54 month construction schedule. It is believed, however, the scheduling bases postulated by EPRI (e.g., Rolling 4 x 10, etc.) would have a positive impact on reducing these durations towards the EPRI target schedule of 54 months.

7.1.4 Schedule Reduction - Construction Innovations

In order to meet EPRI's target 54 month construction schedule between first structural concrete and the 100 hour warranty run, various construction innovations were discussed and are listed below:

- o Installation of NSSS vessels with heavy-lift crane prior to setting dome on containment - thus avoiding large temporary construction opening in containment wall.
- o Extensive modularization of rebar and steel plate.
- o Elimination of helical rebar to carry seismic and wind shear loads in the plane of the RCCV cylindrical shell.
- o Use of threaded mechanical couplers in lieu of Cadwelds.
- o Use of double shift, rolling 4x10 work week.

To achieve the desired 54 month schedule would necessitate the use of these as well as other innovations and superior management of materials and crafts. This would result in premium costs for prefabrication, overtime, etc.

An 80% sustained rate for commodity installation necessary to achieve the 54 month construction schedule exceeded the best rate of installation ever achieved in the US. A comparison of 54 month schedule commodity installations rates and the best US rates are listed below:

	<u>54 Month</u>	<u>Best U.S.</u>
Concrete	5924 CYD/Mo	7100 CYD/Mo
L-B Pipe	5764 Lft/Mo	5400 Lft/Mo
S-B Pipe	11458 Lft/Mo	6700 Lft/Mo
Cable Tray	3525 Lft/Mo	3100 Lft/Mo
Metal Conduit	16515 Lft/Mo	16700 Lft/Mo
Wire & Cable	310955 Lft/Mo	260000 Lft/Mo
Connections	14127 ea.	9800 ea.

An example of the 54 month PCCV schedule is shown in Figure 7.11. It was developed for EPRI for inclusion in the ALWR Requirements Document.

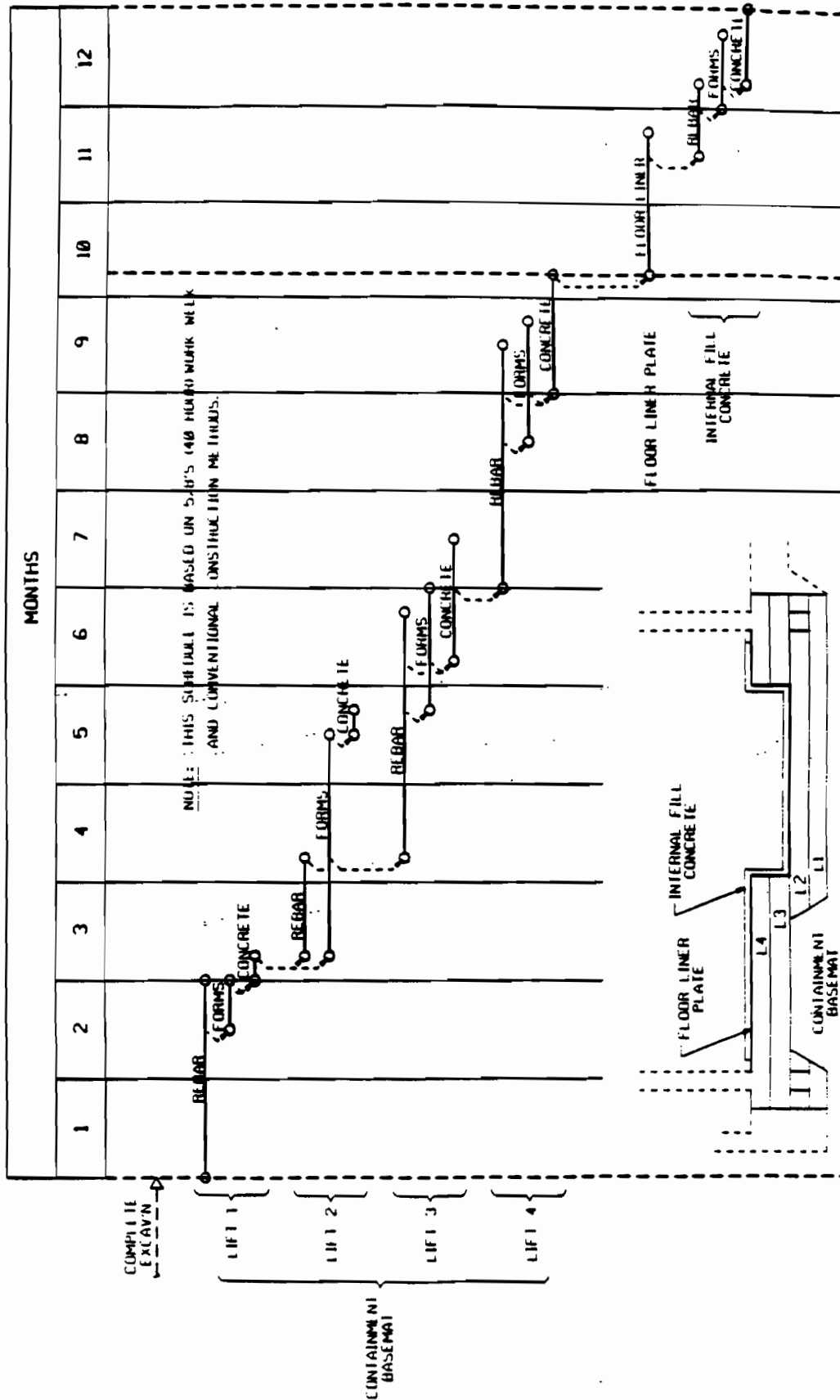


FIGURE 7-1: PCCV - CONSTRUCTION SCHEDULE EXTRACT

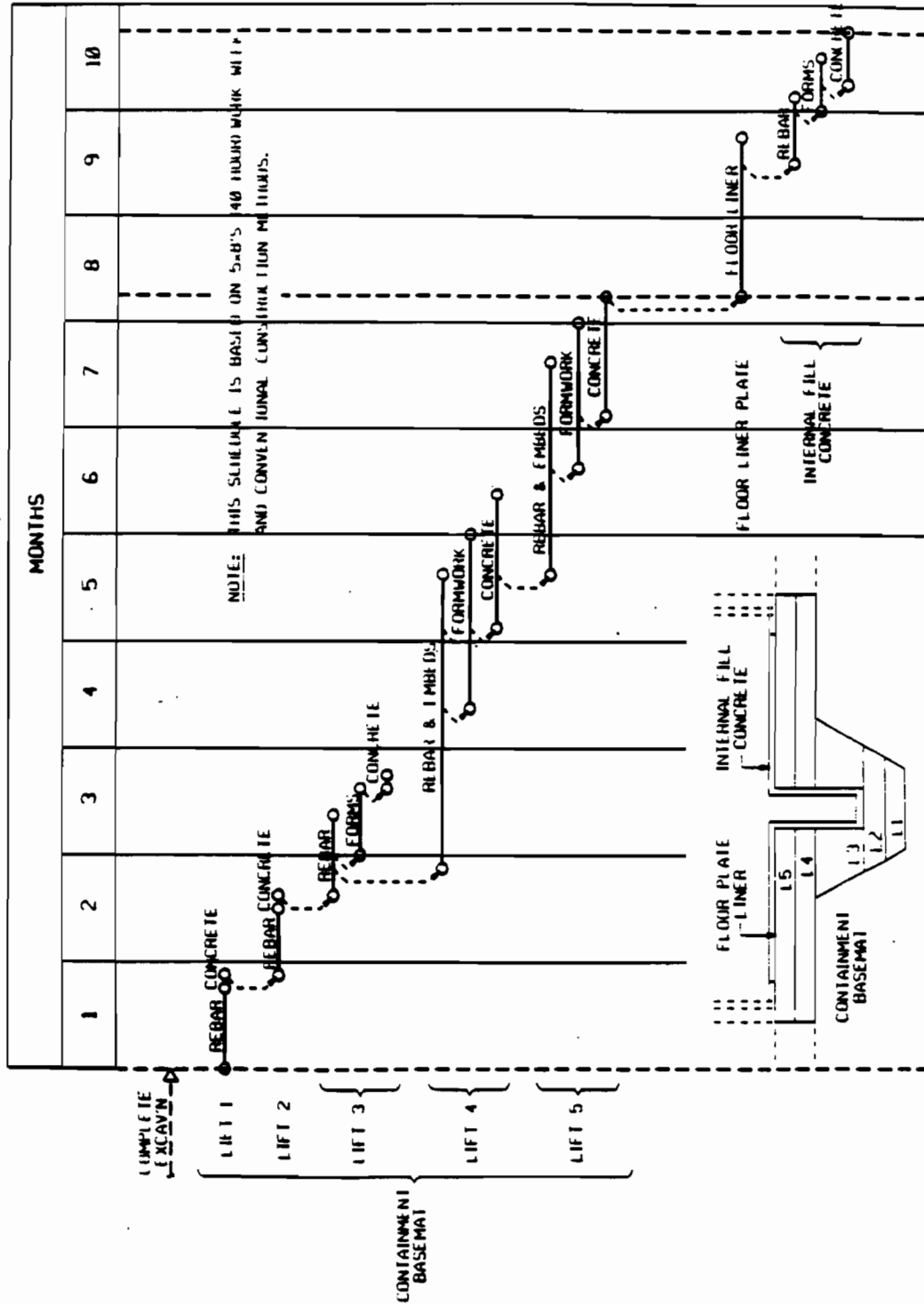


FIGURE 7-2: RCCV - CONSTRUCTION SCHEDULE EXTRACT

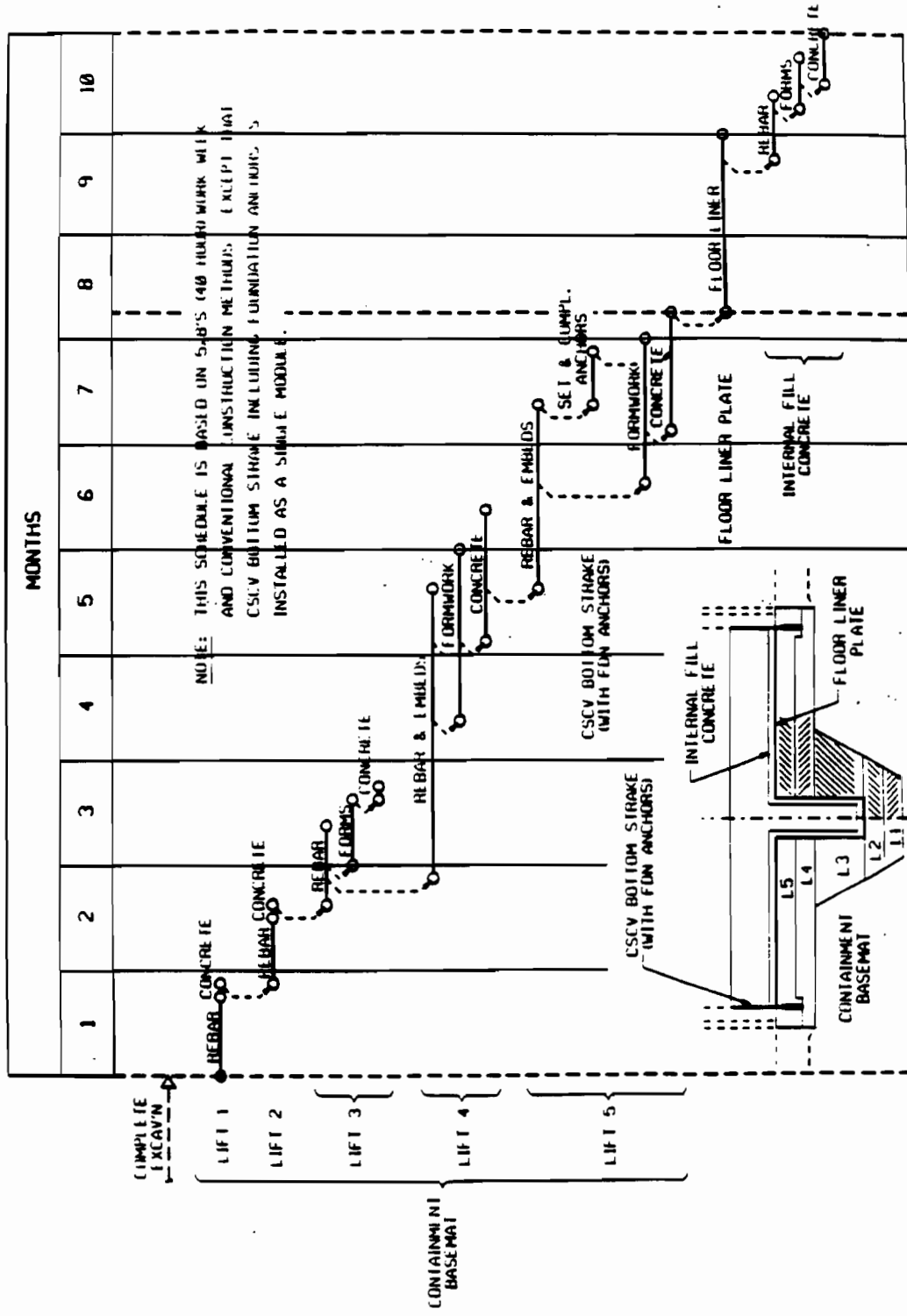


FIGURE 7-3: CSCV (FLAT BOTTOM) - CONSTRUCTION SCHEDULE EXTRACT

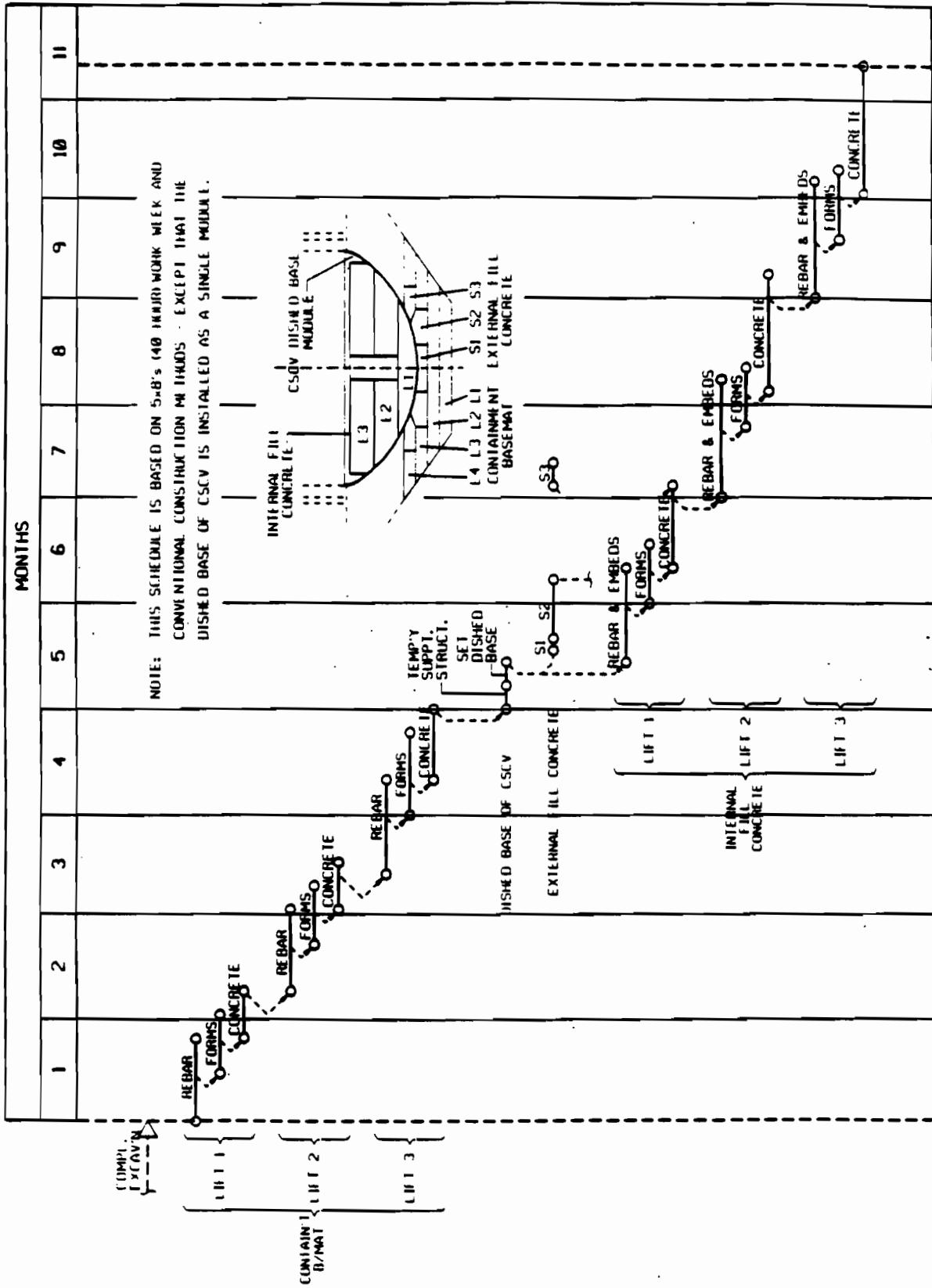


FIGURE 7-4: CSCV (ELLIPSOIDAL BOTTOM) - CONSTRUCTION SCHEDULE EXTRACT

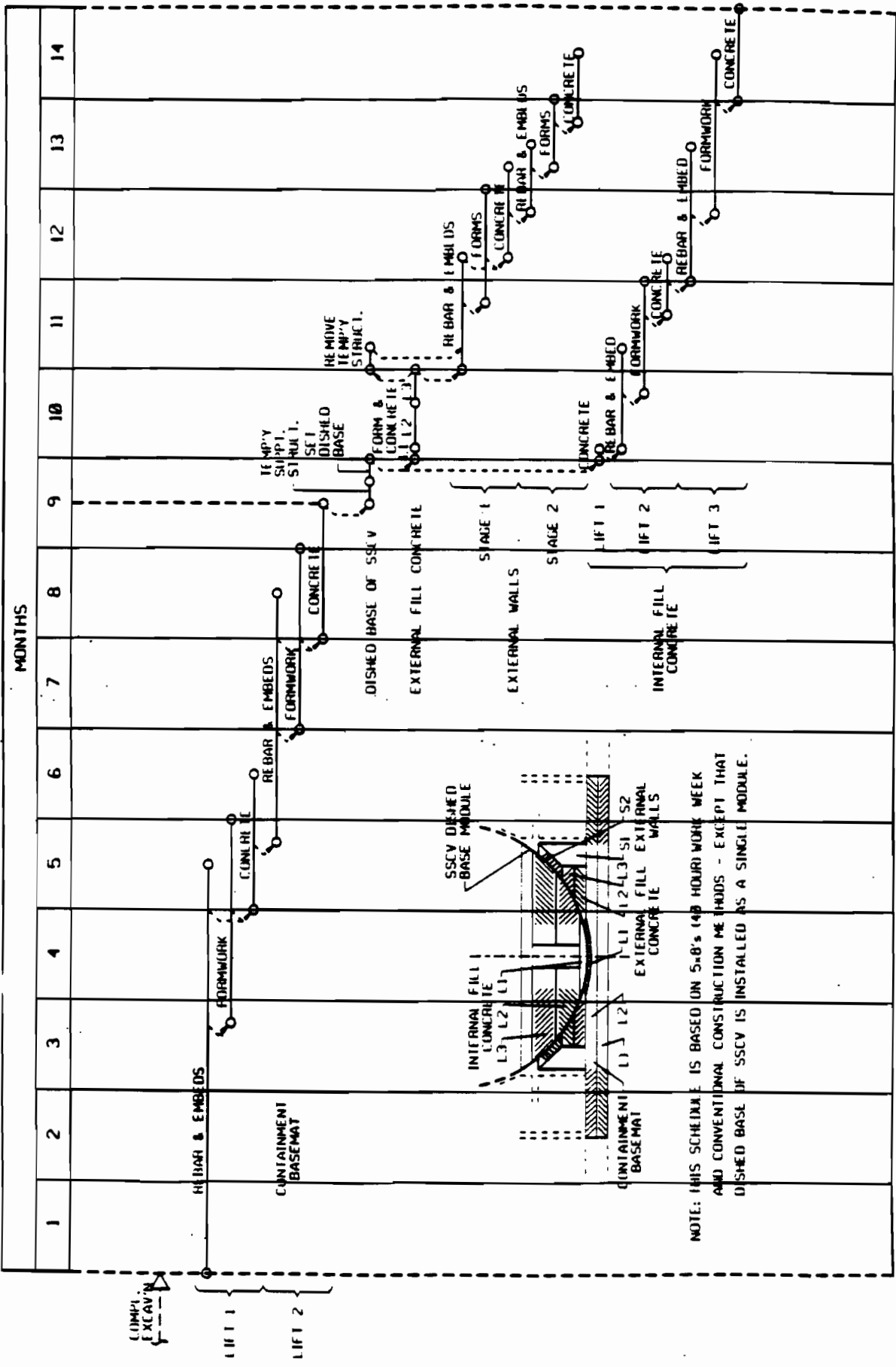
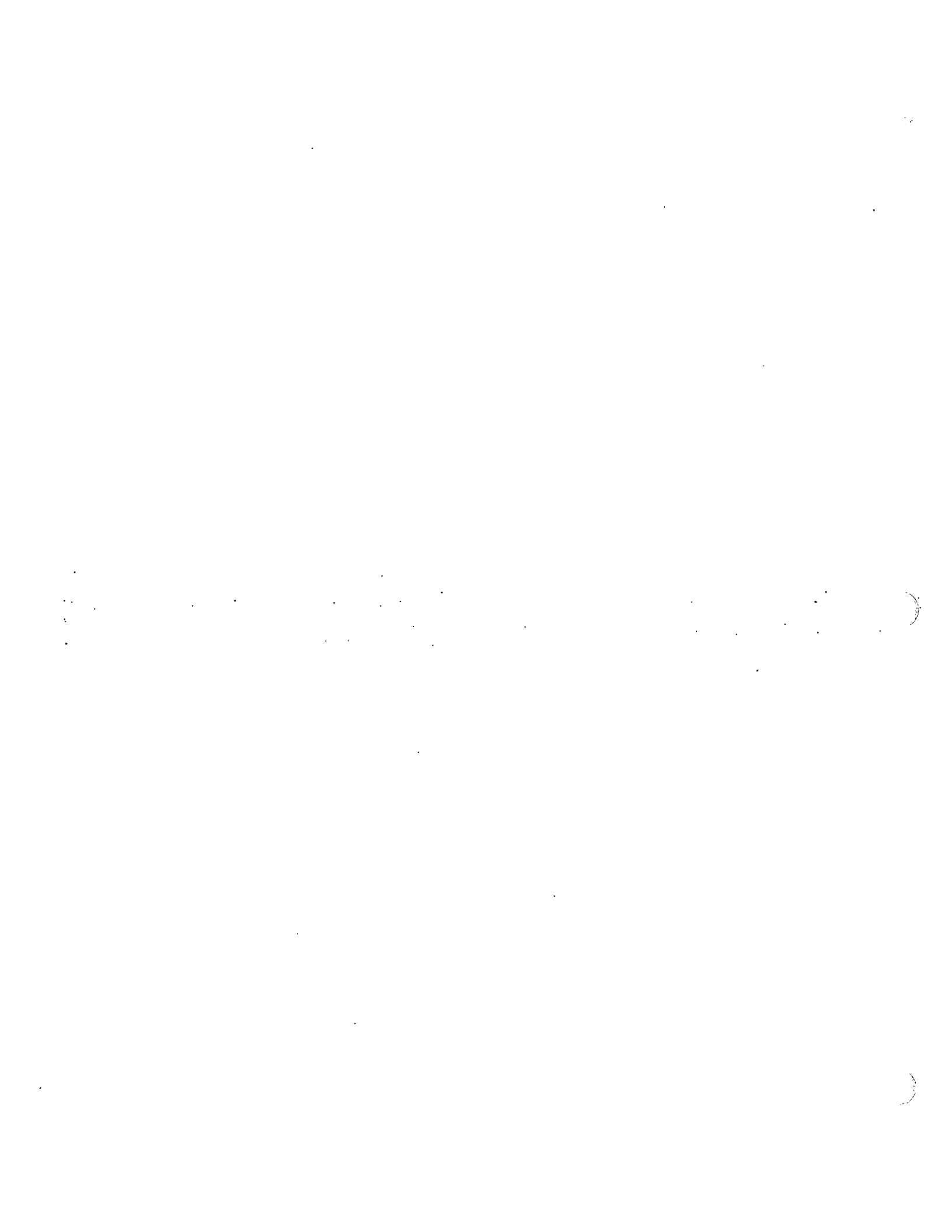


FIGURE 7-5: SSCV - CONSTRUCTION SCHEDULE EXTRACT



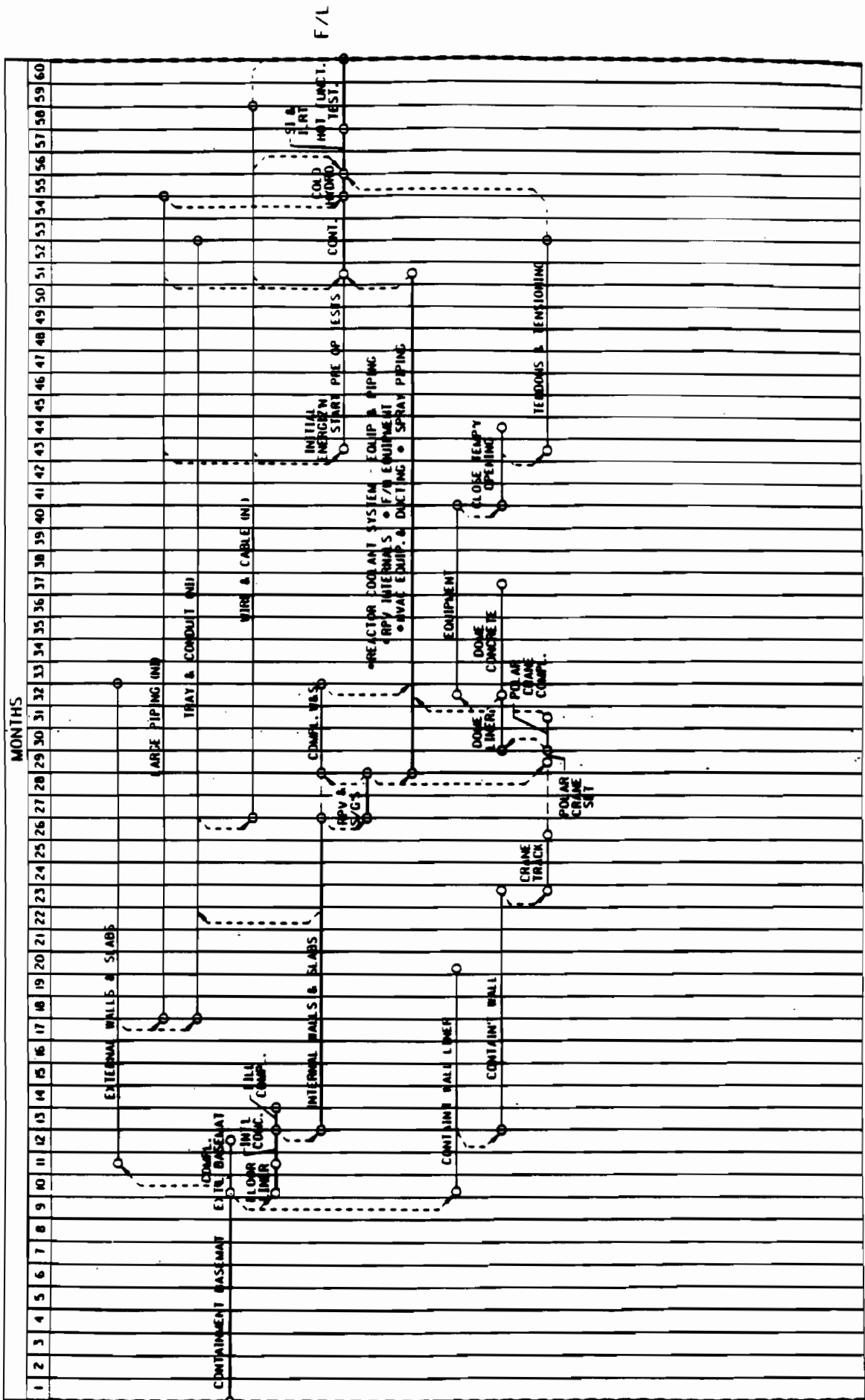


FIGURE 7-6 PCCV - CRITICAL CONSTRUCTION SCHEDULE

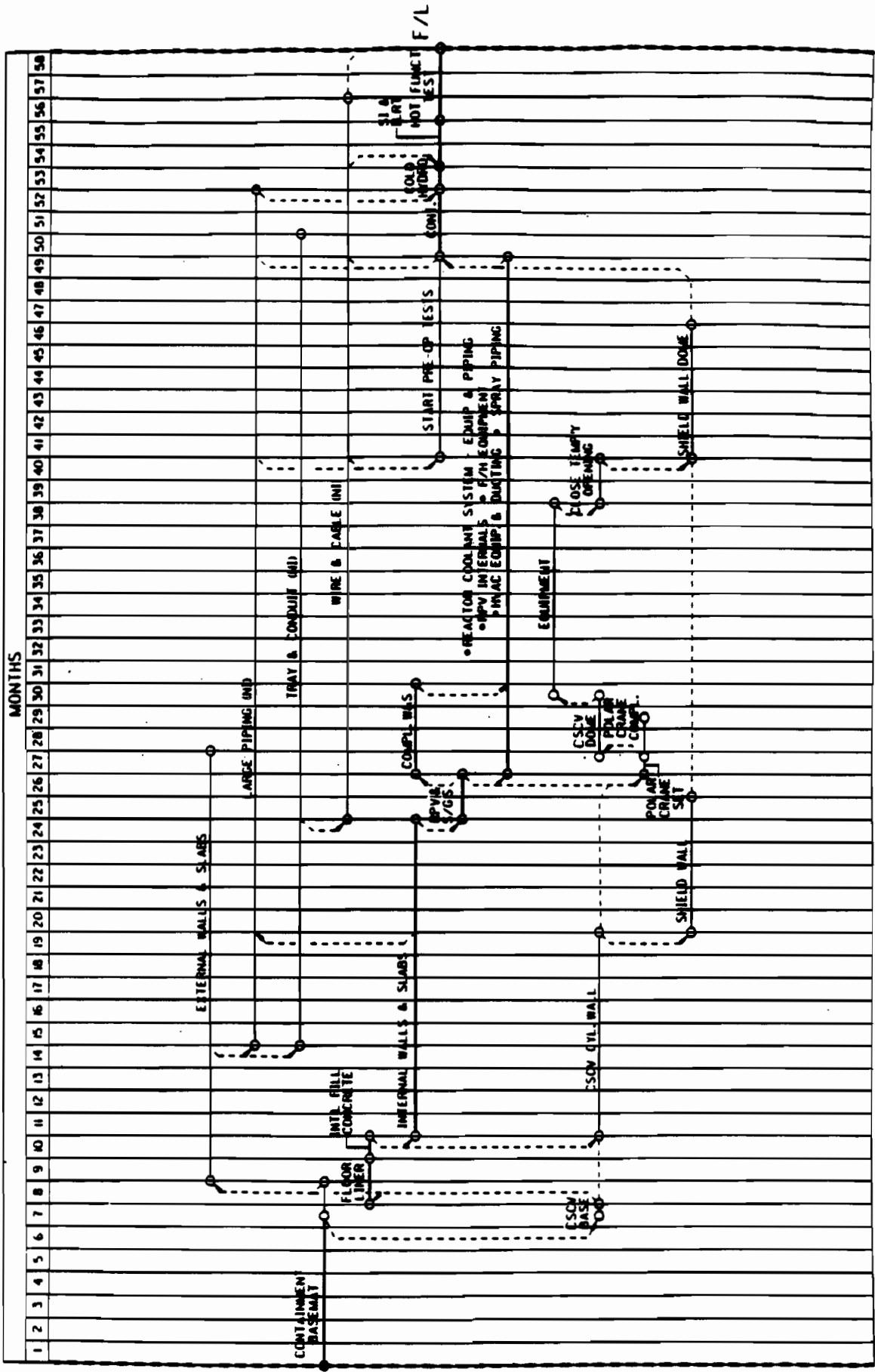


FIGURE 7-8: CSCV (FLAT BOTTOM) - CRITICAL CONSTRUCTION SCHEDULE

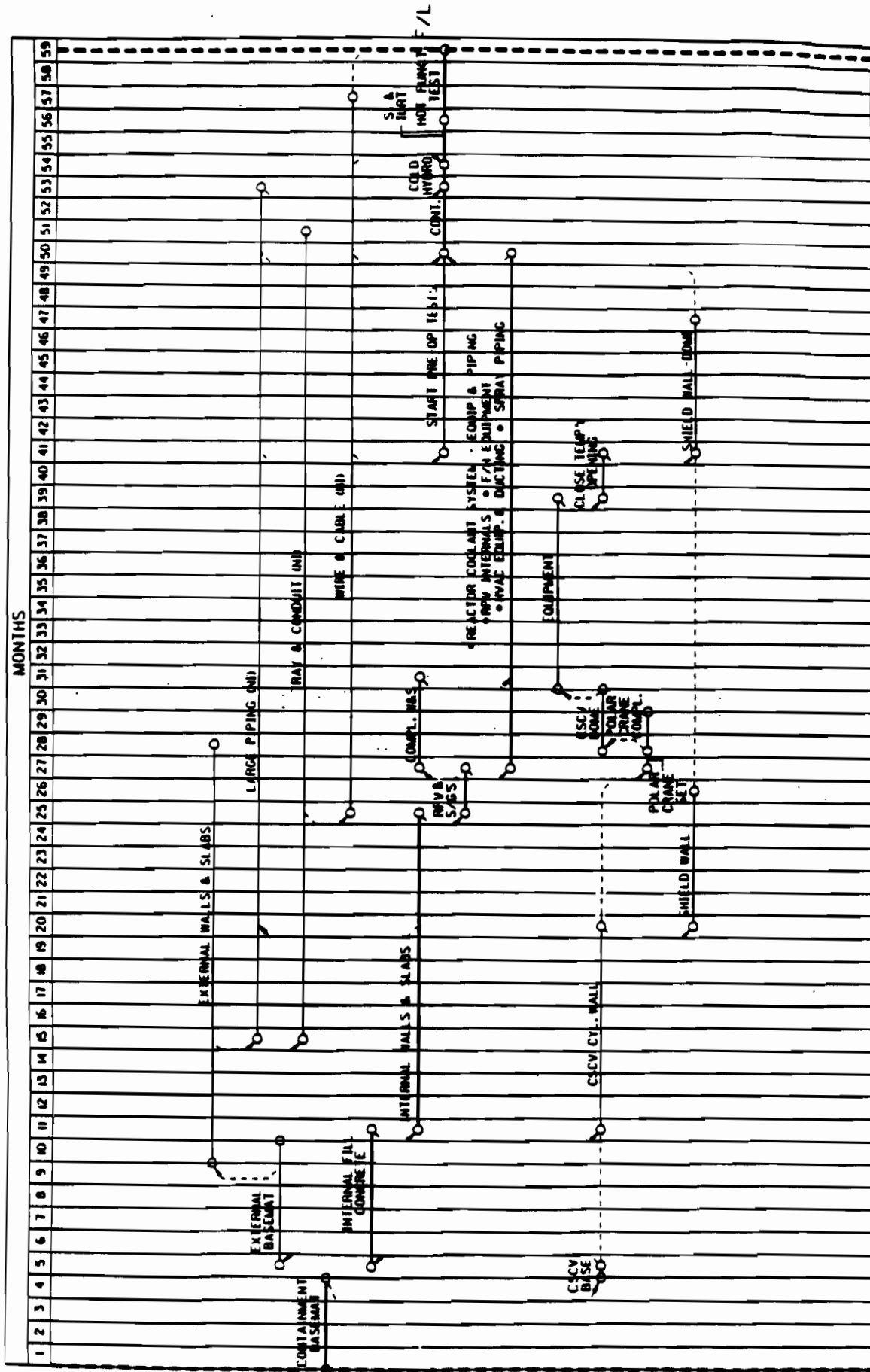


FIGURE 7-9: CSCV (ELLIPSOIDAL BOTTOM) - CRITICAL CONSTRUCTION SCHEDULE

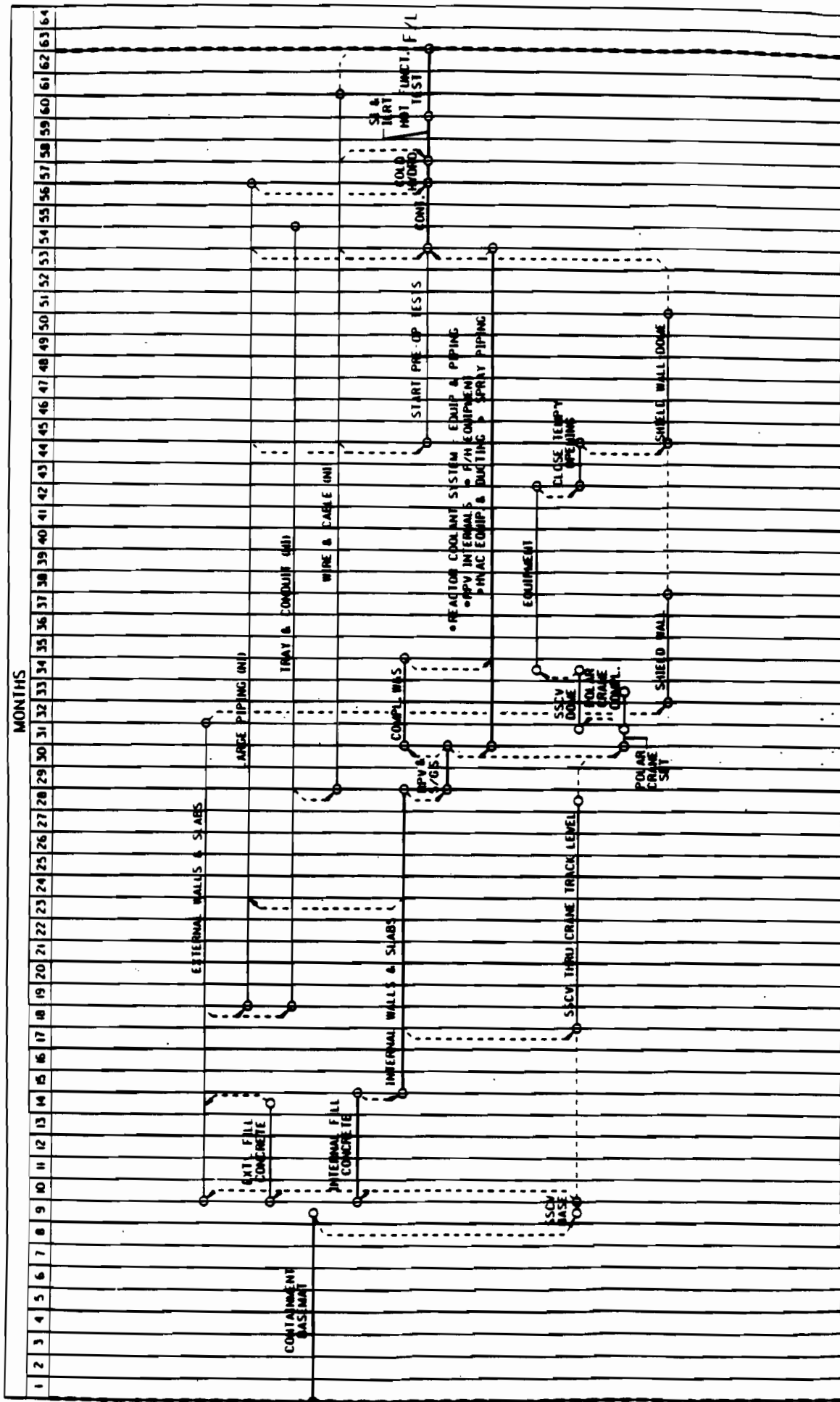
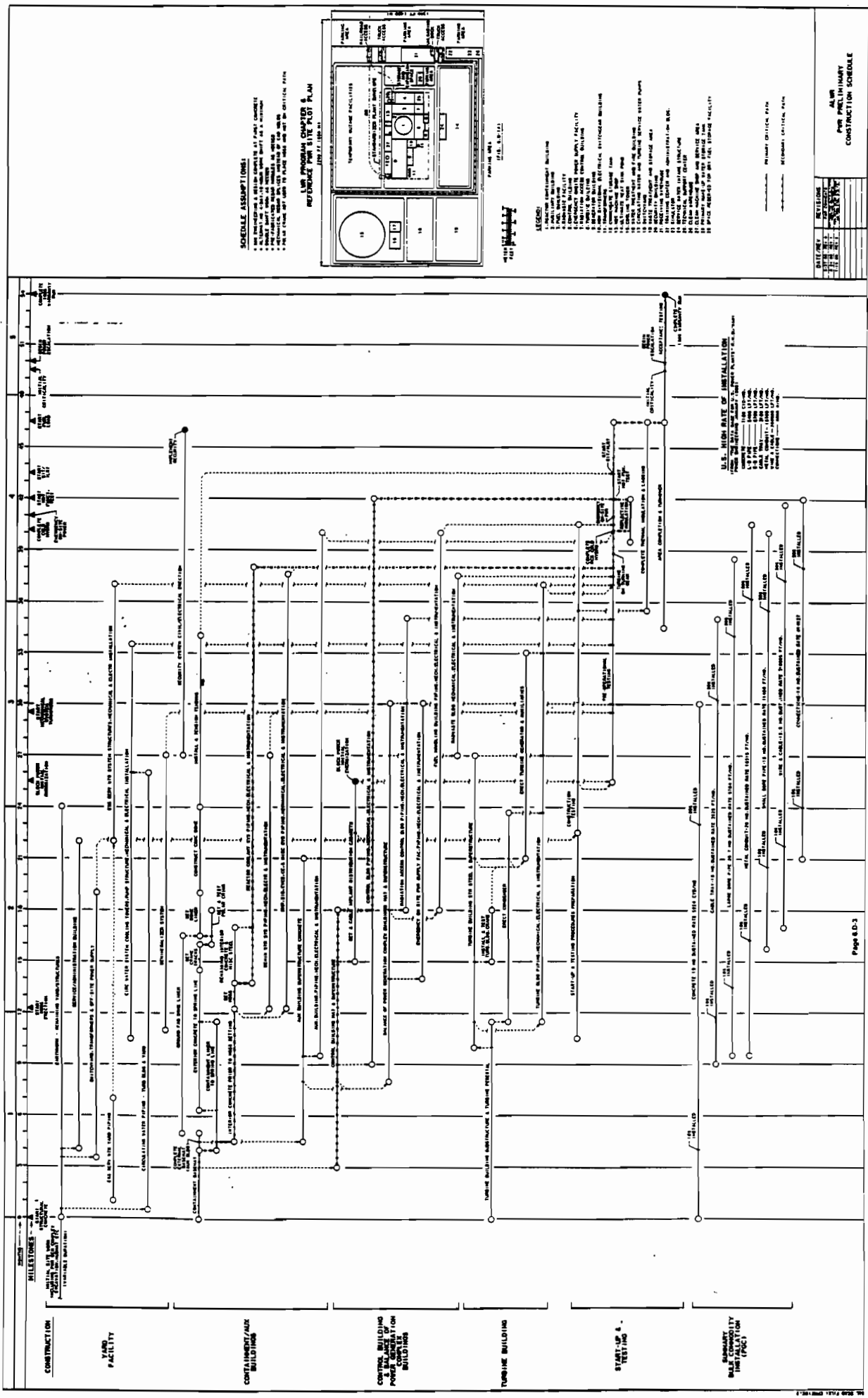


FIGURE 7-10: SSCV - CRITICAL CONSTRUCTION SCHEDULE



SCHEDULE ASSUMPTIONS:

- 1. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 2. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 3. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 4. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 5. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 6. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
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- 11. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 12. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 13. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 14. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 15. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 16. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 17. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 18. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 19. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.
- 20. ALL ACTIVITIES ARE TO BE COMPLETED BY 1972.

LWR PROGRAM CHAPTER 6 REFINERY PLOT PLAN

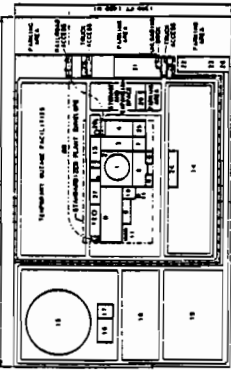


FIG. 6.1.1.1

LEGEND:

- 1. PRELIMINARY DESIGN
- 2. PRELIMINARY DESIGN
- 3. PRELIMINARY DESIGN
- 4. PRELIMINARY DESIGN
- 5. PRELIMINARY DESIGN
- 6. PRELIMINARY DESIGN
- 7. PRELIMINARY DESIGN
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- 14. PRELIMINARY DESIGN
- 15. PRELIMINARY DESIGN
- 16. PRELIMINARY DESIGN
- 17. PRELIMINARY DESIGN
- 18. PRELIMINARY DESIGN
- 19. PRELIMINARY DESIGN
- 20. PRELIMINARY DESIGN

U.S. HIGH RATE OF INSTALLATION

ACTIVITY	UNIT	PERCENTAGE
CONCRETE	CU YD	100%
STEEL	TONS	100%
PIPE	LINEAL FT	100%
WELDING	LINEAL FT	100%
PAINTING	SQ YD	100%
INSULATION	SQ YD	100%
MECHANICAL	NO. OF UNITS	100%
ELECTRICAL	NO. OF UNITS	100%
PLUMBING	NO. OF UNITS	100%
HEATING	NO. OF UNITS	100%
VENTILATION	NO. OF UNITS	100%
AC	NO. OF UNITS	100%
LIFTS	NO. OF UNITS	100%
STAIRS	NO. OF UNITS	100%
ROOFING	SQ YD	100%
GLAZING	SQ YD	100%
LANDSCAPING	SQ YD	100%
UTILITIES	NO. OF UNITS	100%
FINISHING	SQ YD	100%
MOVING	NO. OF UNITS	100%
DEMOLITION	SQ YD	100%
GRADING	SQ YD	100%
PAVING	SQ YD	100%
SEWERAGE	NO. OF UNITS	100%
WATER SUPPLY	NO. OF UNITS	100%
WATER TREATMENT	NO. OF UNITS	100%
WATER STORAGE	NO. OF UNITS	100%
WATER DISTRIBUTION	NO. OF UNITS	100%
WATER PUMPING	NO. OF UNITS	100%
WATER TREATMENT	NO. OF UNITS	100%
WATER STORAGE	NO. OF UNITS	100%
WATER DISTRIBUTION	NO. OF UNITS	100%
WATER PUMPING	NO. OF UNITS	100%

REVISIONS

NO.	DATE	DESCRIPTION
1	10/1/68	ISSUED FOR CONSTRUCTION
2	11/1/68	REVISED FOR CONSTRUCTION
3	12/1/68	REVISED FOR CONSTRUCTION
4	1/1/69	REVISED FOR CONSTRUCTION
5	2/1/69	REVISED FOR CONSTRUCTION
6	3/1/69	REVISED FOR CONSTRUCTION
7	4/1/69	REVISED FOR CONSTRUCTION
8	5/1/69	REVISED FOR CONSTRUCTION
9	6/1/69	REVISED FOR CONSTRUCTION
10	7/1/69	REVISED FOR CONSTRUCTION
11	8/1/69	REVISED FOR CONSTRUCTION
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98	11/1/76	REVISED FOR CONSTRUCTION
99	12/1/76	REVISED FOR CONSTRUCTION
100	1/1/77	REVISED FOR CONSTRUCTION

8.0 REVIEW OF LICENSING ISSUES, OPTIMIZATION TRENDS AND RECOMMENDATIONS FOR FUTURE ACTION

8.1 Review of Licensing Issues

- o All alternatives have been previously licensed.
- o Current licensing concerns: Severe Accidents (core melt, hydrogen generation, large seismic event).
- o Desirable Characteristics
 - o Large margins to failure
 - o Predictable, non-explosive failure mode
- o Current Evaluation
 - o No acceptable basis to determine failure margins generically for pressure and seismic.
 - o Sandia tests demonstrate overpressurized steel containments liable to catastrophic failure; RCCV demonstrated Leak-before-Break behavior failure mode.
- o Secondary Containment Option
 - o Conversion of the external shield structure to secondary containment will always be less disruptive to design than adding a structure, regardless of criteria.

8.2 Optimization Trends

The following are some of the trends developing towards cost optimization of the various containment alternatives.

8.2.1 PCCV

- o Reduce the number of buttresses from 6 to 3 to 2.
- o Increase tendon load rating.
- o Use hemispherical dome with over-the-top vertical tendons.

8.2.2 RCCV

- o Eliminate inclined (diagonal) reinforcing per ASME Section III, Division 2.

8.2.3 CSCV

- o Extend capability of steel shells without PWHT.

8.2.4 All Containments

- o Apply large scale modularization to steel shells, liners, reinforcing and tendon sheaths.

8.3 Recommendations for Future Action

- o Pursue design and external arrangement for PCCV and RCCV with secondary containment.
- o Evaluate licensability aspects, especially related to severe accidents.
- o Develop more comprehensive schedule through fuel load especially for two loop plants.
- o Pursue relaxation of ASME requirements from both design and construction aspect.

9:0 EXAMPLE OF DECISION MATRIX

Use of the Decision Matrix is subjective because of the experience base of each evaluator. Based on the perspective of the evaluator, a difference of opinion on the weights for each evaluation criteria exists. Example of the Decision Matrix use were performed by the following companies.

- o Stone & Webster Figure 9.1
- o Combustion Engineering Figure 9.2
- o Westinghouse Figure 9.3
- o Babcock and Wilcox Figure 9.4
- o Duke Power Company Figure 9.5
- o Bechtel (Matrix not shown)

A summary of conclusions based on review of these matrices is described below:

- o Combustion Engineering selected SSCV with CSCV elliptical bottom second.
- o Bechtel selected RCCV (improved) with PCCV second.
- o Westinghouse selected CSCV elliptical bottom.
- o Duke Power Company selected SSCV with CSCV elliptical bottom second.
- o Stone and Webster selected RCCV (improved) with PCCV second.
- o Babcock & Wilcox selected CSCV elliptical bottom.

From the results, it can be seen that containment type selection for the future ALWR is subjective and depends on your perspective as an evaluator. It will be the responsibility of current and future ALWR participants to evaluate the selection parameters and weigh them based on their perspective. They must then rate the differences between candidate types and determine which meets the needs and objectives.

**DUKE / DOE DESIGN FOR CONSTRUCTABILITY PROGRAM
 ADVANCED PWR CONTAINMENT CONSTRUCTABILITY
 CONTAINMENT TYPE DECISION MATRIX**

FIGURE 9-1
 STONE & WEBSTER

EVALUATION CRITERIA

WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)						
	CASE A	CASE B	CASE C	CASE D	CASE E	CASE F	CASE G
10	8	8	6	6	7	6	7
10	8	8	6	7	7	6	7
10	9	9	8	7	7	7	7
15	8	9	7	6	6	6	5
15	8	9	7	7	7	6	5
15	8	9	8	7	7	7	5
10	9	8	8	8	6	6	5
15	9	9	8	8	7	6	6
100	835	870	730	700	675	625	575

RATING SCALE R
 10 - EXCELLENT
 1 - MARGINAL

WEIGHING FACTOR W
 TOTAL = 100

D. CSCV F/B (BASE)
 E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT
 F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT
 G. SSCV (BASE)

I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH)

A. OPERABILITY / MAINTAINABILITY (EVERDAY)

B. RELIABILITY / AVAILABILITY (LIFETIME)

- ISI
- CORROSION RESISTANCE
- S / G REMOVAL

C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY)

- RESISTANCE TO FIRE, FLOOD, SABOTAGE
- PRESSURE MARGIN
- SA COPING

II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT)

OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.)

TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)

III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS)

(SCHEDULE)

(PROVEN TECHNOLOGY)

A. SCHEDULE CONTROLLABILITY / BREVITY

B. PROVEN TECHNOLOGY

C. LICENSABILITY (NPC / PUC)

(LICENSABILITY)

TOTAL

CANDIDATE DESCRIPTIONS

A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)

B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASON-ABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)

C. PCCV (IMPROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2

**DUKE / DOE DESIGN FOR CONSTRUCTABILITY PROGRAM
 ADVANCED PWR CONTAINMENT CONSTRUCTABILITY
 CONTAINMENT TYPE DECISION MATRIX**

FIGURE 9-2

COMBUSTION ENGINEERING

EVALUATION CRITERIA

	WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)						TOTAL	WEIGHTING FACTOR TOTAL
		CASE A	CASE B	CASE C	CASE D	CASE E	CASE F		
I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH)	15	6	6	5	7	7	7	7	9
A. OPERABILITY / MAINTAINABILITY (EVERDAY)	10	6	6	5	8	8	8	8	9
B. RELIABILITY / AVAILABILITY (LIFETIME)									
. ISI									
. CORROSION RESISTANCE									
. S / G REMOVAL									
C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY)	10	7	7	7	8	8	8	8	9
. RESISTANCE TO FIRE, FLOOD, SABOTAGE									
. PRESSURE MARGIN									
. SA COPING									
II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT)	35	7	8	7	6	7	7	8	7
OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.)									
TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)	10	7	7	7	7	7	7	8	9
III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS)	10	8	9	7	8	9	9	9	10
(SCHEDULE)									
(PROVEN TECHNOLOGY)	5	8	8	8	10	9	9	9	9
A. SCHEDULE CONTROLLABILITY / BREVITY									
B. PROVEN TECHNOLOGY	5	7	7	7	9	9	9	9	10
C. LICENSABILITY (NPC / PUC)	100	690	735	655	720	760	805	845	

CANDIDATE DESCRIPTIONS

- A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)
- B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)
- C. PC (PROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2
- D. CSCV F/B (BASE)
- E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT
- F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT
- G. SS (BASE)

RATING SCALE R
 10 - EXCELLENT
 1 - MARGINAL

DUKE / DOE DESIGN FOR CONSTRUCTABILITY PROGRAM
ADVANCED PWR CONTAINMENT CONSTRUCTABILITY
CONTAINMENT TYPE DECISION MATRIX

FIGURE 9-3
WESTINGHOUSE

EVALUATION CRITERIA

	WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)									
		CASE A	CASE B	CASE C	CASE D	CASE E	CASE F	CASE G			
I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH)											
A. OPERABILITY / MAINTAINABILITY (EVERDAY)	10	7	7	7	7	7	7	7	7	7	8
B. RELIABILITY / AVAILABILITY (LIFETIME) ISI CORROSION RESISTANCE S / G REMOVAL	10	8	8	6	8	8	8	8	8	8	8
C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY) RESISTANCE TO FIRE, FLOOD, SABOTAGE PRESSURE MARGIN SA COPING	10	5	5	8	8	8	8	8	8	10	10
II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT)											
OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.)	35	7	8	8	7	7	7	7	7	9	6
TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)											
III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS)											
A. SCHEDULE PROTECTION (SCHEDULE)	20	7	8	8	7	7	7	7	7	10	6
B. PROVEN TECHNOLOGY (PROVEN TECHNOLOGY)	10	8	6	8	7	6	7	6	7	7	8
C. LICENSABILITY (NPC / PUC) (LICENSABILITY)	5	8	4	8	7	4	7	7	7	8	10
TOTAL	100	705	720	770	720	710	720	710	710	875	720

RATING SCALE R
10 - EXCELLENT
1 - MARGINAL

WEIGHING FACTOR W
TOTAL = 100

D. CSCV F/B (BASE)
E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT
F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT
G. SSCV (BASE)

CANDIDATE DESCRIPTIONS

A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)
B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)
C. PCCV (IMPROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2

**DUKE / DOE DESIGN FOR CONSTRUCTABILITY PROGRAM
 ADVANCED PWR CONTAINMENT CONSTRUCTABILITY
 CONTAINMENT TYPE DECISION MATRIX**

FIGURE - 9
 BABCOCK & WILCOX

EVALUATION CRITERIA

	WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)									
		CASE A	CASE B	CASE C	CASE D	CASE E	CASE F	CASE G			
I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH) A. OPERABILITY / MAINTAINABILITY (EVERDAY) B. RELIABILITY / AVAILABILITY (LIFETIME) . ISI . CORROSION RESISTANCE . S / G REMOVAL C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY) . RESISTANCE TO FIRE, FLOOD, SABOTAGE . PRESSURE MARGIN . SA COPING	20	5	7	4	7	6	7	9			
	12	8	10	6	8	7	7	9			
	12	8	7	7	8	7	9	10			
II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT) OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.) TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)	7	8	8	7	7	6	6	5			
	27	7	6	5	5	6	6	4			
	10	4	4	6	9	10	10	6			
III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS) A. SCHEDULE CONTROLLABILITY / BREVITY B. PROVEN TECHNOLOGY C. LICENSABILITY (NPC / PUC)	5	9	6	9	9	6	6	7			
	7	9	8	9	8	6	7	7			
	100	685	688	588	707	664	715	695			
TOTAL											

EVALUATION CRITERIA

A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)

B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)

C. PC (PROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2

D. CSCV F/B (BASE)

E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT

F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT

G. SS (BASE)

RATING SCALE R
 10 - EXCELLENT
 1 - MARGINAL

WEIGHING FACTOR TOTAL

DUKE / DOE DESIGN FOR CONSTRUCTABILITY PROGRAM
ADVANCED PWR CONTAINMENT CONSTRUCTABILITY
CONTAINMENT TYPE DECISION MATRIX

FIGURE 9-5
 DUKE POWER COMPANY

EVALUATION CRITERIA

	WEIGHING FACTOR (W)	CANDIDATE RATINGS (1-10)																		
		CASE A	CASE B	CASE C	CASE D	CASE E	CASE F	CASE G	CASE H	CASE I	CASE J									
I. FINISHED PRODUCT - SERVICEABILITY (FEATURES / DESIGN WHICH OWNERS PREFER AND WHICH MAKE PLANT EASIEST TO LIVE WITH)																				
A. OPERABILITY / MAINTAINABILITY (EVERDAY)	20	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
B. RELIABILITY / AVAILABILITY (LIFETIME) . ISI . CORROSION RESISTANCE . S / G REMOVAL	15	7	7	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
C. UPSET (SAFETY MARGINS & ACCIDENT RECOVERABILITY) . RESISTANCE TO FIRE, FLOOD, SABOTAGE . PRESSURE MARGIN . SA COPING	5	6	6	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
II. CONSTRUCTION IMPACT - COSTS (FEATURES / DESIGN WHICH RESULT IN LEAST CAPITAL INVESTMENT)	25	7	9	9	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
OVERNIGHT COSTS (ENG'G, DIRECTS, ETC.)	15	6	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
TIME RELATED COSTS (INDIRECTS, AFUDC, ETC.)																				
III. INVESTMENT PROTECTION - CONSIDERATIONS, BEYOND THE ABOVE (FEATURES WHICH MINIMIZE INVESTOR'S VULNERABILITY TO MAJOR LOSS)																				
(SCHEDULE)	10	6	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
(PROVEN TECHNOLOGY)	5	9	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
A. SCHEDULE CONTROLLABILITY / BREVITY																				
B. PROVEN TECHNOLOGY																				
C. LICENSABILITY (NPC / PUC)	5	9	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
(LICENSABILITY)																				
TOTAL	100	690	745	730	720	720	720	720	720	760	810	810	810	810	810	810	810	810	810	810

CANDIDATE DESCRIPTIONS

- A. RCCV (BASE) - AS EVALUATED (BUT ADJUSTED TO INCLUDE EFFECT OF ASME II, DIV. 2)
- B. RCCV (IMPROVED) - NO DIAGONAL BARS (IMPROVED REINF. STEEL COUPLINGS, REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2)
- C. PCCV (IMPROVED) - REASONABLE CODE CHANGES, INCLUDING ASME III, DIV. 2
- D. CSCV F/B (BASE)
- E. CSCV F/B (IMPROVED) - CODE CHANGE ON PWHT
- F. CSCV E/B (IMPROVED) - CODE CHANGE ON PWHT
- G. SSCV (BASE)

RATING SCALE R
 10 - EXCELLENT
 1 - MARGINAL

WEIGHTING FACTOR W
 TOTAL = 100

10.0 CONCLUSIONS

Before the present study was started, it was well recognized that PWR containment type selection is a complex decision with multiple and diverse impacts on the plant design and performance. It was also recognized that several containment types have been used extensively worldwide. This indicates that ranking of these established alternates is greatly influenced by the evaluator's particular set of criteria and priorities.

The five containment concepts that are evaluated in this study all meet the current ALWR requirements. Compared to recent U.S. containment designs, these concepts incorporate or assume the following major improvements:

- o Improved constructability that reduces construction cost and schedule, mainly as the result of standardization, prelicensing, good construction access and improved construction methods.
- o Improved plant safety mainly as the result of enhanced severe accident mitigation/confinement capability.
- o Improved plant operability and maintainability, mainly as a result of increased containment size, improved hatches and locks, and improved layouts both inside and outside of the containment.
- o Improved licensability and generic applicability, due to standardization and prelicensing.
- o Advance, low NPSH primary safeguards pump of the vertical short shaft type.

Advancement of technologies could sway the selection of the ideal future containment type tremendously. Recommendation of a particular containment type based on today's experiences was not the objective of this study. This report identifies major parameters for selection of containment and provides a

means for evaluation of containment type by use of a Decision Matrix Methodology. Subjectivity continues to be the drawback of the evaluation criteria. This must be minimized before it can be applied to a future ALWR.

EECS161

B-74

APPENDIX A

CONTAINMENT SELECTION STUDY MEETINGS

CONTAINMENT SELECTION STUDY MEETINGS
SPONSORED BY DUKE POWER COMPANY

DATE	LOCATION	ATTENDEES
10/26/87	SF, CA.	DUKE POWER CO. S. LEVY, INC. BECHTEL
12/3/87	CHICAGO, IL.	DUKE POWER CO. SARGENT & LUNDY (S&L) STONE & WEBSTER (SWEC) EBASCO BECHTEL
12/14-15/87	SF, CA.	DUKE POWER CO. EPRI COMBUSTION ENG. (C-E) SWEC MPR ASSOC. S&L WESTINGHOUSE BECHTEL
2/22/88	DALLAS, TX.	DUKE POWER CO. C-E BECHTEL ENER. FED INC.

<u>DATE</u>	<u>LOCATION</u>	<u>ATTENDEES</u>
2/23-25/88	DALLAS, TX. SECOND CONSTRUCTIBILITY WORKSHOP	DUKE POWER CO. BECHTEL <u>REACTOR MFRs</u> W, C-E, GE, B&W <u>A/E's</u> S&L, S&W, UE&C, BURNS & ROE <u>UTILITIES</u> EPRI DOE S. LEVY, INC.
3/7-8/88	NEW ORLEANS, LA.	DUKE POWER CO. ENER FEL, INC. BECHTEL WESTINGHOUSE C-E B&W S&L SWEC EPRI

CONTAINMENT SELECTION STUDY MEETINGS
SPONSORED BY EPRI

DATE	LOCATION	ATTENDEES
6/13-14/88	CHICAGO, IL.	DUKE POWER CO. BECHTEL EPRI COMM. EDISON EBASCO S&L SWEC
6/29-30/88	PALO ALTO, CA.	DUKE POWER CO. BECHTEL EPRI C-E WESTINGHOUSE S&L SWEC
7/20/88	EPRI - UTILITY STEERING COMMITTEE MEETING	

APPENDIX B

CONSTRUCTION QUANTITIES AND COST DETAILS

1 B A S E
 2 =====
 3 WESTINGHOUSE "NSSS"
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JOBNO - 18984-002
 APRR - CONTAINMENT STUDY
 F I N A L E V A L U A T I O N
 CASE - PRESTRESSED CONCRETE VESSEL (PCCV)
 =====

takeoff- ENG
 priced- SB
 DATE 06/22/88
 FILE NAME : PCCV.FNL

ITEM and DESCRIPTION	QUANTITY	UNIT	UNIT COST		MAN UNIT	HOURS		\$/HR	MATERIAL	LABOR	TOTAL COST		TOTAL ALL INCLUDED
			MATL	S/C		TOTAL	SUB-CONT						
10 EXCAVATION	47140	CY			0	0.35	16500	20.95	0	346,000	0	346,000	\$465,000
11 INTERNAL FILL CONCRETE	1350	CY	65			3	4100	20.95	88,000	86,000	0	174,000	
12 CONCRETE	4800	SF	2.2			0.67	3200	20.95	11,000	67,000	0	78,000	
13 FORMS	100	TN	560			2.0	2000	20.95	56,000	42,000	0	98,000	
14 REBAR	100	EA	47			2.4	200	20.95	5,000	4,000	0	9,000	
15 CADWELDS	4000	LB	2.55			0.18	700	20.95	10,000	15,000	0	25,000	\$516,000
16 EMBEDS													
17 INTERNAL WALL & SLAB													
18 CONCRETE	9200	CY	65			6	55200	20.95	598,000	1,156,000	0	1,754,000	
19 FORMS(WALL)	87800	SF	2.2			1.2	105400	20.95	193,000	2,208,000	0	2,401,000	
20 FORMS(SLAB)	5700	SF	2.2			1.4	8000	20.95	13,000	168,000	0	181,000	
21 METAL DECK	26400	SF	1.5			0.14	3700	20.95	40,000	78,000	0	118,000	
22 REBAR	2210	TN	560			45	99500	20.95	1,238,000	2,085,000	0	3,323,000	
23 CADWELDS	18700	EA	47			2.4	44900	20.95	879,000	941,000	0	1,820,000	
24 EMBEDS	46000	LB	2.55			0.18	8300	20.95	117,000	174,000	0	291,000	\$13,285,000
25 CNTNMT/SHIELD CYLWALL													
26 CONCRETE	10640	CY	65			5.3	56400	20.95	692,000	1,182,000	0	1,874,000	
27 FORMS	74300	SF	2.2			1.2	89200	20.95	1,63,000	1,869,000	0	2,032,000	
28 REBAR	1400	TN	560			7.0	98000	20.95	784,000	2,053,000	0	2,837,000	
29 CADWELDS	4200	EA	47			2.4	10100	20.95	197,000	212,000	0	409,000	
30 EMBEDS	17900	LB	2.55			0.18	3200	20.95	46,000	67,000	0	113,000	\$9,761,000
31 CNTNMT/SHIELD DOME													
32 CONCRETE	4100	CY	65			6	24600	20.95	267,000	515,000	0	782,000	
33 FORMS	18300	SF	2.2			1.32	24000	20.95	40,000	503,000	0	543,000	
34 REBAR	500	TN	560			6.0	30000	20.95	280,000	629,000	0	909,000	
35 CADWELDS	1500	EA	47			2.4	3600	20.95	71,000	75,000	0	146,000	
36 EMBEDS	6900	LB	2.55			0.3	2100	20.95	18,000	44,000	0	62,000	\$3,281,000
37 CONTAINMENT BASE MAT													
38 CONCRETE	12500	CY	65			3	37500	20.95	813,000	786,000	0	1,599,000	
39 FORMS	34140	SF	2.2			0.67	22900	20.95	75,000	480,000	0	555,000	
40 REBAR	2390	TN	560			2.0	47800	20.95	1,338,000	1,001,000	0	2,339,000	
41 CADWELDS	6880	EA	47			2.4	16500	20.95	323,000	346,000	0	669,000	
42 EMBEDS	18500	LB	2.55			0.18	3300	20.95	47,000	69,000	0	116,000	\$7,091,000
43 EXTERNAL FILL CONCRETE													
44 CONCRETE	0	CY	65			3	0	20.95	0	0	0	0	
45 FORMS	0	SF	2.2			0.67	0	20.95	0	0	0	0	
46 REBAR	0	TN	560			2.0	0	20.95	0	0	0	0	
47 EMBEDS	0	LB	2.55			0.18	0	20.95	0	0	0	0	\$0
48 EXTERNAL BASE MAT													
49 CONCRETE	7840	CY	65			3	23500	20.95	510,000	492,000	0	1,002,000	
50 FORMS	8673	SF	2.2			0.67	5800	20.95	19,000	122,000	0	141,000	
51 REBAR	590	TN	560			2.0	11800	20.95	330,000	247,000	0	577,000	
52 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0	
53 EMBEDS	13000	LB	2.55			0.18	2300	20.95	33,000	48,000	0	81,000	\$2,420,000
54 EXTERNAL WALL & SLAB													
55 CONCRETE	10100	CY	65			6	60600	20.95	657,000	1,270,000	0	1,927,000	
56 FORMS(WALL)	87000	SF	2.2			1.2	104400	20.95	191,000	2,187,000	0	2,378,000	
57 FORMS(SLAB)	11000	SF	2.2			1.4	15400	20.95	32,000	323,000	0	347,000	
58 METAL DECK	40000	SF	1.5			0.14	5600	20.95	60,000	117,000	0	177,000	
59 REBAR	1530	TN	560			45	68900	20.95	857,000	1,443,000	0	2,300,000	
60 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0	

1 B A S E

2 =====
 3 WESTINGHOUSE "WSSS"
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JOBNO -18984-002

APAR -CONTAINMENT STUDY
 F I M A L E V A L U A T I O N

CASE - REINFORCED CONCRETE VESSEL (RCCV)

FILE NAME : RCCV_FNL

takeoff- ENG
 priced- SB

DATE 06/22/88

ITEM and DESCRIPTION	QUANTITY	UNIT	MATERIAL	UNIT COST	S/C	MAN UNIT	HOURS		\$/HR	MATERIAL	LABOR	COST		TOTAL ALL INCLUDED
							UNIT	TOTAL				SUB-COMT	TOTAL	
10 EXCAVATION	43400	CY				0.35	15200	20.95	0	318,000	0	318,000	\$440,000	
11 INTERNAL FILL CONCRETE														
12 CONCRETE	1350	CY	65			3	4100	20.95	88,000	86,000	0	174,000		
13 FORMS	4800	SF	2.2			0.67	3200	20.95	11,000	67,000	0	78,000		
14 REBAR	100	TN	560			20	2000	20.95	56,000	42,000	0	98,000		
15 CADWELDS	100	EA	47			2.4	200	20.95	5,000	4,000	0	9,000		
16 EMBEDS	4000	LB	2.55			0.18	700	20.95	10,000	15,000	0	25,000	\$531,000	
17 INTERNAL WALL & SLAB														
18 CONCRETE	9200	CY	65			6	55200	20.95	598,000	1,156,000	0	1,754,000		
19 FORMS(WALL)	87800	SF	2.2			1.2	105400	20.95	193,000	2,208,000	0	2,401,000		
20 FORMS(SLAB)	5700	SF	2.2			1.4	8000	20.95	13,000	168,000	0	181,000		
21 METAL DECK	26400	SF	1.5			0.14	3700	20.95	40,000	78,000	0	118,000		
22 REBAR	2210	TN	560			45	99500	20.95	1,238,000	2,085,000	0	3,323,000		
23 CADWELDS	18700	EA	47			2.4	44900	20.95	879,000	941,000	0	1,820,000		
24 EMBEDS	46000	LB	2.55			0.18	8300	20.95	117,000	174,000	0	291,000	\$13,679,000	
25 CNTNMT/SHIELD CYLWALL														
26 CONCRETE	13300	CY	65			5.3	70500	20.95	865,000	1,477,000	0	2,342,000		
27 FORMS	74300	SF	2.2			1.2	89200	20.95	163,000	1,869,000	0	2,032,000		
28 REBAR	3300	TN	560			70	231000	20.95	1,848,000	4,839,000	0	6,687,000		
29 CADWELDS	9800	EA	47			2.4	23500	20.95	461,000	492,000	0	953,000		
30 EMBEDS	17600	LB	2.55			0.18	3200	20.95	45,000	67,000	0	112,000	\$16,775,000	
31 CNTNMT/SHIELD DOME														
32 CONCRETE	5120	CY	65			6	30700	20.95	333,000	643,000	0	976,000		
33 FORMS	17500	SF	2.2			1.32	23000	20.95	39,000	482,000	0	521,000		
34 REBAR	925	TN	560			60	55500	20.95	518,000	1,163,000	0	1,681,000		
35 CADWELDS	2900	EA	47			2.4	7000	20.95	136,000	147,000	0	283,000		
36 EMBEDS	6800	LB	2.55			0.3	2000	20.95	17,000	42,000	0	59,000	\$4,869,000	
37 CONTAINMENT BASE MAT														
38 CONCRETE	11000	CY	65			3	33000	20.95	715,000	691,000	0	1,406,000		
39 FORMS	7040	SF	2.2			0.67	4700	20.95	15,000	98,000	0	113,000		
40 REBAR	2300	TN	560			20	46000	20.95	1,288,000	964,000	0	2,252,000		
41 CADWELDS	6900	EA	47			2.4	16600	20.95	324,000	348,000	0	672,000		
42 EMBEDS	16000	LB	2.55			0.18	2900	20.95	41,000	61,000	0	102,000	\$6,287,000	
43 EXTERNAL FILL CONCRETE														
44 CONCRETE	0	CY	65			3	0	20.95	0	0	0	0		
45 FORMS	0	SF	2.2			0.67	0	20.95	0	0	0	0		
46 REBAR	0	TN	560			20	0	20.95	0	0	0	0		
47 EMBEDS	0	LB	2.55			0.18	0	20.95	0	0	0	0	\$0	
48 EXTERNAL BASE MAT														
49 CONCRETE	7840	CY	65			3	23500	20.95	510,000	492,000	0	1,002,000		
50 FORMS	8673	SF	2.2			0.67	5800	20.95	19,000	122,000	0	141,000		
51 REBAR	590	TN	560			20	11800	20.95	330,000	247,000	0	577,000		
52 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0		
53 EMBEDS	13000	LB	2.55			0.18	2300	20.95	33,000	48,000	0	81,000	\$2,491,000	
54 EXTERNAL WALL & SLAB														
55 CONCRETE	10100	CY	65			6	60600	20.95	657,000	1,270,000	0	1,927,000		
56 FORMS(WALL)	87000	SF	2.2			1.2	104400	20.95	191,000	2,187,000	0	2,378,000		
57 FORMS(SLAB)	11000	SF	2.2			1.4	15400	20.95	24,000	323,000	0	347,000		
58 METAL DECK	40000	SF	1.5			0.14	5600	20.95	60,000	117,000	0	177,000		
59 REBAR	1530	TN	560			45	68900	20.95	857,000	1,443,000	0	2,300,000		
60 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0		

1 B A S E

JOBNO -18984-002

FILE NAME : RCCV_FML

APUR -CONTAINMENT STUDY

F I N A L E V A L U A T I O N

takeoff- ENG

CASE - REINFORCED CONCRETE VESSEL (RCCV)

dated- SB

DATE 06/22/88

ITEM and DESCRIPTION	QUANTITY	UNIT	UNIT COST		MAN UNIT	HOURS	\$/HR	MATERIAL	LABOR	TOTAL COST		TOTAL ALL INCLUDED
			MATL	S/C						SUB-COMT	TOTAL	
61 EMBEDS	50500	LB	2.55		0.18	9100	20.95	129,000	191,000	0	320,000	\$10,305,000
62 POST TENSIONING	0	LF	20		0.3	0	23.87	0	0	0	0	\$0
63 STEEL CONTAIN VESSEL	0	TN	0		0	0	0	0	0	0	0	\$0
64 STEEL LINER PLATE	1210	TN	3000		50	60500	23.87	3,630,000	1,444,000	0	5,074,000	\$7,019,000
65 CRANE SUPPORT	350	TN	2500		40	14000	23.87	875,000	334,000	0	1,209,000	
66 INTERNAL STEEL STR	450	TN	1500		28	12600	23.87	675,000	301,000	0	976,000	
67 EXTERNAL STEEL												
68 STRUCTURAL	670	TN	1200		25	16800	23.87	804,000	401,000	0	1,205,000	\$4,691,000
69 ANCHORAGE WELD PLATE	0	TN	1500		30	0	23.87	0	0	0	0	\$0
70												
71 TOTAL DIRECT COSTS						1,400,500	21.17	18,850,000	29,645,000	0	48,495,000	
72												
73 DISTRIBUTABLES												
74 DISTRIB MATERIALS								3,770,000	7,411,000	0	3,770,000	
75 DISTRIB LABOR						350,100		7,411,000	7,411,000	0	7,411,000	
76 NONMANUAL LABOR						350,100		7,411,000	7,411,000	0	7,411,000	
77 DISTRIB SUBCONTRACT										0	0	
78												
79 SUB TOTAL DISTRIBS.						700,200		3,770,000	14,822,000	0	18,592,000	
80												
81 TOTAL FIELD COSTS						2,100,700		22,620,000	44,467,000	0	\$67,087,000	\$67,087,000
82												
83												

ALTERNATE :

ADVANCED REBAR DIFF. COST \$												
THREAD REBAR	5820	TN	240			0	20.95	1,397,000	0	0	1,397,000	
REPLACE CADWELD/COUPERS	38400	EA	-20		-0.6	-23000	20.95	(768,000)	(482,000)	0	(1,250,000)	
RECT REBAR VS DIAG.												
WALL	3300	TN			-30	-99000	20.95	0	(2,074,000)	0	(2,074,000)	
DOME	925	TN			-10	-9300	20.95	0	(195,000)	0	(195,000)	
TOTAL DIRECT COST DIFF.						-131300		629000	-2751000	0	-2122000	
DISTRIBUTABLES												
DISTRIB MATERIALS								126,000	(688,000)	0	126,000	
DISTRIB LABOR						(32,800)		(688,000)	(688,000)	0	(688,000)	
NONMANUAL LABOR						(32,800)		(688,000)	(688,000)	0	(688,000)	
DISTRIB SUBCONTRACT										0	0	
SUB TOTAL DISTRIBS.						(65,600)		126,000	(1,376,000)	0	(1,250,000)	
TOTAL FIELD COSTS DIFF						(196,900)		755,000	(4,127,000)	0	(\$3,372,000)	

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1 B A S E
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 3 WESTINGHOUSE "N5SS"
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JOBNO - 18984-002
 APUR -CONTAINMENT STUDY
 F I N A L E V A L U A T I O N
 CASE - CYLINDRICAL STEEL VESSEL (CSCV); FLAT BOTTOM.
 =====

takeoff- ENG
 priced- SB
 DATE 06/03/88
 FILE NAME : CSCV_FML

ITEM and DESCRIPTION	QUANTITY	UNIT	MATERIAL	S/C	UNIT COST	MAN UNIT	HOURS		\$/HR	MATERIAL	LABOR	TOTAL COST	TOTAL ALL INCLUDED
							MA	TOTAL					
10 EXCAVATION	43000	CY			0	0.35	15100	120.95	0	316,000	0	316,000	\$398,000
11 INTERNAL FILL CONCRETE													
12 CONCRETE	1350	CY	65			3	4100	20.95	88,000	86,000	0	174,000	
13 FORMS	4800	SF	2.2			0.67	3200	20.95	11,000	67,000	0	78,000	
14 REBAR	100	TN	560			20	2000	20.95	56,000	42,000	0	98,000	
15 CADWELDS	100	EA	47			2.4	200	20.95	5,000	4,000	0	9,000	
16 EMBEDS	4000	LB	2.55			0.18	700	20.95	10,000	15,000	0	25,000	\$484,000
17 INTERNAL WALL & SLAB													
18 CONCRETE	9200	CY	65			6	55200	20.95	598,000	1,156,000	0	1,754,000	
19 FORMS(WALL)	87800	SF	2.2			1.2	105400	20.95	193,000	2,208,000	0	2,401,000	
20 FORMS(SLAB)	5700	SF	2.2			1.4	8000	20.95	13,000	168,000	0	181,000	
21 METAL DECK	26400	SF	1.5			0.14	3700	20.95	40,000	78,000	0	118,000	
22 REBAR	2210	TN	560			45	99500	20.95	1,238,000	2,085,000	0	3,323,000	
23 CADWELDS	18700	EA	47			2.4	44900	20.95	879,000	941,000	0	1,820,000	
24 EMBEDS	46000	LB	2.55			0.18	8300	20.95	117,000	174,000	0	291,000	\$12,456,000
25 CNTNMT/SHIELD CYLWALL													
26 CONCRETE	11500	CY	65			5.3	61000	20.95	748,000	1,278,000	0	2,026,000	
27 FORMS(BOTH SIDE)	191400	SF	0.44			0.24	45900	20.95	84,000	962,000	0	1,046,000	
28 REBAR	1020	TN	560			40	40800	20.95	571,000	855,000	0	1,426,000	
29 CADWELDS	1020	EA	47			2.4	2400	20.95	48,000	50,000	0	98,000	
30 EMBEDS	30000	LB	2.55			0.18	54000	20.95	765,000	1,131,000	0	1,896,000	\$8,178,000
31 CNTNMT/SHIELD DOME													
32 CONCRETE	2200	CY	65			6	13200	20.95	143,000	277,000	0	420,000	
33 FORMS	20400	SF	2.2			0.94	19200	20.95	45,000	402,000	0	447,000	
34 REBAR	150	TN	560			50	7500	20.95	84,000	157,000	0	241,000	
35 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0	
36 EMBEDS	3700	LB	2.55			0.3	1100	20.95	9,000	23,000	0	32,000	\$1,436,000
37 CONTAINMENT BASE MAT													
38 CONCRETE	11644	CY	65			3	34900	20.95	757,000	731,000	0	1,488,000	
39 FORMS	11644	SF	2.2			0.67	7800	20.95	26,000	163,000	0	189,000	
40 REBAR	2329	TN	560			20	46600	20.95	1,304,000	976,000	0	2,280,000	
41 CADWELDS	7000	EA	47			2.4	16800	20.95	329,000	352,000	0	681,000	
42 EMBEDS	16000	LB	2.55			0.18	2900	20.95	41,000	61,000	0	102,000	\$5,971,000
43 EXTERNAL FILL CONCRETE													
44 CONCRETE	0	CY	65			3	0	20.95	0	0	0	0	
45 FORMS	0	SF	2.2			0.67	0	20.95	0	0	0	0	
46 REBAR	0	TN	560			20	0	20.95	0	0	0	0	
47 EMBEDS	0	LB	2.55			0.18	0	20.95	0	0	0	0	\$0
48 EXTERNAL BASE MAT													
49 CONCRETE	9116	CY	65			3	27300	20.95	593,000	572,000	0	1,165,000	
50 FORMS	9116	SF	2.2			0.67	6100	20.95	20,000	128,000	0	148,000	
51 REBAR	684	TN	560			20	13700	20.95	383,000	287,000	0	670,000	
52 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0	
53 EMBEDS	15497	LB	2.55			0.18	2800	20.95	40,000	59,000	0	99,000	\$2,623,000
54 EXTERNAL WALL & SLAB													
55 CONCRETE	10900	CY	65			6	65400	20.95	709,000	1,370,000	0	2,079,000	
56 FORMS(WALL)	93960	SF	2.2			1.2	112800	20.95	207,000	2,363,000	0	2,570,000	
57 FORMS(SLAB)	11000	SF	2.2			1.4	15400	20.95	24,000	323,000	0	347,000	
58 METAL DECK	40000	SF	1.5			0.14	5600	20.95	60,000	117,000	0	177,000	
59 REBAR	1660	TN	560			45	74700	20.95	930,000	1,565,000	0	2,495,000	
60 CADWELDS	0	EA	47			2.4	0	20.95	0	0	0	0	

1 B A S E

2 WESTINGHOUSE "HSSS"

3 JOBNO -18984-002
4 APUR - CONTAINMENT STUDY
5 F I M A L E V A L U A T I O N
6 CASE - CYLINDRICAL STEEL VESSEL (CSCV); FLAT BOTTOM.

7 FILE NAME : CSCV.FML
8 takeoff- ENG
9 priced- SB **DATE** **06/03/88**

ITEM and DESCRIPTION	QUANTITY		UNIT COST		S/C	UNIT	MAN HOURS		\$/HR	MATERIAL	LABOR	TOTAL COST		TOTAL ALL INCLUDED
	UNIT	AMT	MATL	S/C			UNIT	TOTAL				TOTAL	SUB-CONT	
61 EMBEDS	54000	LB	2.55			0.16	9700	20.95	138,000	203,000	0	341,000	\$10,089,000	
62 POST TENSIONING	0	LF	20	61		0.3	0	23.87	0	0	0	0	\$28,142,000	
63 STEEL CONTAIN VESSEL	3437	TN	0	6500		0	0	0	0	0	0	0	\$739,000	
64 STEEL LINER PLATE	140	TN	3000			50	7000	23.87	420,000	167,000	0	587,000		
65 CRANE SUPPORT	350	TN	2500			40	14000	23.87	875,000	334,000	0	1,209,000		
66 INTERNAL STEEL STR	450	TN	1500			28	12600	23.87	675,000	301,000	0	976,000		
67 EXTERNAL STEEL	720	TN	1200			25	18000	23.87	864,000	430,000	0	1,294,000	\$4,362,000	
68 STRUCTURAL	70	TN	1500			30	2100	23.87	105,000	50,000	0	155,000	\$195,000	
69 ANCHORAGE WELD PLATE														
70 TOTAL DIRECT COSTS							1,091,600	21.09	114,245,000	23,027,000	22,341,000	59,613,000		
72 DISTRIBUTABLES														
73 DISTRIB MATERIALS									2,849,000	5,757,000		2,849,000		
74 DISTRIB LABOR										5,757,000		5,757,000		
75 DISTRIB LABOR										5,757,000		5,757,000		
76 NONMANUAL LABOR											1,117,000	1,117,000		
77 DISTRIB SUB CONTRACT														
78														
79 SUB TOTAL DISTBS.							545,800		2,849,000	11,514,000	1,117,000	15,480,000		
80														
81 TOTAL FIELD COSTS							1,637,400		17,094,000	34,541,000	23,458,000	\$75,093,000	\$75,093,000	
82														
83														

ALTERNATE :

ADVANCED REBAR DIFF. COST \$														
THREAD REBAR	2474	TN	240				0	20.95	594,000	0	0	594,000		
REPLACE CADWELD/COUPERS	26820	EA	-20			-0.6	-16100	20.95	(536,000)	(337,000)	0	(873,000)		
REBAR DIAG. VS STAND.														
WALL	0	TN				0	0	20.95	0	0	0	0		
DOME	0	TN				0	0	20.95	0	0	0	0		
TOTAL DIRECT COST DIFF.							-16100		58000	-337000	0	-279000		
DISTRIBUTABLES														
DISTRIB MATERIALS									12,000	(84,000)	0	12,000		
DISTRIB LABOR							(4,000)			(84,000)	0	(84,000)		
NONMANUAL LABOR							(4,000)			(84,000)	0	(84,000)		
DISTRIB SUB CONTRACT											0	0		
SUB TOTAL DISTBS.							(8,000)		12,000	(168,000)	0	(156,000)		
TOTAL FIELD COSTS DIFF							(24,100)		70,000	(505,000)	0	(435,000)		

1 B A S E

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3 WESTINGHOUSE "WSSS"

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JOBNO -18984-002

APMR -CONTAINMENT STUDY

F I N A L E V A L U A T I O N

CASE - CYLINDRICAL STEEL VESSEL (CSCV); ELLIPSOIDAL BOTTOM. Priced- SB

takeoff- ENG

DATE 06/03/88

FILE NAME : CSCV_ELL

ITEM and DESCRIPTION	QUANTITY		UNIT COST		MAN UNIT	HOURS		\$/HR	MATERIAL	LABOR	TOTAL COST		TOTAL ALL INCLUDED
	UNIT	AMOUNT	MATL	S/C		TOTAL	SUB-COMT				TOTAL		
10 EXCAVATION	68200	CY		0	0.35	23900	20.95	0	501,000	0	501,000	\$623,000	
11 INTERNAL FILL CONCRETE													
12 CONCRETE	16362	CY	65		3	49100	20.95	1,064,000	1,029,000	0	2,093,000		
13 FORMS	4800	SF	2.2		0.67	3200	20.95	11,000	67,000	0	78,000		
14 REBAR	818	TM	560		20	16400	20.95	458,000	344,000	0	802,000		
15 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0		
16 EMBEDS	7100	LB	2.55		0.18	1300	20.95	18,000	27,000	0	45,000	\$3,753,000	
17 INTERNAL WALL & SLAB													
18 CONCRETE	9200	CY	65		6	55200	20.95	598,000	1,156,000	0	1,754,000		
19 FORMS(WALL)	87800	SF	2.2		1.2	105400	20.95	193,000	2,208,000	0	2,401,000		
20 FORMS(SLAB)	5700	SF	2.2		1.4	8000	20.95	13,000	168,000	0	181,000		
21 METAL DECK	26400	SF	1.5		0.14	3700	20.95	40,000	78,000	0	118,000		
22 REBAR	2210	TM	560		45	99500	20.95	1,238,000	2,085,000	0	3,323,000		
23 CADWELDS	18700	EA	47		2.4	44900	20.95	879,000	941,000	0	1,820,000		
24 EMBEDS	46000	LB	2.55		0.18	8300	20.95	117,000	174,000	0	291,000	\$12,295,000	
25 CNTNMT/SHIELD CYLWALL													
26 CONCRETE	11500	CY	65		5.3	61000	20.95	748,000	1,278,000	0	2,026,000		
27 FORMS(BOTH SIDE)	191400	SF	0.44		0.24	45900	20.95	84,000	962,000	0	1,046,000		
28 REBAR	1020	TM	560		40	40800	20.95	571,000	855,000	0	1,426,000		
29 CADWELDS	1020	EA	47		2.4	2400	20.95	48,000	50,000	0	98,000		
30 EMBEDS	300000	LB	2.55		0.18	54000	20.95	765,000	1,131,000	0	1,896,000	\$8,072,000	
31 CNTNMT/SHIELD DOME													
32 CONCRETE	2200	CY	65		6	13200	20.95	143,000	277,000	0	420,000		
33 FORMS	20400	SF	2.2		0.94	19200	20.95	45,000	402,000	0	447,000		
34 REBAR	150	TM	560		50	7500	20.95	84,000	157,000	0	241,000		
35 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0		
36 EMBEDS	3700	LB	2.55		0.3	1100	20.95	9,000	23,000	0	32,000	\$1,417,000	
37 CONTAINMENT BASE MAT													
38 CONCRETE	9532	CY	65		3	28600	20.95	620,000	599,000	0	1,219,000		
39 FORMS	9532	SF	2.2		0.67	6400	20.95	21,000	134,000	0	155,000		
40 REBAR	715	TM	560		20	14300	20.95	400,000	300,000	0	700,000		
41 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0		
42 EMBEDS	0	LB	2.55		0.18	0	20.95	0	0	0	0	\$2,579,000	
43 EXTERNAL FILL CONCRETE													
44 CONCRETE	5895	CY	65		3	17700	20.95	383,000	371,000	0	754,000		
45 FORMS	0	SF	2.2		0.67	0	20.95	0	0	0	0		
46 REBAR	0	TM	560		20	0	20.95	0	0	0	0		
47 EMBEDS	0	LB	2.55		0.18	0	20.95	0	0	0	0	\$938,000	
48 EXTERNAL BASE MAT													
49 CONCRETE	14728	CY	65		3	44200	20.95	957,000	926,000	0	1,883,000		
50 FORMS	11492	SF	2.2		0.67	7700	20.95	25,000	161,000	0	186,000		
51 REBAR	1105	TM	560		20	22100	20.95	619,000	463,000	0	1,082,000		
52 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0		
53 EMBEDS	25000	LB	2.55		0.18	4500	20.95	64,000	94,000	0	158,000	\$4,114,000	
54 EXTERNAL WALL & SLAB													
55 CONCRETE	10900	CY	65		6	65400	20.95	709,000	1,370,000	0	2,079,000		
56 FORMS(WALL)	93960	SF	2.2		1.2	112800	20.95	207,000	2,363,000	0	2,570,000		
57 FORMS(SLAB)	11000	SF	2.2		1.4	15400	20.95	24,000	323,000	0	347,000		
58 METAL DECK	40000	SF	1.5		0.14	5600	20.95	60,000	117,000	0	177,000		
59 REBAR	1660	TM	560		45	74700	20.95	930,000	1,565,000	0	2,495,000		
60 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0		

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JOBNO - 18984-002
 APUR - CONTAINMENT STUDY
 F I N A L E V A L U A T I O N
 CASE - CYLINDRICAL STEEL VESSEL (CSCV); ELLIPSOIDAL BOTTOM. priced- \$0
 FILE NAME : CSCV ELL
 DATE 06/03/88
 takeoff- ENG

ITEM and DESCRIPTION	QUANTITY	UNIT	MATL	S/C	MAN UNIT	HOURS TOTAL	\$/HR	MATERIAL	LABOR	SUB-CONT	TOTAL	TOTAL ALL INCLUDED
61 EMBEDS	54000	LB	2.55		0.18	9700	20.95	130,000	203,000	0	341,000	\$9,959,000
62 POST TENSIONING	0	LF	20		0.3	0	23.87	0	0	0	0	\$0
63 STEEL CONTAIN VESSEL	4304	TM	0	6500	0	0	0	0	0	28,496,000	28,496,000	\$35,432,000
64 STEEL LINER PLATE	0	TM	3000		50	0	23.87	0	0	0	0	\$0
65 CRANE SUPPORT	350	TM	2500		40	14000	23.87	875,000	334,000	0	1,209,000	\$0
66 INTERNAL STEEL STR	450	TM	1500		28	12600	23.87	675,000	301,000	0	976,000	\$0
67 EXTERNAL STEEL	720	TM	1200		25	18000	23.87	864,000	430,000	0	1,294,000	\$4,326,000
68 STRUCTURAL	0	TM	1500		30	0	23.87	0	0	0	0	\$0
69 ANCHORAGE WELD PLATE												
70												
71 TOTAL DIRECT COSTS						1,137,700	21.07	14,697,000	23,967,000	28,496,000	67,160,000	
72												
73 DISTRIBUTABLES												
74 DISTRIB MATERIALS						284,400		2,939,000	5,992,000		2,939,000	
75 DISTRIB LABOR						284,400			5,992,000		5,992,000	
76 NONMANUAL LABOR										1,425,000	1,425,000	
77 DISTRIB SUB CONTRACT										1,425,000	1,425,000	
78												
79 SUB TOTAL DISTBS.						568,800		2,939,000	11,984,000	1,425,000	16,348,000	
80												
81 TOTAL FIELD COSTS						1,706,500		17,636,000	35,951,000	29,921,000	\$83,508,000	\$83,508,000
82												
83												

ALTERNATE :

ADVANCED REBAR DIFF. COST \$												
THREAD REBAR	1309	TM	240			0	20.95	314,000	0	0	314,000	
REPLACE CADWELD/COUPERS	19720	EA	-20			-11800	20.95	(394,000)	(247,000)	0	(641,000)	
REBAR DIAG. VS STAND.												
WALL	0	TM				0	20.95	0	0	0	0	
DOVE	0	TM				0	20.95	0	0	0	0	
TOTAL DIRECT COST DIFF.						-11800		-80000	-247000	0	-327000	
DISTRIBUTABLES												
DISTRIB MATERIALS								(16,000)	(62,000)		(16,000)	
DISTRIB LABOR						(3,000)			(62,000)		(62,000)	
NONMANUAL LABOR						(3,000)			(62,000)	0	(62,000)	
DISTRIB SUB CONTRACT										0	0	
SUB TOTAL DISTBS.						(6,000)		(16,000)	(124,000)	0	(140,000)	
TOTAL FIELD COSTS DIFF						(17,800)		(96,000)	(371,000)	0	(\$467,000)	

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3 WESTINGHOUSE "N5SS"

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JOBNO - 18984-002

APMR - CONTAINMENT STUDY

F I N A L E V A L U A T I O N

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CASE - SPHERICAL STEEL CONTAINMENT VESSEL (SSCV)

FILE NAME : SSCV.FML

takeoff- ENG

DATE 06/23/88

ITEM and DESCRIPTION	QUANTITY	UNIT	MATERIAL	UNIT COST		MAN	HOURS	TOTAL	\$/HR	MATERIAL	LABOR	TOTAL COST		TOTAL ALL INCLUDED
				S/C	S/C							UNIT	HOURS	
10 EXCAVATION	79000	CY		0	0.35	27700	20.95	580,000	0	580,000	0	580,000	\$740,000	
11 INTERNAL FILL CONCRETE														
12 CONCRETE	7300	CY	65		3	21900	20.95	459,000	475,000	934,000	0	934,000		
13 FORMS	36500	SF	2.2		0.67	24500	20.95	513,000	80,000	593,000	0	593,000		
14 REBAR	547	TN	560		20	10900	20.95	228,000	306,000	534,000	0	534,000		
15 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0		
16 EMBEDS	10921	LB	2.55		0.18	2000	20.95	42,000	28,000	70,000	0	70,000	\$2,720,000	
17 INTERNAL WALL & SLAB														
18 CONCRETE	12700	CY	65		6	76200	20.95	1,596,000	826,000	2,422,000	0	2,422,000		
19 FORMS(WALL)	87800	SF	2.2		1.2	105400	20.95	2,208,000	193,000	2,401,000	0	2,401,000		
20 FORMS(SLAB)	5700	SF	2.2		1.4	8000	20.95	168,000	13,000	181,000	0	181,000		
21 METAL DECK	37600	SF	1.5		0.14	5300	20.95	111,000	56,000	167,000	0	167,000		
22 REBAR	2910	TN	560		45	131000	20.95	2,744,000	1,630,000	4,374,000	0	4,374,000		
23 CADWELDS	18700	EA	47		2.4	44900	20.95	941,000	879,000	1,820,000	0	1,820,000		
24 EMBEDS	63500	LB	2.55		0.18	11400	20.95	239,000	162,000	401,000	0	401,000	\$15,019,000	
25 CNTNMT/SHIELD CYLWALL														
26 CONCRETE	6600	CY	65		5.3	35000	20.95	733,000	429,000	1,162,000	0	1,162,000		
27 FORMS	131700	SF	2.2		1.2	158000	20.95	3,310,000	290,000	3,600,000	0	3,600,000		
28 REBAR	870	TN	560		40	34800	20.95	729,000	487,000	1,216,000	0	1,216,000		
29 CADWELDS	870	EA	47		2.4	2100	20.95	44,000	41,000	85,000	0	85,000		
30 EMBEDS	9900	LB	2.55		0.18	1800	20.95	38,000	25,000	63,000	0	63,000	\$7,820,000	
31 CNTNMT/SHIELD DOME														
32 CONCRETE	7300	CY	65		6	43800	20.95	918,000	475,000	1,393,000	0	1,393,000		
33 FORMS	86300	SF	2.2		0.94	81100	20.95	1,699,000	190,000	1,889,000	0	1,889,000		
34 REBAR	540	TN	560		50	27000	20.95	566,000	302,000	868,000	0	868,000		
35 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0		
36 EMBEDS	25550	LB	2.55		0.3	7700	20.95	161,000	65,000	226,000	0	226,000	\$5,586,000	
37 CONTAINMENT BASE MAT														
38 CONCRETE	13820	CY	65		3	41500	20.95	869,000	898,000	1,767,000	0	1,767,000		
39 FORMS	20730	SF	2.2		0.67	13900	20.95	291,000	46,000	337,000	0	337,000		
40 REBAR	3200	TN	560		20	64000	20.95	1,341,000	1,792,000	3,133,000	0	3,133,000		
41 CADWELDS	3200	EA	47		2.4	7700	20.95	161,000	150,000	311,000	0	311,000		
42 EMBEDS	20730	LB	2.55		0.18	3700	20.95	78,000	53,000	131,000	0	131,000	\$7,249,000	
43 EXTERNAL FILL CONCRETE														
44 CONCRETE	1605	CY	65		3	4800	20.95	101,000	104,000	205,000	0	205,000		
45 FORMS	2700	SF	2.2		0.67	1800	20.95	38,000	6,000	44,000	0	44,000		
46 REBAR	160	TN	560		20	3200	20.95	67,000	90,000	157,000	0	157,000		
47 EMBEDS	0	LB	2.55		0.18	0	20.95	0	0	0	0	0		
48 EXTERNAL BASE MAT														
49 CONCRETE	0	CY	65		3	0	20.95	0	0	0	0	0		
50 FORMS	0	SF	2.2		0.67	0	20.95	0	0	0	0	0		
51 REBAR	0	TN	560		20	0	20.95	0	0	0	0	0		
52 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0		
53 EMBEDS	0	LB	2.55		0.18	0	20.95	0	0	0	0	0		
54 EXTERNAL WALL & SLAB														
55 CONCRETE	11850	CY	65		6	71100	20.95	1,490,000	770,000	2,260,000	0	2,260,000		
56 FORMS(WALL)	104000	SF	2.2		1.2	124800	20.95	2,615,000	229,000	2,844,000	0	2,844,000		
57 FORMS(SLAB)	11000	SF	2.2		1.4	15400	20.95	323,000	24,000	347,000	0	347,000		
58 METAL DECK	33100	SF	1.5		0.14	4600	20.95	96,000	50,000	146,000	0	146,000		
59 REBAR	1740	TN	560		45	78300	20.95	1,640,000	974,000	2,614,000	0	2,614,000		
60 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0		

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JOBNO - 18984-002

APWR - CONTAINMENT STUDY

FILE NAME : PCCV.FNL

F I N A L E V A L U A T I O N

takeoff- ENG

DATE 06/22/88

CASE -- PRESTRESSED CONCRETE VESSEL (PCCV)

priced- SB

ITEM and DESCRIPTION	QUANTITY	UNIT	UNIT COST		S/C	MAN UNIT	MAN HOURS		\$/HR	MATERIAL	LABOR	COST		TOTAL ALL INCLUDED
			MATL	S/C			UNIT	TOTAL				SUB	CONT	
10 EXCAVATION	47140	CY				0	0.35	16500	20.95	0	346,000	0	0	\$462,000
11 INTERNAL FILL CONCRETE														
12 CONCRETE	1350	CY	65				3	4100	20.95	88,000	86,000	0	0	174,000
13 FORMS	4800	SF	2.2				0.67	3200	20.95	11,000	67,000	0	0	78,000
14 REBAR	100	TN	560				20	2000	20.95	56,000	42,000	0	0	98,000
15 CADWELDS	100	EA	47				2.4	200	20.95	5,000	4,000	0	0	9,000
16 EMBEDS	4000	LB	2.55				0.18	700	20.95	10,000	15,000	0	0	25,000
17 INTERNAL WALL & SLAB														
18 CONCRETE	9200	CY	65				6	55200	20.95	598,000	1,156,000	0	0	1,754,000
19 FORMS(WALL)	87800	SF	2.2				1.2	105400	20.95	193,000	2,208,000	0	0	2,401,000
20 FORMS(SLAB)	5700	SF	2.2				1.4	8000	20.95	13,000	168,000	0	0	181,000
21 METAL DECK	26400	SF	1.5				0.14	3700	20.95	40,000	78,000	0	0	118,000
22 REBAR	2210	TN	560				45	99500	20.95	1,238,000	2,085,000	0	0	3,323,000
23 CADWELDS	18700	EA	47				2.4	44900	20.95	879,000	941,000	0	0	1,820,000
24 EMBEDS	46000	LB	2.55				0.18	8300	20.95	117,000	174,000	0	0	291,000
25 CONTNMT/SHIELD CYLWALL														
26 CONCRETE	10640	CY	65				5.3	56400	20.95	692,000	1,182,000	0	0	1,874,000
27 FORMS	74300	SF	2.2				1.2	89200	20.95	163,000	1,869,000	0	0	2,032,000
28 REBAR	1400	TN	560				70	98000	20.95	784,000	2,053,000	0	0	2,837,000
29 CADWELDS	4200	EA	47				2.4	10100	20.95	197,000	212,000	0	0	409,000
30 EMBEDS	17900	LB	2.55				0.18	3200	20.95	46,000	67,000	0	0	113,000
31 CONTNMT/SHIELD DOME														
32 CONCRETE	4100	CY	65				6	24600	20.95	267,000	515,000	0	0	782,000
33 FORMS	18300	SF	2.2				1.32	24000	20.95	40,000	503,000	0	0	543,000
34 REBAR	500	TN	560				60	30000	20.95	280,000	629,000	0	0	909,000
35 CADWELDS	1500	EA	47				2.4	3600	20.95	71,000	75,000	0	0	146,000
36 EMBEDS	6900	LB	2.55				0.3	2100	20.95	18,000	44,000	0	0	62,000
37 CONTAINMENT BASE MAT														
38 CONCRETE	12500	CY	65				3	37500	20.95	813,000	786,000	0	0	1,599,000
39 FORMS	34140	SF	2.2				0.67	22900	20.95	75,000	480,000	0	0	555,000
40 REBAR	2390	TN	560				20	47800	20.95	1,338,000	1,001,000	0	0	2,339,000
41 CADWELDS	6800	EA	47				2.4	16500	20.95	323,000	346,000	0	0	669,000
42 EMBEDS	18500	LB	2.55				0.18	3300	20.95	47,000	69,000	0	0	116,000
43 EXTERNAL FILL CONCRETE														
44 CONCRETE	0	CY	65				3	0	20.95	0	0	0	0	0
45 FORMS	0	SF	2.2				0.67	0	20.95	0	0	0	0	0
46 REBAR	0	TN	560				20	0	20.95	0	0	0	0	0
47 EMBEDS	0	LB	2.55				0.18	0	20.95	0	0	0	0	0
48 EXTERNAL BASE MAT														
49 CONCRETE	7840	CY	65				3	23500	20.95	510,000	492,000	0	0	1,002,000
50 FORMS	8673	SF	2.2				0.67	5800	20.95	19,000	122,000	0	0	141,000
51 REBAR	590	TN	560				20	11800	20.95	330,000	247,000	0	0	577,000
52 CADWELDS	0	EA	47				2.4	0	20.95	0	0	0	0	0
53 EMBEDS	13000	LB	2.55				0.18	2300	20.95	33,000	48,000	0	0	81,000
54 EXTERNAL WALL & SLAB														
55 CONCRETE	10100	CY	65				6	60600	20.95	657,000	1,270,000	0	0	1,927,000
56 FORMS(WALL)	87000	SF	2.2				1.2	104400	20.95	191,000	2,187,000	0	0	2,378,000
57 FORMS(SLAB)	11000	SF	2.2				1.4	15400	20.95	24,000	323,000	0	0	347,000
58 METAL DECK	40000	SF	1.5				0.14	5600	20.95	60,000	117,000	0	0	177,000
59 REBAR	1530	TN	560				45	68900	20.95	857,000	1,443,000	0	0	2,300,000
60 CADWELDS	0	EA	47				2.4	0	20.95	0	0	0	0	0

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JOBNO - 18984-002

APUR - CONTAINMENT STUDY

F I N A L E V A L U A T I O N

CASE - REINFORCED CONCRETE VESSEL (RCCV)

takeoff - ENG
 priced - SB

FILE NAME : RCCV.FNL

DATE 06/22/88

ITEM and DESCRIPTION	QUANTITY	UNIT	MATL	UNIT COST	S/C	MAN UNIT	HOURS	TOTAL	\$/HR	MATERIAL	LABOR	SUB-COST	TOTAL	TOTAL ALL INCLUDED
10 EXCAVATION	434.00	CY		0		0.35	152.00	120.95	318,000	0	0	0	318,000	\$440,000
11 INTERNAL FILL CONCRETE														
12 CONCRETE	1350	CY	65			3	4100	20.95	86,000	0	0	0	174,000	
13 FORMS	4800	SF	2.2		0.67	20	3200	20.95	67,000	0	0	0	78,000	
14 REBAR	100	TN	560		2.4	200	2000	20.95	42,000	0	0	0	98,000	
15 CADWELDS	100	EA	47		2.4	700	20.95	4,000	15,000	0	0	0	25,000	\$532,000
16 EMBEDS	4000	LB	2.55		0.18	6	55200	20.95	1,156,000	0	0	0	1,754,000	
17 INTERNAL WALL & SLAB														
18 CONCRETE	87800	SF	2.2		1.2	105400	20.95	2,208,000	193,000	0	0	0	2,401,000	
19 FORMS(WALL)	5700	SF	2.2		1.4	8000	20.95	13,000	168,000	0	0	0	181,000	
20 FORMS(SLAB)	26400	SF	1.5		0.14	3700	20.95	40,000	78,000	0	0	0	118,000	
21 METAL DECK	2210	TN	560		45	99500	20.95	2,085,000	1,238,000	0	0	0	3,323,000	
22 REBAR	18700	EA	47		2.4	44900	20.95	941,000	879,000	0	0	0	1,820,000	
23 CADWELDS	46000	LB	2.55		0.18	8300	20.95	174,000	117,000	0	0	0	291,000	\$13,689,000
24 EMBEDS														
25 CONTNMENT/SHIELD CYLWALL														
26 CONCRETE	13300	CY	65		5.3	70500	20.95	1,477,000	865,000	0	0	0	2,342,000	
27 FORMS	74300	SF	2.2		1.2	89200	20.95	1,869,000	163,000	0	0	0	2,032,000	
28 REBAR	4000	TN	560		70	280000	20.95	5,866,000	2,240,000	0	0	0	8,106,000	
29 CADWELDS	12000	EA	47		2.4	28800	20.95	603,000	564,000	0	0	0	1,167,000	
30 EMBEDS	17600	LB	2.55		0.18	3200	20.95	67,000	45,000	0	0	0	112,000	\$19,048,000
31 CONTNMENT/SHIELD DOME														
32 CONCRETE	5120	CY	65		6	30700	20.95	643,000	333,000	0	0	0	976,000	
33 FORMS	17500	SF	2.2		1.32	23000	20.95	482,000	39,000	0	0	0	521,000	
34 REBAR	1140	TN	560		60	68400	20.95	1,433,000	638,000	0	0	0	2,071,000	
35 CADWELDS	3420	EA	47		2.4	8200	20.95	172,000	161,000	0	0	0	333,000	
36 EMBEDS	6800	LB	2.55		0.3	2000	20.95	42,000	17,000	0	0	0	59,000	\$5,482,000
37 CONTAINMENT BASE MAT														
38 CONCRETE	11000	CY	65		3	33000	20.95	691,000	715,000	0	0	0	1,406,000	
39 FORMS	7040	SF	2.2		0.67	4700	20.95	98,000	15,000	0	0	0	113,000	
40 REBAR	2315	TN	560		20	46300	20.95	970,000	1,296,000	0	0	0	2,266,000	
41 CADWELDS	6950	EA	47		2.4	16700	20.95	350,000	327,000	0	0	0	677,000	
42 EMBEDS	16000	LB	2.55		0.18	2900	20.95	61,000	41,000	0	0	0	102,000	\$6,318,000
43 EXTERNAL FILL CONCRETE														
44 CONCRETE	0	CY	65		3	0	20.95	0	0	0	0	0	0	
45 FORMS	0	SF	2.2		0.67	0	20.95	0	0	0	0	0	0	
46 REBAR	0	TN	560		20	0	20.95	0	0	0	0	0	0	
47 EMBEDS	0	LB	2.55		0.18	0	20.95	0	0	0	0	0	0	\$0
48 EXTERNAL BASE MAT														
49 CONCRETE	7840	CY	65		3	23500	20.95	492,000	510,000	0	0	0	1,002,000	
50 FORMS	8673	SF	2.2		0.67	5800	20.95	122,000	19,000	0	0	0	141,000	
51 REBAR	590	TN	560		20	11800	20.95	247,000	330,000	0	0	0	577,000	
52 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0	0	
53 EMBEDS	13000	LB	2.55		0.18	2300	20.95	48,000	33,000	0	0	0	81,000	\$2,493,000
54 EXTERNAL WALL & SLAB														
55 CONCRETE	10100	CY	65		6	60600	20.95	1,270,000	657,000	0	0	0	1,927,000	
56 FORMS(WALL)	87000	SF	2.2		1.2	104400	20.95	2,187,000	191,000	0	0	0	2,378,000	
57 FORMS(SLAB)	11000	SF	2.2		1.4	15400	20.95	323,000	24,000	0	0	0	347,000	
58 METAL DECK	40000	SF	1.5		0.14	5600	20.95	117,000	60,000	0	0	0	177,000	
59 REBAR	1530	TN	560		45	68900	20.95	1,443,000	857,000	0	0	0	2,300,000	
60 CADWELDS	0	EA	47		2.4	0	20.95	0	0	0	0	0	0	

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JOBNO - 18984-002
 APWR - CONTAINMENT STUDY
 FINAL EVALUATION
 CASE - CYLINDRICAL STEEL VESSEL (CSCV); FLAT BOTTOM.

FILE NAME : CSCV.FNL
 takeoff- ENG
 priced- SB
 DATE 06/03/88

ITEM and DESCRIPTION	QUANTITY	UNIT	MATL	UNIT COST	S/C	MAN UNIT	HOURS	TOTAL	\$/HR	MATERIAL	LABOR	TOTAL COST	SUB-CONT	TOTAL	TOTAL ALL INCLUDED
10 EXCAVATION	43000	CY				0	0.35	15100	20.95	0	316,000	0	0	316,000	\$392,000
11 INTERNAL FILL CONCRETE															
12 CONCRETE	1350	CY	65				3	4100	20.95	88,000	86,000	174,000	0	174,000	
13 FORMS	4800	SF	2.2				0.67	3200	20.95	11,000	67,000	78,000	0	78,000	
14 REBAR	100	TM	560				20	2000	20.95	56,000	42,000	98,000	0	98,000	
15 CADWELDS	100	EA	47				2.4	200	20.95	5,000	4,000	9,000	0	9,000	
16 EMBEDS	4000	LB	2.55				0.18	700	20.95	10,000	15,000	25,000	0	25,000	\$476,000
17 INTERNAL WALL & SLAB															
18 CONCRETE	9200	CY	65				6	55200	20.95	598,000	1,156,000	1,754,000	0	1,754,000	
19 FORMS(WALL)	87800	SF	2.2				1.2	105400	20.95	193,000	2,208,000	2,401,000	0	2,401,000	
20 FORMS(SLAB)	5700	SF	2.2				1.4	8000	20.95	13,000	168,000	181,000	0	181,000	
21 METAL DECK	26400	SF	1.5				0.14	3700	20.95	40,000	78,000	118,000	0	118,000	
22 REBAR	560	TM	560				45	99500	20.95	1,238,000	2,085,000	3,323,000	0	3,323,000	
23 CADWELDS	18700	EA	47				2.4	44900	20.95	879,000	941,000	1,820,000	0	1,820,000	
24 EMBEDS	46000	LB	2.55				0.18	8300	20.95	117,000	174,000	291,000	0	291,000	\$12,259,000
25 CNTNMT/SHIELD CYLWALL															
26 CONCRETE	11500	CY	65				5.3	61000	20.95	748,000	1,278,000	2,026,000	0	2,026,000	
27 FORMS(BOTH SIDE)	191400	SF	0.44				0.24	45900	20.95	84,000	962,000	1,046,000	0	1,046,000	
28 REBAR	1020	TM	560				40	40800	20.95	571,000	855,000	1,426,000	0	1,426,000	
29 CADWELDS	1020	EA	47				2.4	2400	20.95	48,000	50,000	98,000	0	98,000	
30 EMBEDS	300000	LB	2.55				0.18	54000	20.95	765,000	1,131,000	1,896,000	0	1,896,000	\$8,049,000
31 CNTNMT/SHIELD DOME															
32 CONCRETE	2200	CY	65				6	13200	20.95	143,000	277,000	420,000	0	420,000	
33 FORMS	20400	SF	2.2				0.94	19200	20.95	45,000	402,000	447,000	0	447,000	
34 REBAR	150	TM	560				50	7500	20.95	84,000	157,000	241,000	0	241,000	
35 CADWELDS	0	EA	47				2.4	0	20.95	0	0	0	0	0	
36 EMBEDS	3700	LB	2.55				0.3	1100	20.95	9,000	23,000	32,000	0	32,000	\$1,413,000
37 CONTAINMENT BASE MAT															
38 CONCRETE	11644	CY	65				3	34900	20.95	757,000	731,000	1,488,000	0	1,488,000	
39 FORMS	11644	SF	2.2				0.67	7800	20.95	26,000	163,000	189,000	0	189,000	
40 REBAR	2329	TM	560				20	46600	20.95	1,304,000	976,000	2,280,000	0	2,280,000	
41 CADWELDS	7000	EA	47				2.4	16800	20.95	329,000	352,000	681,000	0	681,000	
42 EMBEDS	16000	LB	2.55				0.18	2900	20.95	41,000	61,000	102,000	0	102,000	\$5,877,000
43 EXTERNAL FILL CONCRETE															
44 CONCRETE	0	CY	65				3	0	20.95	0	0	0	0	0	
45 FORMS	0	SF	2.2				0.67	0	20.95	0	0	0	0	0	
46 REBAR	0	TM	560				20	0	20.95	0	0	0	0	0	
47 EMBEDS	0	LB	2.55				0.18	0	20.95	0	0	0	0	0	
48 EXTERNAL BASE MAT															
49 CONCRETE	9116	CY	65				3	27300	20.95	593,000	572,000	1,165,000	0	1,165,000	
50 FORMS	9116	SF	2.2				0.67	6100	20.95	20,000	128,000	148,000	0	148,000	
51 REBAR	684	TM	560				20	13700	20.95	383,000	287,000	670,000	0	670,000	
52 CADWELDS	0	EA	47				2.4	0	20.95	0	0	0	0	0	
53 EMBEDS	15497	LB	2.55				0.18	2800	20.95	40,000	59,000	99,000	0	99,000	\$2,581,000
54 EXTERNAL WALL & SLAB															
55 CONCRETE	10900	CY	65				6	65400	20.95	709,000	1,370,000	2,079,000	0	2,079,000	
56 FORMS(WALL)	93960	SF	2.2				1.2	112800	20.95	207,000	2,363,000	2,570,000	0	2,570,000	
57 FORMS(SLAB)	11000	SF	2.2				1.4	15400	20.95	24,000	323,000	347,000	0	347,000	
58 METAL DECK	40000	SF	1.5				0.14	5600	20.95	60,000	117,000	177,000	0	177,000	
59 REBAR	1660	TM	560				45	74700	20.95	930,000	1,565,000	2,495,000	0	2,495,000	
60 CADWELDS	0	EA	47				2.4	0	20.95	0	0	0	0	0	

1 A L T E R N A T E

JOBNO -18984-002

APUR -CONTAINMENT STUDY

F I N A L E V A L U A T I O N

CASE - CYLINDRICAL STEEL VESSEL (CSCV);ELLIPSOIDAL BOTTOM. Priced- SB

FILE NAME : CSCV_ELL

DATE 06/03/88

PAGE 1

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT COST		MAN UNIT	HOURS	TOTAL	\$/HR	MATERIAL	LABOR	COST		TOTAL ALL INCLUDED
				MATL	S/C							SUB-COMT	TOTAL	
10	EXCAVATION	68200	CY			0	23900	20.95	0	501,000	0	0	501,000	\$612,000
11	INTERNAL FILL CONCRETE													
12	CONCRETE	16362	CY	65			49100	20.95	1,064,000	1,029,000	0	0	2,093,000	
13	FORMS	4800	SF	2.2			3200	20.95	11,000	67,000	0	0	78,000	
14	REBAR	818	TN	560			16400	20.95	458,000	344,000	0	0	802,000	
15	CADWELDS	0	EA	47			0	20.95	0	0	0	0	0	
16	EMBEDS	7100	LB	2.55			1300	20.95	18,000	27,000	0	0	45,000	\$3,689,000
17	INTERNAL WALL & SLAB													
18	CONCRETE	9200	CY	65			55200	20.95	598,000	1,156,000	0	0	1,754,000	
19	FORMS(WALL)	87600	SF	2.2			105400	20.95	193,000	2,208,000	0	0	2,401,000	
20	FORMS(SLAB)	5700	SF	2.2			8000	20.95	13,000	168,000	0	0	181,000	
21	METAL DECK	26400	SF	1.5			3700	20.95	40,000	78,000	0	0	118,000	
22	REBAR	2210	TN	560			99500	20.95	1,238,000	2,085,000	0	0	3,323,000	
23	CADWELDS	18700	EA	47			44900	20.95	879,000	941,000	0	0	1,820,000	
24	EMBEDS	46000	LB	2.55			8300	20.95	117,000	174,000	0	0	291,000	\$12,088,000
25	CNTNMENT/SHIELD CYLWALL													
26	CONCRETE	11500	CY	65			61000	20.95	748,000	1,278,000	0	0	2,026,000	
27	FORMS(BOTH SIDE)	191400	SF	0.44			45900	20.95	84,000	962,000	0	0	1,046,000	
28	REBAR	1020	TN	560			40800	20.95	571,000	855,000	0	0	1,426,000	
29	CADWELDS	1020	EA	47			2400	20.95	48,000	50,000	0	0	98,000	
30	EMBEDS	300000	LB	2.55			54000	20.95	765,000	1,131,000	0	0	1,896,000	\$7,936,000
31	CNTNMENT/SHIELD DOME													
32	CONCRETE	2200	CY	65			13200	20.95	143,000	277,000	0	0	420,000	
33	FORMS	20400	SF	2.2			19200	20.95	45,000	402,000	0	0	447,000	
34	REBAR	150	TN	560			7500	20.95	84,000	157,000	0	0	241,000	
35	CADWELDS	0	EA	47			0	20.95	0	0	0	0	0	
36	EMBEDS	3700	LB	2.55			1100	20.95	9,000	23,000	0	0	32,000	\$1,394,000
37	CONTAINMENT BASE MAT													
38	CONCRETE	9532	CY	65			28600	20.95	620,000	599,000	0	0	1,219,000	
39	FORMS	9532	SF	2.2			6400	20.95	21,000	134,000	0	0	155,000	
40	REBAR	715	TN	560			14300	20.95	400,000	300,000	0	0	700,000	
41	CADWELDS	0	EA	47			0	20.95	0	0	0	0	0	
42	EMBEDS	0	LB	2.55			0	20.95	0	0	0	0	0	\$2,535,000
43	EXTERNAL FILL CONCRETE													
44	CONCRETE	5895	CY	65			17700	20.95	383,000	371,000	0	0	754,000	
45	FORMS	0	SF	2.2			0	20.95	0	0	0	0	0	
46	REBAR	0	TN	560			0	20.95	0	0	0	0	0	\$922,000
47	EMBEDS	0	LB	2.55			0	20.95	0	0	0	0	0	
48	EXTERNAL BASE MAT													
49	CONCRETE	14728	CY	65			44200	20.95	957,000	926,000	0	0	1,883,000	
50	FORMS	11492	SF	2.2			7700	20.95	25,000	161,000	0	0	186,000	
51	REBAR	1105	TN	560			22100	20.95	619,000	463,000	0	0	1,082,000	
52	CADWELDS	0	EA	47			0	20.95	0	0	0	0	0	
53	EMBEDS	25000	LB	2.55			4500	20.95	64,000	94,000	0	0	158,000	\$4,045,000
54	EXTERNAL WALL & SLAB													
55	CONCRETE	10900	CY	65			65400	20.95	709,000	1,370,000	0	0	2,079,000	
56	FORMS(WALL)	93960	SF	2.2			112800	20.95	207,000	2,363,000	0	0	2,570,000	
57	FORMS(SLAB)	16000	SF	2.2			15400	20.95	24,000	347,000	0	0	347,000	
58	METAL DECK	40000	SF	1.5			5600	20.95	60,000	117,000	0	0	177,000	
59	REBAR	1660	TN	560			74700	20.95	930,000	1,565,000	0	0	2,495,000	
60	CADWELDS	0	EA	47			0	20.95	0	0	0	0	0	

1 A L T E R N A T E

JOBNO - 189B4-002

FILE NAME : SSSV_FML

2 APNR -CONTAINMENT STUDY

APNR -CONTAINMENT STUDY

DATE 06/23/88

3 C - E 'N S S S'

F I N A L E V A L U A T I O N

takeoff- EMG

4

CASE - SPHERICAL STEEL CONTAINMENT VESSEL (SSCV) -priced- SB

DATE 06/23/88

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7 I T E M and DESCRIPTION

QUANTITY

TOTAL ALL INCLUDED

UNIT	MATL	S/C	MAN UNIT	HOURS TOTAL	\$/HR	MATERIAL	LABOR	SUB-CONT	TOTAL
79000	CY	0	0.35	27700	120.95	0	580,000	0	580,000
7300	CY	65	3	21900	20.95	475,000	459,000	0	934,000
36500	SF	2.2	0.67	24500	20.95	80,000	513,000	0	593,000
547	TN	560	20	10900	20.95	306,000	228,000	0	534,000
0	EA	47	2.4	0	20.95	0	0	0	0
10921	LB	2.55	0.18	2000	20.95	28,000	42,000	0	70,000
12700	CY	65	6	76200	20.95	826,000	1,596,000	0	2,422,000
87800	SF	2.2	1.2	105400	20.95	193,000	2,208,000	0	2,401,000
5700	SF	2.2	1.4	8000	20.95	13,000	168,000	0	181,000
37600	SF	1.5	0.14	5300	20.95	56,000	111,000	0	167,000
2910	TN	560	45	131000	20.95	1,630,000	2,744,000	0	4,374,000
18700	EA	47	2.4	44900	20.95	879,000	941,000	0	1,820,000
63500	LB	2.55	0.18	11400	20.95	162,000	239,000	0	401,000
6600	CY	65	5.3	35000	20.95	429,000	733,000	0	1,162,000
131700	SF	2.2	1.2	158000	20.95	290,000	3,310,000	0	3,600,000
870	TN	560	40	34800	20.95	487,000	729,000	0	1,216,000
870	EA	47	2.4	2100	20.95	41,000	44,000	0	85,000
9900	LB	2.55	0.18	1800	20.95	25,000	38,000	0	63,000
7300	CY	65	6	43800	20.95	475,000	918,000	0	1,393,000
86300	SF	2.2	0.94	81100	20.95	190,000	1,699,000	0	1,889,000
540	TN	560	50	27000	20.95	302,000	566,000	0	868,000
0	EA	47	2.4	0	20.95	0	0	0	0
25550	LB	2.55	0.3	7700	20.95	65,000	161,000	0	226,000
13020	CY	65	3	41500	20.95	898,000	869,000	0	1,767,000
20730	SF	2.2	0.67	13900	20.95	46,000	291,000	0	337,000
3200	TN	560	20	64000	20.95	1,792,000	1,341,000	0	3,133,000
3200	EA	47	2.4	7700	20.95	150,000	161,000	0	311,000
20730	LB	2.55	0.18	3700	20.95	53,000	78,000	0	131,000
1605	CY	65	3	4800	20.95	104,000	101,000	0	205,000
2700	SF	2.2	0.67	1800	20.95	6,000	38,000	0	44,000
160	TN	560	20	3200	20.95	90,000	67,000	0	157,000
0	LB	2.55	0.18	0	20.95	0	0	0	0
0	CY	65	3	0	20.95	0	0	0	0
0	SF	2.2	0.67	0	20.95	0	0	0	0
0	TN	560	20	0	20.95	0	0	0	0
0	EA	47	2.4	0	20.95	0	0	0	0
0	LB	2.55	0.18	0	20.95	0	0	0	0
11850	CY	65	6	71100	20.95	770,000	1,490,000	0	2,260,000
104000	SF	2.2	1.2	124800	20.95	229,000	2,615,000	0	2,844,000
11000	SF	2.2	1.4	15400	20.95	24,000	323,000	0	347,000
33100	SF	1.5	0.14	4600	20.95	50,000	96,000	0	146,000
1740	TN	560	45	78300	20.95	974,000	1,640,000	0	2,614,000
0	EA	47	2.4	0	20.95	0	0	0	0

60 CADWELDS

APPENDIX C

Scheduling Impact on AFUDC

PURPOSE:

The purpose of this study is to illustrate, by use of simple examples, the relationship between cash flow, critical path schedule, and AFUDC charges for a future ALWR. This will demonstrate that the reduction in the plant critical path with or without an increase in capital cost will save significant dollars to the future owner of an ALWR.

ASSUMPTIONS:

For the use of this study the following assumptions were used:

- . Plant capacity - 1300 Mw
- . Capital cost - \$1,680/Mw (1986 dollars)
- . Seven (7) year expenditure period
- . AFUDC rate - 9 1/4%
- . Cash flow parallels the Catawba Nuclear Station Unit 1 cash flow compressed to a seven-year expenditure period.

STUDY DESCRIPTION:

The following is a description of the different scenarios used in this study:

Base Case

The cash flow for this case was based on a percentage of the actual Catawba Unit 1 cash flow compressed to a seven (7) year expenditure period. The cash expenditures shown on Table 1 are summarized in 14 six-month periods.

Case A

Case A was identical to the base case with the following exception: the expenditure schedule was shortened from 14 periods to 13 periods to simulate shortening the plant critical path by six months while maintaining the total direct dollars. To accomplish this schedule reduction, the expenditure for period 8 (\$223,704,936) was divided equally and then added to periods 6-7 and 9-14. The increase in total direct cost per period was approximately \$27,963,117. This case was developed to demonstrate the AFUDC savings by shortening the plant critical path by six months. Shortening of the critical path was started during time period 6 to simulate overall schedule savings due to an accelerated containment vessel erection.

Cases B and C

Cases B and C are similar to Case A except that an additional capital expenditure was added at the start of period 6 (10 million - Case B, 17 million - Case C). These cases are used to illustrate the impact of these type capital expenditures when needed to shorten the construction critical path and accomplish the AFUDC savings illustrated in Case A.

Case D

Case D is identical to Case C except that the construction schedule was shortened by three months at the end of period 13. The capital expenditure for period 13 remained constant but was compressed to three months.

Case E

Case E is identical to Case C except that the construction schedule was delayed three months at the start of period 1. The capital expenditure for period 1 remained constant but was compressed to three months.

OBSERVATIONS:

From review of Table 2, the following observations can be made:

- . Shortening of the construction critical path by six months, during the approximate time of the containment vessel erection can reduce AFUDC charges by approximately 66.8 million dollars.

- . Increasing capital expenditures to shorten construction critical path schedules can be economically justified. The additional expenditure of 17 million dollars at the beginning of time period 6 produced a savings of 42.3 million dollars. The difference in savings between cases A and C amounted to 24.5 million dollars, for which 17 million dollars was the actual capital expenditure.

Shortening of the critical path at the latter portion of the project can save significantly larger amounts of AFUDC charges than delaying the project. Case D clearly demonstrates in terms of AFUDC dollars the cost of delaying or accelerating commercial operation. However, Case D is misleading since shortening of the critical path near the end of the project is not realistic. During this period of time AFUDC charges are maximized. Industry experience shows us that there is less chance of shortening the start-up and testing schedule to take advantage of this savings potential. Case E is more realistic since additional shortening of the critical path permits you to delay expenditures.

TABLE 2
Direct Dollars and AFDC *
Advanced Light Water Reactor
(000's)

Direct Dollars	6 Month Period	Base Case 7 Years	Case A	Case B	Case C	Case D	Case E
			Same Cost 6 1/2 Years	Increased Cost \$10 Million 6 1/2 Years	Increased Cost \$17 Million 6 1/2 Years	Increased Cost \$17 Million 6 1/4 Years	Increased Cost \$17 Million 6 1/4 Years
	1	\$423,696	\$423,696	\$423,696	\$423,696	\$423,696	\$423,696 **
	2	4,962,048	4,962,048	4,962,048	4,962,048	4,962,048	4,962,048
	3	24,227,112	24,227,112	24,227,112	24,227,112	24,227,112	24,227,112
	4	56,266,392	56,266,392	56,266,392	56,266,392	56,266,392	56,266,392
	5	117,936,000	117,936,000	117,936,000	117,936,000	117,936,000	117,936,000
	6	133,459,872	161,422,989	171,422,989	178,422,989	178,422,989	178,422,989
	7	255,796,632	283,759,749	293,759,749	283,759,749	283,759,749	293,759,749
	8	223,704,936	228,561,333	229,561,333	228,561,333	228,561,333	228,561,333
	9	200,598,216	245,419,629	245,419,629	245,419,629	245,419,629	245,419,629
	10	217,456,512	273,995,085	273,995,085	273,995,085	273,995,085	273,995,085
	11	246,031,968	316,733,781	316,733,781	316,733,781	316,733,781	316,733,781
	12	288,770,664	325,775,541	325,775,541	325,775,541	325,775,541	325,775,541
	13	297,812,424	144,514,461	144,514,461	144,514,461	144,514,461 **	144,514,461
	14	116,551,344					
Total direct dollars		\$2,183,997,816	\$2,183,997,816	\$2,193,997,816	\$2,200,997,816	\$2,200,997,816	\$2,200,997,816
Total AFDC		\$574,274,000	\$507,436,000	\$511,684,000	\$514,997,000	\$455,659,000	\$514,989,000
Total cost		\$2,758,271,816	\$2,691,433,816	\$2,705,681,816	\$2,715,994,816	\$2,656,656,816	\$2,715,986,816
Savings			\$66,838,000	\$52,390,000	\$42,277,000	\$101,615,000	\$42,285,000

* Reflects "overnight" costs.

** Assumes these expenditures are made over a 3 month period.

APPENDIX D

April 28, 1989

Memo to File

Subject: Design for Constructability Program
Second Design for Constructability Workshop
Impact of ASME Division 2 Code on Containment
Constructability
Duke File: RED-0608

As discussed in the Second Design for Constructability Workshop and several containment constructability meetings, the selection of a containment type for use as the reference design for the future Advanced Light Water Reactor Design (ALWR) is a complex decision impacted by various containment parameters. Among these parameters is the cost impact of constructing a concrete containment to Division 2 of the ASME Code. This memo summarizes the findings of a study undertaken to quantify this impact.

Because of the slow down of the US Nuclear Industry since the late 1970's, there is a limited experience base to draw from. The study was based on interviews with Utilities and Architect/Engineers (A/E)'s that had first hand experience with the construction of concrete containments that conformed to ASME Div. 2.

Washington Public Power Supply System (WPPSS) is the owner of the only ASME code stamped concrete containment vessel in the United States, Washington Nuclear Project 1 (WNP-1). Seabrook Station (SS) also has a reinforced concrete containment built to ASME Div. 2, however it is not 'N' stamped. The State of New Hampshire granted the owners, New Hampshire Yankee (NHY), a State Special Wavier on the Code Stamping and Certified Data Reporting for Seabrook's containment. The A/E for both projects was United Engineers & Contractors (UE&C).

Interviews conducted with UE&C, NHY, and WPPSS personnel determined that attempting to quantify the cost of building a concrete containment to ASME Div. 2 is difficult due to lack of historical data to evaluate. All agreed there were quantifiable and non-quantifiable cost impacts. Most of the quantifiable impacts provided were minor in nature and insignificant when compared to the total cost of containment (per the UE&C Engineering Economic Data Base, the approximate cost of containment exceeds 214 million dollars). Some examples of quantifiable impacts are as follows:

Authorized Nuclear Inspector (ANI) on the job site.

Writing the ASME Construction Report.

Level 3 Examiner on the job site.

ASME survey team for obtaining an "N" stamp.

Examples of the non-quantifiable cost impacts that exist but can not be evaluated due to the lack of historical data are as follows:

Increased material qualification and testing

Increased mixing and concrete placing requirements

Increased process testing

Increased documentation review, approval, and storage

Development of Code Cases

These additional costs are real, but the overall magnitude is probably insignificant when compared to the cost of containment. UE&C attempted to quantify the additional cost increases due to implementation of ASME Div. 2 as a direct result of the increased material qualification and testing during the 1975-1976 time frame. An excerpt from that study is found in the attached Table A.

A similar inquiry concerning the cost of a concrete containment vessel that conformed to ASME Div 2 was asked 2 to 3 years ago at SS. With respect to Engineering, Testing, and Construction, ASME Div. 2 and ANSI 45.2.5 were considered parallel with no quantifiable differences. Additional costs associated with the concrete vessel were attributed to overhead costs of the ANI and Site Level 3 Examiner and to preparation of the ASME Construction Report.

A major consideration which directly influences containment constructability is the involvement of the ANI. Differences of opinion were expressed during containment constructability meetings on the potential impact an ANI could have on the construction critical path. Untimely intervention of an ANI during containment construction could delay the critical path and subsequently increase plant costs by millions of dollars per day in finance charges. The parties interviewed at both WPPSS and UE&C agreed the potential was there for this intervention but they had not experienced this specific problem at SS or WNP-1. This was attributed mainly to the short period of time containment construction was on the critical path. WPPSS felt the ANI would not have impacted the WNP-1 critical path unless the structural integrity test was impacted.

To summarize, the parties agreed, that the additional cost incurred by constructing a concrete containment to ASME Div. 2 was a nuisance cost that could not be accurately predicted or described. - Also, the cost impacts anticipated are significantly small when compared to the overall cost of the plant.

D. A. Kelley, Senior Engineer
Engineering Support Division

Attachment

11-10-80

Tabulation of Differences Between ASME and ANSI Test Requirements for Concrete Materials

<u>Material</u>	<u>Requirement</u>	<u>Test Method</u>	<u>ASME Min. Frequency</u>	<u>ANSI Min. Frequency</u>	<u>Decrease in # of tests w/ANSI</u>	<u>Cost/ Test</u>	<u>Annual Savings</u>
Aggregate	Gradation	ASTM C136	1/day; 2/day if > 200 CY placed	1/day	0 to 260/yr	N/A ²	
	Moisture Content	ASTM C566	2/day	1/day	260/yr	N/A ²	
	Organic Impurities	ASTM C40	1/day	1/week	208/yr	N/A ²	
	Flat & Elong. Particles	CRD C119	1/month	1/six mo.	10/yr	N/A ²	
	Specific Grav. & Absorption	ASTM C127 or C128	1/month	Not required	12/yr	N/A ²	
	Chlorides ¹	ASTM D1411	1/month	Not required	12/yr	\$71.00	\$852.00
Water & Ice	Compressive Strength	ASTM C109	1/month	1/six mo.	10/yr	\$76.00	\$760.00
	Setting Time	ASTM C191	1/month	1/six mo.	10/yr	\$32.00	\$320.00
	Soundness	ASTM C151	1/month	1/six mo.	10/yr	\$32.00	\$320.00
	Total Solids	ASTM D1888	1/month	Not required	12/yr	\$22.00	\$264.00
	Chlorides	ASTM D512	1/month	Not required	12/yr	\$22.00	\$264.00
						Total	\$2780.00

¹ Performance of the D1411 test, while not listed in Table CC-5200-1 of the ASME Code, is required to satisfy the mixing water test requirements contained in CC-5225 and CC-2223.

² This test is performed on site by PTL personnel. No specific dollar value for this test is available.

Appendix C. Computer Modeling

**Review and Summary Report
Current CAD/CAE Systems**

Provided by:

**C. R. Jones
Management Consultant
S. Levy Incorporated**

on December 4, 1987

INTRODUCTION

Several companies were requested to review and report on their application of computer modeling in nuclear and non-nuclear industries. These companies were:

Stone & Webster Engineering Corporation
Bechtel North American Power Corporation
Combustion Engineering
Sargent & Lundy

The following is a digest of the reports submitted by each of the companies together with an appraisal of the probable benefits and possible problems with application of the system to the broader needs of the utility industry. In addition, an assessment of future prospects for CAD/CAM systems is provided. The assessment is based on recent publications. References 6 through 10 are provided as typical of recent computer industry projections.

The EPRI report, "Guidelines for Specifying Integrated Computer-Aided Engineering Applications for Electric Power Plants" (Ref. 1), was used as a reference for judging compatibility of the system described to overall utility CAE objectives. (An abstract of the report is included with the references.)

THE STONE & WEBSTER REPORT (Ref. 2)

A. REVIEW

The system is an integrated 3-Dimensional (3D) modeling package and relational database called Plant Digital Model (PDM). The system applies CATIA, a 3D solid modeler, CADAM, a 2D drawing package and DB2, a relational Data Base.

The package is a joint development of Stone & Webster and IBM.

The hardware and software is entirely IBM. A mainframe computer is used for central storage of the integrated plant database, including drawings,

diagrams, geometric data and operational data. Color graphic work stations are provided for plant design and viewing of 3D color models of the plant. Personal computer work stations are utilized for database access and viewing of drawings and models.

A primary aim of the system is the integration of the project management system with the Engineering and Construction process. After plant start-up, the same system is applied to operation, maintenance and retrofits.

In the approach envisioned by Stone & Webster, selected portions of the plant are modeled as 3D solid objects before the two dimensional models are prepared. Each component is individually selected and located in the plant. Since individual components can be moved as entities, changes or retrofits can be accomplished quickly. According to the report, analysis programs for structural, piping, shielding, and other analysis can be input directly from the 3D model configuration.

Material quantities are automatically taken off the 3D model. The same model is used in constructability reviews, interferences, crane positioning, etc.

Two dimensional construction drawings are made by taking slices or views from the appropriate area of the 3D model.

According to Stone & Webster, the Integrated Plant Data Base "... integrates the 3D geometric location data that defines the layout of the plant components with the technical and management attributes which describe and document components, systems and structures."

B. COMMENTS

The following comments are based solely on the document provided for review. There may be many more capabilities of the system than has been described in the document.

Generally, designs evolve from system level P&ID's, to the definition and selection of components, to the arrangement of the components in 3D space.

The first step in the iterative design process is not spatially oriented, as seems to be suggested in the process described. Of course, some aspects of the project management process precede that of engineering design. This suggests that the data base should be developed for the support of the project management and engineering design activities first and later be enlarged by information generated as the 3D model is developed. The design process and the data base structural requirements are clearly defined in the EPRI report (see Ref. 1).

Section 1.3 Current Development contains a very good description of problems associated with what is described as "institutional barriers" which are related to differences in operating systems, compatibility of hardware, software, data formats, differences in information coding, etc. One possible solution, the one apparently selected, is to use one computer type together with its peripherals and software developed for that computer. However, this does not deal with a very important system requirement, which is the ability to transfer information between systems, internal and external. Note that a great deal of 3D and other types of design information is supplied to the AE from external sources, some of which will have been developed on CAD/CAE systems utilizing different hardware and software. In this case, it would be much more cost effective if conversion could be achieved without reentering the data. The system proposed by Stone & Webster may, in fact, meet the compatibility requirements even though it was not clear from the report.

A related but somewhat different question is, following plant turnover, does the utility get hard copy or magnetic media and all necessary software for a complete operating system that is fully functional and independent of what computer hardware is selected?

The report described an excellent system that appears to be well suited for power plant design and construction. However, it is not altogether clear that it can be fully utilized by the utility without extensive ongoing support by Stone & Webster and IBM. For this and other reasons, training on the use of CAD/CAE systems prior to plant turnover becomes a very important consideration.

THE BECHTEL NORTH AMERICAN POWER CORPORATION REPORT (Ref. 3)

A. REVIEW

The system is 3D-CADD modeling package with related software modules that interface to "neutral" data files.

The system was developed by Bechtel engineer-programmers by building upon an Intergraph 2D-CADD base which permitted the use of the same hardware and many software modules.

With the availability of 3D model data files, Bechtel's capability was expanded to include the generation of 2D drawings and isometrics, data extraction for equipment lists, commodities, etc., for procurement and installation tracking. Utilizing existing engineering analysis programs, interfacing and supporting programs were developed to employ the 3D model data. Interactive design tools were added to permit functions like automatic pipe or cable routing with interference checking to be performed.

The most recent evolution has been in the development of a system for movement through a 3D model, a construction sequence simulation, an automatic part numbering system and the application of an artificial intelligence aid to Engineering Design and Construction.

Bechtel plans to add expert systems, expand the use of distributed database interfaces, expand "as-built" status updating and continue to add CAE modules.

B. COMMENTS

Bechtel's report consists of a three page letter, five flip chart type figures and several CAE bulletins. From the report alone, it is difficult to summarize and assess total system capabilities.

Although it appears that all the main elements of a CAD/CAE are present, it is not clear how the design engineering information system is integrated in a manner that it can contribute directly to the needs of project management and construction.

Under "Future Directions," Bechtel observes "... a need for a dominant standard in the SLQ-Distributed Database area. We anticipate that we will at some time or another be required to transfer information between non-compatible databases." This comment suggest that Bechtel's databases are not all able to communicate directly.

THE COMBUSTION ENGINEERING REPORT (Ref. 4)

A. REVIEW

The Combustion Engineering system is a fully integrated combination of software programs and databases that are accessible through database management utilities. The system, "Plant Applications and Systems from Combustion Engineering" (PASCE), is database driven with a graphics utility for information transfer.

The system was initiated by Combustion Engineering with Duke Power Company joining the effort as a partner for development and usage of the system. The development of PASCE was preceded by detail workflow and requirements analysis by Duke and CE subsidiaries.

The PASCE system is focused on plant design automation. The software includes a Physical Modeler for spatially oriented activities, a Schematic Modeler for logical disciplines and Database Access Routines to integrate PASCE components. A number of utilities are provided for such functions as general drafting, report writing, 2D to 3D, (i.e., data transfer between schematics and physical applications) change control and material management.

System utilities include the major layout and design analysis activities such as those related to steel, concrete, equipment, piping, HVAC and electrical wiring. Provisions have been made for future addition of design analysis modules.

The system is designed to be adaptable for operation in mixed hardware environments.

B. COMMENTS

An important aspect of PASCE is that graphics are a utility for information transfer from a completely database driven system. This concept would appear

to offer considerably more flexibility in application and further development of the system relative to CAD/CAM systems that use graphics as the foundation tool.

The PASCE system is focused on plant design automation. However, since it is database driven, data transfers for project management and construction functions, already planned, should not be difficult to achieve.

In addition, developments planned in photogrammetry and the integration of scanning technology to capture existing drawings may be expected to further improve an already comprehensive system.

THE SARGENT & LUNDY REPORT (Ref. 5)

A. REVIEW

The system is 3D design and drafting package software package called the Plant Design System.

The system was developed by Sargent & Lundy using the 3D design and drafting package and database management software supplied by Integraph as building blocks.

The system is organized around a central plant model which is used to maintain the design. Engineers and designers use CAD/CAE interface software to move descriptions back and forth between the central plant model and a number of computer aided engineering systems which are used for design calculations and analysis work. Drafting software is used to prepare drawings using the plant model as input.

"List System Interface Software" is used to construct interfaces between the plant model and project information management and/or construction planning software. Examples are cost estimating packages, material control packages, procurement list software, engineering data list software, configuration control software and construction planning and scheduling packages.

Computer aided engineering programs currently in use include structural steel design, piping design and drafting, piping analysis, pipe support design and drafting, and cable routing. Under development are automated pipe routing and cable routing directly on the plant model and detailed architectural design software using the plant model as input.

The system is linked to two UNISYS computers.

B. COMMENTS

From the system description, it appears that there is considerable manual information transfer required by the designer and the engineer as the 3D model is developed. Further, the system appears less comprehensive than others reviewed.

FUTURE PROSPECTS

Considering the next three to five years as the future, of the many changes resulting from the next computer revolution, those most likely to have a profound effect on computer aided design and engineering are developments in optical data storage, the effective or equivalent data handling rates, communication links and improvements in smart system database management software. References 6, 7, 8, 9 and 10 are examples of the direction the technology is likely to take, in the areas described above.

Developments in practical and reasonably affordable storage capability should make possible the storage and retrieval of all documents required for a nuclear power station. It should be possible to significantly reduce duplication, improve data retrieval and dramatically reduce the need for hard copy record retention, particularly the storage of archival hard copies.

Improvements in data processing speed should make it possible for the large number of people that need data to access any segment of the total plant data rapidly and on-line. This development will permit larger more detailed 3D models, more CAD/CAE modules that are easier to use, and at the same time increases the distribution of data.

Further developments in Smart System Software should simplify data searches which will permit expanded utilization of databases, not only by designers and engineers but also by project management and construction personnel.

However, computer generated 3D models in the foreseeable future will be 2D representations of 3D objects on the surface of a viewing window that is small relative to the scale of an entire plant. For this reason, plastic models will still be needed but it should be sufficient to use these models primarily for selection of a location for viewing the detailed 3D computer model of a much smaller segment of the plant. For this purpose, the plastic model can be much smaller, have much less detail and does not need to be kept up to date except in gross terms.

Future developments in applying CAD/CAE to Nuclear Power Plant Design offer great promise for increased efficiency and improved accuracy in design and engineering with concomitant improvements in data access. However, there is a price and there are risks. The price is in terms of the cost of hardware, the cost of software and perhaps most important, the cost of maintaining personnel capable of full system utilization. The risk is in terms of the commitment to a system that is expected to become obsolete within about three to five years. Further, the capability to implement design changes rapidly can result in the rapid completion of a design, but it can just as easily result in a continuous barrage of changes that inhibit the completion of a design that can be constructed. In addition, there have been cases where an installed computer system did not meet the expectations of the user. It is clear that, in terms of cost and schedule, reliance on a system that never actually fulfills its mission could result in forcing project management to employ expensive time consuming alternate solutions.

SUMMARY

The reports reviewed indicate that utilization of CAD/CAE systems by Architect Engineer firms is progressing rapidly with similar objectives and similar capabilities. It appears that PASCE has some advantages in flexibility in application, in hardware variations, and in accommodating advances in hardware and software.

One of the main benefits of the various systems, as stated in the reports, was applicability to plant operation and design changes after the plant is turned over to the utility. Although this may be true, it is not clear what is necessary for this transfer in terms of hardware, software and personnel training. This concern may be more commercial than technical but technical issues, like system integration, hardware compatibility, and data storage and manipulation have, in the past, been dominated by commercial considerations. Specified system requirements are necessary but will probably not be sufficient to avoid the utility becoming captive to a specific supplier.

There are a number of means for utilities to acquire the power of the CAD/CAE data for operation, maintenance and engineering changes. Three examples are:

The utility could require the physical transfer of all hardware and software at plant turnover, or, as the plant nears completion, the utility could install a duplicate hardware package at the site and implement a gradual software transfer together with appropriate personnel training. A third approach is to arrange a transition period, say five years, during which the system originator maintains the basic hardware and software as a service and information is transferred to the utility via high speed communication techniques. This approach might have the advantage of delaying purchasing hardware for less expensive next generation equipment.

In any case, a very carefully considered specification that is tailored to the specific needs of the utility is essential to avoid the utility becoming captive to a CAD/CAE system owned and operated by others.

REFERENCES

Ref. 1 Guidelines for Specifying Integrated Computer-Aided Engineering Applications for Electric Power Plants, Electric Power Research Institute, EPRI NP-5159M, May 1987, Project Manager: John Carey.

Abstract: "These guidelines will enable engineers to develop integrated CAE applications for power plant work activities. Researchers based the guidelines on a comprehensive plant data model that integrates all the information needed to perform work activities during the life cycle of a power plant."

Ref. 2 Design for Constructability Program, First Industry Review Workshop Program Study, Stone & Webster Engineering Corporation, August 1987.¹

Ref. 3 Bechtel 3D-CADD-CAE Modeling Capabilities, Bechtel North American Power Corp. September 1987.¹

Ref. 4 Plant Applications and Systems from Combustion Engineering, Integrated CAD/CAE Plant Design, Combustion Engineering, (cover letter E. P. Flynn dated October 12, 1987).¹

Ref. 5 Review of Computer Modeling at Sargent & Lundy, D. R. Larson and C. R. Podczerwinski, November 2, 1987.¹

Ref. 6 Optical Techniques and Data/Knowledge Base Machines, P. Bruce Berra and Nikos B. Troullinos, COMPUTER, October 1987.

Ref. 7 The Next Computer Revolution, Abraham Peled, SCIENTIFIC AMERICAN, October 1987.

Ref. 8 Data-Storage Technologies for Advanced Computing, Mark H. Kryder, SCIENTIFIC AMERICAN, October 1987.

Ref. 9 Hyper Text: An Introduction and Survey, Jeff Conklin, COMPUTER, September 1987.

Ref. 10 Hypermedia: finally here, Teka S. Perry, IEEE SPECTRUM, November 1987.

1. Selected representative pages from the report are attached.

EDS376

R E P O R T S U M M A R Y

SUBJECTS	Reliability, operations, maintenance, and human factors / Power system operation / Corporate planning methods	
TOPICS	Information systems Power plants Databases	Design Construction Operation
AUDIENCE	Generation engineers and planners	

Guidelines for Specifying Integrated Computer-Aided Engineering Applications for Electric Power Plants

These guidelines will enable utility engineers to develop integrated CAE applications for power plant work activities. Researchers based the guidelines on a comprehensive plant data model that integrates all the information needed to perform work activities during the life cycle of a power plant.

BACKGROUND	The use of computer-aided engineering (CAE) technology in the design, construction, operation, and maintenance of generating plants could substantially reduce plant costs. The power industry has already developed CAE systems and applications for a variety of plant work activities. However, most of these systems are stand-alone, unable to share plant data. The results are costly redundancies in capturing, handling, and maintaining data. To eliminate this problem, the industry needed a data model that integrated all the data required to perform work activities during a plant's life cycle. By standardizing data definitions, defining the relationships between these data, and describing the flow of information between activities, such a model would provide a base for the development of integrated CAE applications.
OBJECTIVES	To develop a data model integrating all plant data for use in developing power plant CAE applications and to develop guidelines for using this model.
APPROACH	Researchers divided the life cycle of a typical power plant into five phases: site selection and plant concepts, design, construction, operation, and decommissioning. After identifying more than 400 individual work activities performed during the five phases, the team selected 140 for detailed study. Parameters studied included the data required for each activity, the relationships among these data, and the flow of data between the activities. The team incorporated the results into a single plant information network (PIN) and prepared guidelines for using this tool to develop functional specifications for CAE applications.
RESULTS	• Study findings demonstrated the need for a plant data model. For example, many of the work activities used different definitions and names to refer to the same information, obscuring the fact that these activities required

essentially the same data. Resolving these inconsistencies involved a significant effort. And, although almost every activity required the same major data types, each activity often developed its own CAE applications.

- The PIN cross-references plant activities that use the same data or data types and provides consistent definitions of plant data items. A utility can use the PIN to integrate a CAE application with other activities performed by the utility and its contractors during the life of the plant. This tool could save a plant more than \$20 million a year.

**EPRI
PERSPECTIVE**

Use of the (PIN) described in this report could increase employee productivity, reduce design and construction costs, enhance the efficiency and quality of plant modifications, and improve plant operation and maintenance. The structure of the PIN permits gradual evolution toward a totally integrated CAE environment. It is possible to develop applications in any order without compromising integration. Ultimately, the adoption and widespread use of the PIN depends on top-level management acceptance and support. The effectiveness of PIN depends on such commitment because the integration of CAE applications requires cooperation between disciplines and departments. EPRI report NP-5159M, the main volume of this 10-volume report, describes the PIN and its use. EPRI report NP-5159S, volumes 1-9, provides the technical details of the work.

PROJECT

RP2514-3

EPRI Project Manager: John Carey

Nuclear Power Division

Contractors: Duke Power Company; Westinghouse Electric Corporation;
Cygna Corporation

For further information on EPRI research programs, call
EPRI Technical Information Specialists (415) 855-2411.

REFERENCE 2
SELECTED PAGES FROM THE REPORT

Design
for
CONSTRUCTIBILITY PROGRAM
FIRST INDUSTRY REVIEW WORKSHOP
PROGRAM STUDY

Prepared for: The Department of Energy

Integrated Plant Data Base
and
Computerized 3-Dimensional Solids Modeling

Contract No. DE-AC03-86SF16566

August 1987



STONE & WEBSTER ENGINEERING CORPORATION

DESIGN FOR CONSTRUCTIBILITY PROGRAM
FIRST INDUSTRY REVIEW WORKSHOP
PROGRAM STUDY

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SECTION 1

COMPUTER MODELING CAPABILITIES

1.1 Introduction/Overview

In the last few years there have been major advancements in the area of software development. Stone & Webster is applying an industry-unique integrated 3-dimensional (3-D) modeling system and relational data base. This system is called the Plant Digital Model (PDM) and operates on IBM computers.

Stone & Webster has been working jointly with IBM establishing an IBM '3D' Solids Modeling task force. It has been applying three IBM distributed software products to Plant Design functions for the past 23 months. These are CATIA (3D Solids Modeler), CADAM (2D Drawing Package), and DB2 (A relational Data Base).

The mission of this task force encompasses two areas: New Plant Design and Existing Plant Operations and Maintenance Functions.

- New Plant Design - These applications improve our ability to perform engineering, design, and procurement functions more efficiently by taking information directly from the computer model and producing drawings, material takeoffs, and requisitioning materials. In addition the 3D Solids model provides



for more cost effective use of Engineering man-hours by allowing for direct analysis of structural and piping systems from '3D' models and eliminating hard and soft interference problems. It was previously applied to the piping design for a 15 MW wood burning power plant and it is currently being utilized to design the furnaces and piping around the furnaces of a large Ethylene project. This includes structural design and analysis, mechanical and piping design, stress analysis and material takeoff. Plots showing three partial views of the furnaces are provided in Section 3.

- Existing Plant Operations and Maintenance Functions - there appears to be considerable interest in applying the IBM software to existing plant operations and maintenance functions both Nuclear and Non-nuclear. The major problem facing all nuclear clients is configuration management. We believe this can best be accomplished by means of a '3D' model of the physical plant and appropriate database files to store the technical data in a readily retrievable system. We have developed a prototype model of a typical nuclear Feedwater and condensate system (drawings attached) which we are using to demonstrate how a graphic '3D' model combined with DB2 on line query capability can enhance a utilities ability to maintain configuration control and improve efficiency during routine operations and maintenance functions. Radiation mapping



applications have also been developed around this prototype system.

Hardware and software are continuously being enhanced for more and more applications including construction project management. Modularized construction and project management systems can be successfully applied by project managers to complete construction projects both on time and cost effectively. These systems are described in more detail below.

Modularized Construction

Previously, modularized construction was the assembly of components that used orthographic/isometric drawings and as required solid models. Solid models were constructed based on drawings issued at a specific point in time. Since these drawings have to be amended from time to time, the expense of developing and maintaining solid models can be enormous. 3-D computer modeling, on the other hand, is interactive with the design development of the plant, making it more cost effective than traditional solid modeling.

Construction techniques for power plant installations have been characterized as:

- **Stick-built**

Conventional site installation of equipment and the assembly of prefabricated and field fabricated components.



- Skid mounted

Field or shop assembly of a group of functionally related equipment on a common base. Site installation requires construction of structure, placement of skid, installation of off-skid equipment, piping and wiring, and operation tie-in.

- Block assembly

Field or shop assembly of all equipment, piping, wiring, and structural members for a defined area. Site installation limited to placement, completion of the structure, interconnection between blocks, and operational tie-ins.

- Unit assembly

Field or shop assembly of all equipment, piping, wiring, and structure within transport limits. Site installation limited to placement on foundation and operational tie-in.

The objective of modular construction techniques is to minimize cost, optimize labor, and improve project schedule, while lowering plot area requirements and maintaining accessibility and operability. Application of modular construction techniques for power plants has been used to reduce plant construction scheduling by permitting simultaneous work on a number of sequential stick-built construction activities.



Nuclear plant construction practice is to use skid mounted and block assembly construction techniques for the construction of the nuclear island structures and equipment. Modular construction techniques have been used to assemble and place rebar, piping, containment liners, and process units (an assembly of equipment, piping, and wiring of a group of functionally related components) for the nuclear island.

Integration of Project Management Systems
to the Engineering/Construction Process

Existing project management systems were used to simulate the thought process through the engineering, design, procurement, construction and startup efforts. CPM networks were used to model the logical steps in the process and establish dates for each discrete step utilizing arrow or precedence diagrams and estimated time durations. Construction logic was sometimes based on construction assumptions of previous designs. Once construction starts and drawings are issued, there is little opportunity or time for construction to convince engineering to change the design to accommodate modularization techniques or to change the sequence of construction activities.

By utilizing state-of-the-art computer technology, Stone & Webster has greatly improved the ability of construction to participate in the planning process before designs are finalized.



Previous large projects depended on utilizing plastic models for:

- Elimination of interferences
- Visualizing equipment access for operation and maintenance
- Visualizing construction sequence and access

However, to build the plastic model, the design had to be finalized to a substantial degree. A long time period usually elapsed before drawings were accurate enough to build the model and the plastic model itself took time to build.

In addition, the design had to be well advanced to develop accurate quantities to validate the times estimated for construction activities.

In many cases the lead time between model construction and actual construction was insufficient to eliminate interferences, material quantity errors, or arrangement problems.

Three-Dimensional Solids Modeling

To improve the entire project development process, Stone & Webster has developed an integrated approach to computerized plant modeling for engineering, design, construction, operations, and maintenance, which can be applied to future nuclear projects. This system runs entirely on IBM computers, and the data base developed by Stone & Webster during the



design and construction process can be used during the entire life of the plant. The major elements of this system are as follows:

- A mainframe computer for central storage of the integrated plant database, including drawings, diagrams, geometric data, and operational data.
- Color graphic workstations for plant design and viewing of the three-dimensional color models of the plant
- Personal computer workstations for database access and viewing of drawings and models
- A three-dimensional solids modeling software package
- A two-dimensional drafting package
- A relational database system

In the Stone & Webster approach, selected portions of the plant are modeled in the computer as three-dimensional solid objects before the two-dimensional drawings are prepared. This permits each piece of equipment to be individually selected and located in the plant. Pipes, cable trays, structural steel, and other connecting elements are also modeled and located as spatial components. Thus, changes and retrofits are easily and quickly accommodated, as individual components can be moved as entities. The computer program will show any interferences as



the equipment is being located or modified. Analysis programs for structural, piping, shielding, and other analysis can be input directly from the "3D" model configuration.

Because the plant is modeled in true three dimensions, material quantities can be automatically taken off, and changes can be processed automatically. Construction drawings are made by creating slices or views of the appropriate models either horizontally (for plans), vertically (for sections), or obliquely (for isometrics).

The same computer models are used in constructibility review and planning. The movement of equipment can be planned in the true three-dimensional geometry, and cranes can be positioned in the best locations for major lifts, with no interferences. Complex three-dimensional shapes for reinforcing bars, concrete formwork, sheet metal, and other materials are developed and visualized more easily than in two-dimensional drawings. The construction sequence for the plant is developed and visualized in three dimensions by placing components sequentially. Through the database, the material quantities and construction sequence information is tied to the construction CPM networks and to construction work packages. The time required for construction planning is greatly reduced and design problems that would cause problems in construction are eliminated in the design phase.



The computer model has many additional advantages over a plastic model:

- The model always represents the present design, eliminating the time gap which occurs when building the model from drawings. This reduces rework on both the drawings and the model and eliminates repetitive material takeoffs and errors due to timing.
- The interface of the physical configuration with analysis programs such as NUPIPE and STRUDL improves the efficiency of engineering.
- The identity of a component as an object in the model allows us to relate technical requirements, schedule and cost attributes in the database to the model. The direct relationship of the physical configuration with the technical requirements instead of with reference documents is a new and powerful tool.
- The preliminary model can be viewed from many workstations and locations at the same time, by the owner, the engineers, and the construction and operations staff. This is a powerful communications tool to speed up decisions and resolve problems.
- The model can be used to simulate operations such as component installation, equipment mobility, radiation monitoring, security evaluations, and erection sequencing. This provides a powerful tool to try various options and achieve the optimum



sequence. It also facilitates visibility by management, client, and supervisory personnel.

- Plant operators can use the three-dimensional model to review the plant design for operability and maintainability, thereby finalizing the layout early. Operators can walk through the computer model of the plant and assess equipment removal areas, maintenance spaces, truck aisles, platforms and walkways, and other aspects of the plant while they are in the design stage.
- Feedback of as-built information from construction, provides a final geometric model for future maintenance and modification functions.



REFERENCE 3
SELECTED PAGES FROM THE REPORT

BECHTEL

3D-CADD-CAE

MODELLING

CAPABILITIES

September, 1987

Bechtel North American Power Corp

San Francisco, Ca

Job 18984

Bechtel Computer Modelling Capabilities

Introduction

At Bechtel the use of three dimensional computer modelling is very extensive. It is now mandatory for all new EPC projects, and general recommended for design only projects. It is also used selectively for other functions, such as equipment removal modelling, depending upon the applicability.

Capabilities

The existing capabilities of Bechtel computer modelling are summarized in Figure 1. As can be seen, the capabilities reach into all phases of an engineering-procurement-construction project. Summary articles describing many of these capabilities are included in Appendix A. The articles are usually written by the software application author and published in in-house newsletters. A copy of the most recent newsletter, the CAE Bulletin, July 87, is included in Appendix A because five of the seven articles are relevant to power plant modelling capabilities.

Historical Development and Philosophy

Computer modelling at Bechtel (see Figure 2) began in the 1970's with the acquisition of turnkey CADD systems. With time the prime CADD vendor for power plant applications became Intergraph, but systems from other vendors eg., Computervision, Calma are still in use for specific applications. During the 70's plastic models of major projects were also used.

In 1982 a 3D-CADD modelling system was developed by Bechtel engineer-programmers. The 3D system was built upon an Intergraph 2D-CADD base to use the same hardware and many common software modules. The basic philosophy applied in this development included software modularization, with interfaces to "neutral" data files. Several of the articles in Appendix A discuss these functions.

With the availability of the 3D model data files it was natural to expand the data base utilization. The first application, of course were the generation of 2D drawings and isometrics, then followed data extraction functions for equipment lists, commodities, etc., for procurement and installation tracking.

The second wave of applications was the CAE type of functions, ie., structure and pipe stress modelling, hanger models etc. These applications were developed with the philosophy of using existing engineering analysis programs as much as possible and creating interfaces and support programs to utilize the 3D physical model data. At the same time the interactive design tools were also being added. These are functions like automatic pipe or cable routing, or interference checking. These tools are all continuing to evolve. An example is the Bechtel Physical Design System (BPDS) that is described in the July 87, CAE Bulletin (See Appendix A).

The third wave of applications was dependant upon the introduction of faster graphics processing computers and workstations. These applications include the Bechtel WALKTHRU System which is for movement through the 3D model, and a Construction Sequence simulation system presently under development. (See Appendix A.)

In parallel with these graphical display type applications was the introduction of expert system based applications. These so far have taken the form of subroutines or modules fitted into the overall system. An example is given in the July, 87, CAE Bulletin article on "Application of Artificial Intelligence to Drawing Annotation". Another application under development is an automatic part numbering system.

Benefits and Problems

The major benefits and problems are listed in Figure 4. The benefits of using computer modelling are hard to quantify. They are primarily evident as a higher quality product, easier faster revisions to drawings etc., and more control over changes. (eg. a change in a component on a drawing will be electronically passed on to the procurement group, etc.)

The problems are mainly in the training and implementation of a new technology. The use and creation of a 3D model is a complex task with many standard conventions and techniques, and the appropriate use of component libraries. Designers and draftspeople usually undergo a six week training course followed by several months of on the job training before they become proficient at using the system. It is also necessary to train or educate the engineers, supervisors and managers in the capabilities of the system. Most problems in the past have usually been caused by the lack of knowledge about the system capabilities.

Future Directions

The directions of future developments in the computer modelling field are primarily dependent upon our perception of what work will be available in the future. Development efforts will proceed in the parallel modes included in Figure 5, in order to process information faster and add more details. We expect more emphasis in the construction sequencing and distributed database areas rather than the CAE modules areas. We anticipate a much closer linkage between the design engineer and the constructor, primarily through use of the 3D model as a viewing tool (See Appendix A - "3D Display Menu Software").

We also anticipate greater transfer of capabilities to and greater use of microcomputers as they become more powerful, although large projects (e.g., nuclear plants) will still require mini-computer or mainframe power because of the large quantities of data to be processed.

For the capabilities desired list we would add a need for a dominant standard in the SQL-Distributed Database area. We anticipate that we will at some time or another be required to transfer information between non-compatible databases.

3D -- MODELLING CAPABILITIES SUMMARY

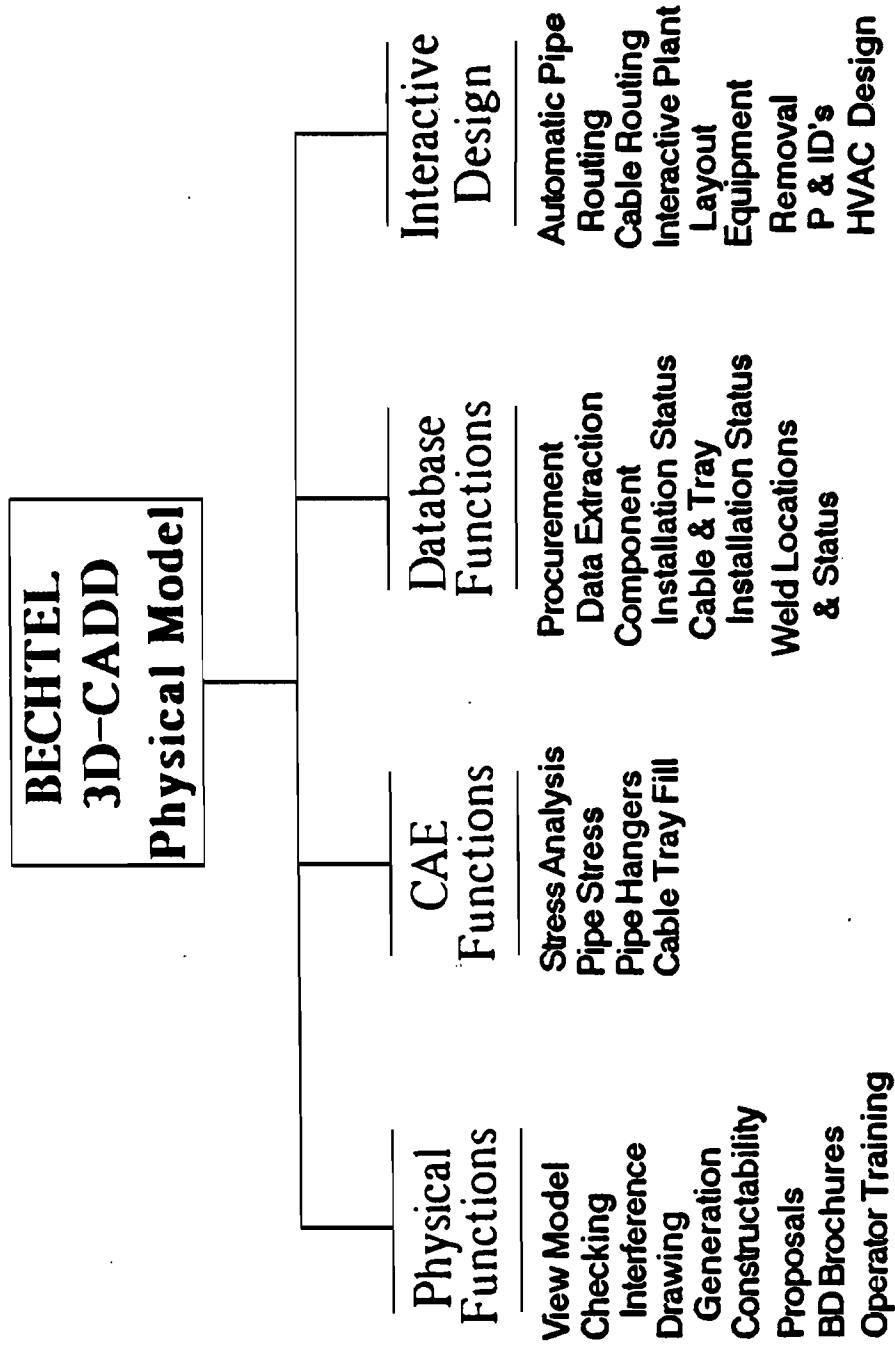


Figure 1

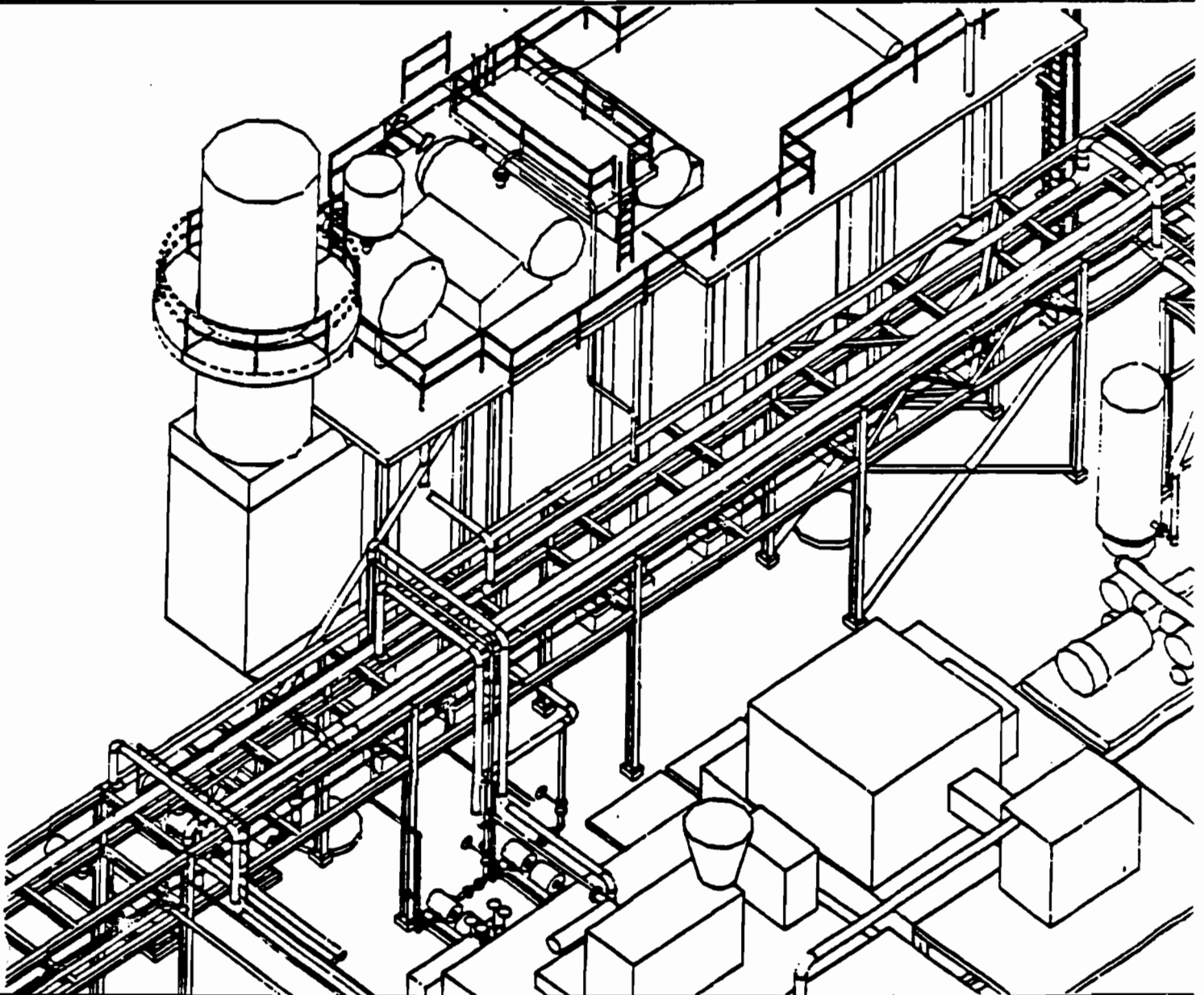


REFERENCE 4
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**PLANT APPLICATIONS and SYSTEMS
from COMBUSTION ENGINEERING**

INTEGRATED CAD/CAE PLANT DESIGN



COMBUSTION ENGINEERING

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1.0 BACKGROUND

Combustion Engineering established and funded a corporate project dedicated to the development and implementation of a plant design system. Subsequently, Duke Power Company, a North Carolina based electric utility, agreed to enter the development effort as a partner for development and usage of the system.

The project represents a major development effort for Combustion Engineering, both from the perspective of the required breadth of functionality to be provided, as well as the associated resources to be invested. This document provides an overview of the objectives of the project, a description of the individual applications, and the scheduled availability of the system.

The system, "*Plans Applications and Systems from Combustion Engineering*" (PASCE), is a composite of software programs and databases, linked together through database management utilities, which allow the layout, engineering, construction, and subsequent operation of large industrial facilities such as power and process plants.

The key to PASCE is its ability to maintain data and information in a consistent manner throughout the life cycle of the facility, reflecting modifications as they become known. Unlike mechanical CAD/CAM systems which use graphics as the foundation tool; in PASCE, graphics are a means for displaying or viewing the databases. PASCE is completely database driven, graphics are a utility for information transfer.

The PASCE development effort was preceded by detailed workflow and requirements analysis at both Duke and several CE subsidiaries. The PASCE system is focused completely on plant design automation, and is uniquely suited to the needs of facility owners and operating companies. General objectives of the PASCE system design include:

- It supports the development and maintenance of an informationally-complete set of databases describing a process plant or power plant.
- It provides full design cycle functionality, allowing the migration from conceptual design to increasingly detailed engineering with minimal loss of information or duplication of effort.
- It is used by design engineering staffs, and compatible with existing workflows.
- It enables the streamlining of present workflows through the proper maintenance of information. It does not replace higher-level decision processes or force unfamiliar workflows.

Both Combustion Engineering and Duke Power Company are major plant design organizations. The system development effort is closely-knit with the user community, reflecting a practical, yet technologically distinctive, product offering.

Combustion Engineering PASCE

2.0 SYSTEM OVERVIEW

PASCE is a large-scale, integrated software system which automates many of the tasks associated with the design of a power or process plant. It consists of a set of task-specific applications, each of which automates a portion of the plant design process. Supporting these applications are foundation software which collects and administers the information generated. The system architecture for PASCE appears in Figure 1.

2.1 Hardware

The system operates in a heterogeneous hardware environment to maximize the utility of existing installations. Initial development of PASCE occurred on the DEC and PRIME environments. Expansion to include IBM machines is in progress.

The majority of the software and databases reside on a minicomputer, which serve as the host in the multi-user environment. The development strategy is to provide local processing power where feasible; and several applications operate on personal computers. Emerging 32 bit workstation hardware will be integrated into the configuration over time.

All system functions are accessible through low cost, multi purpose, graphics terminals. This enables full usage within an organization at an economical price. The PASCE user interacts with the terminal, for creation, editing, and reporting of both physical and schematic data through drawings, lists, reports, and charts.

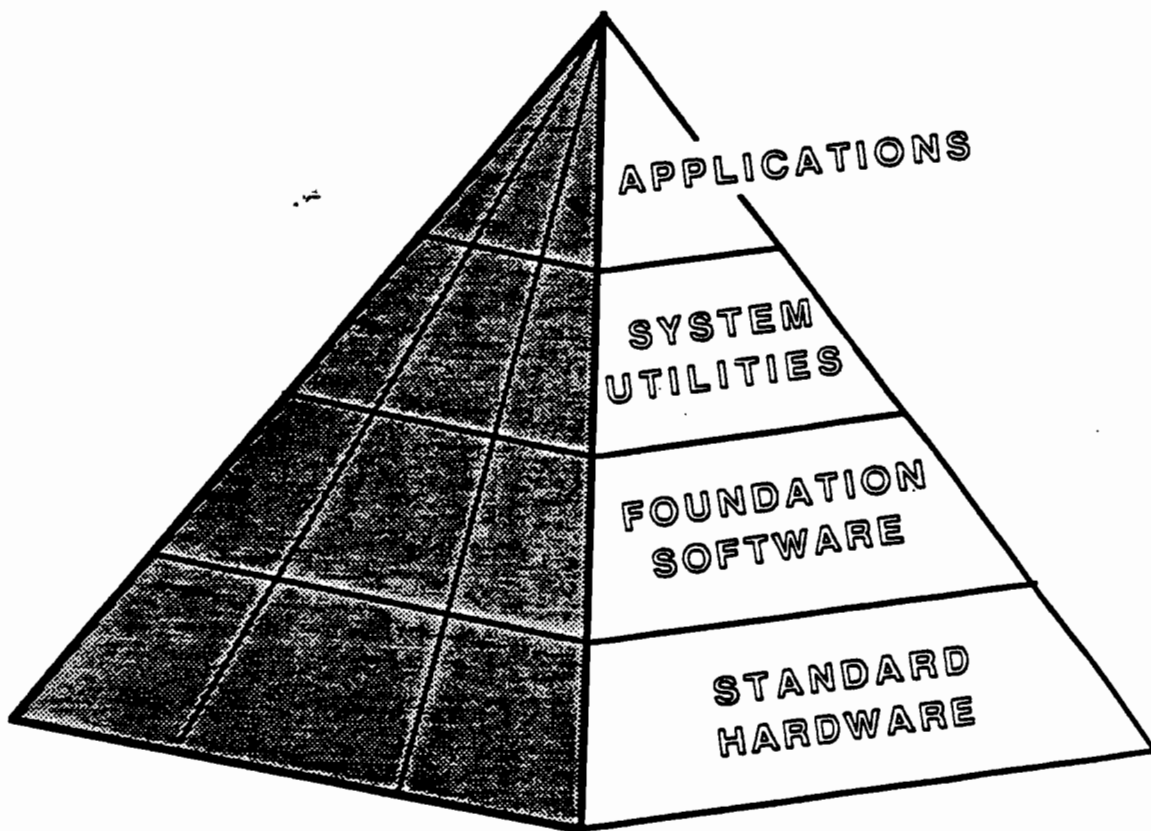
2.2 Foundation Software

The foundation software includes the Physical Modeler, the Schematic Modeler, and the Database Access Routines. The Physical Modeler supports the construction of 3D plant models, by combining geometric modeling functions with a database manager for storing the plant geometry. Applications developed from this foundation are piping, structural, electrical and instrumentation (physical), heating, ventilating and air conditioning (HVAC), and civil engineering.

In a similar way, the Schematic Modeler supports the construction of logical plant models, void of dimensional attributes. Applications developed from this foundation include: piping and instrumentation diagrams (P&ID), electrical schematics, electrical control logics, equipment applications, and process flow diagrams.

The Database access routines provides tools which integrate and tie together PASCE components. Examples of these tools include document generation, communications, workstation implementations, and consistent access to the various design databases. The Database Access Routines provide a means to link external client applications, such as commercial systems, proprietary process data banks, or special purpose analysis programs to the PASCE system.

Figure 1



Combustion Engineering PASCE

2.3 System Utilities

In addition to physical and schematic applications, several system applications are provided through the Database Access Routines. These applications are accessible by all disciplines, and provide generic utilities for manipulation and reporting of the plant data.

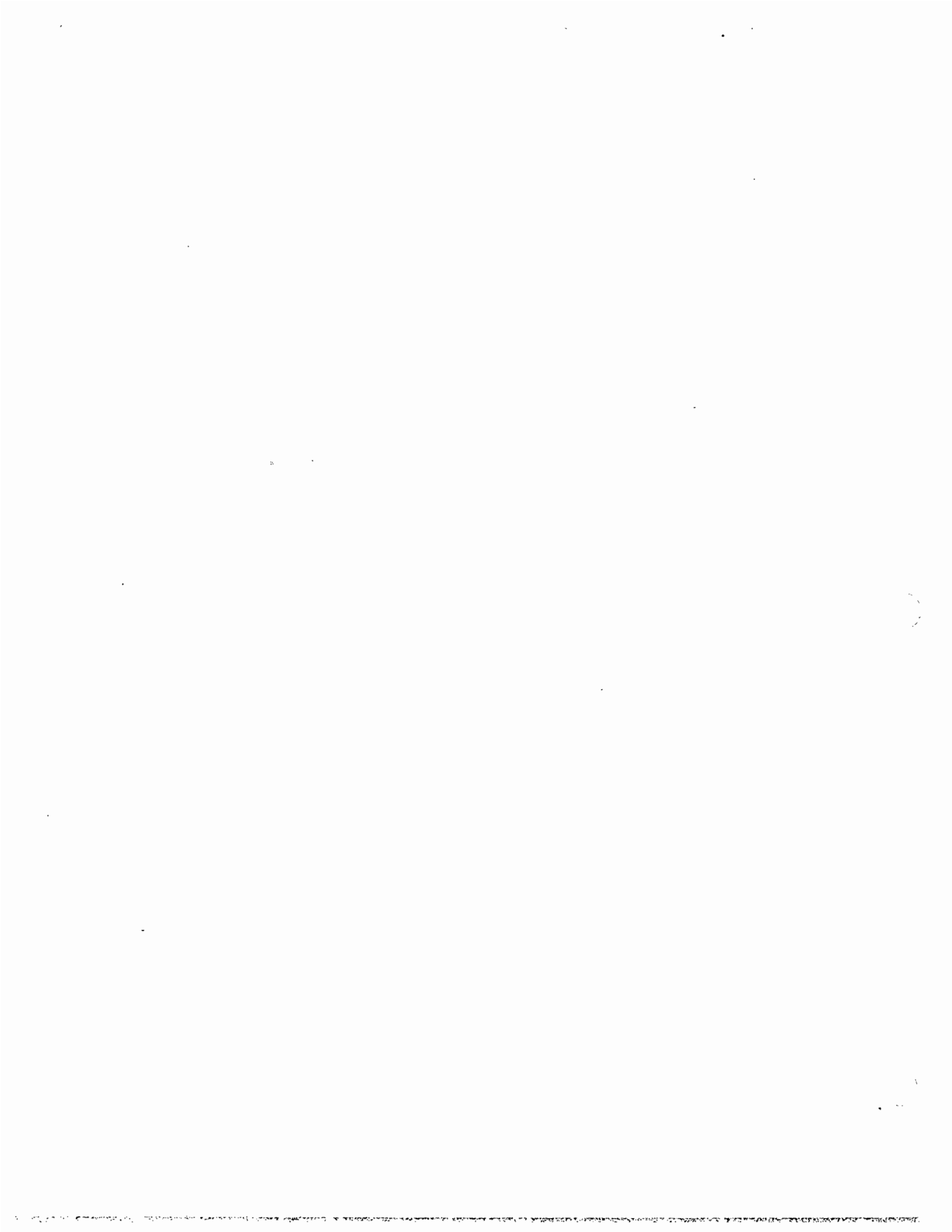
2.4 Applications

For both schematic and physical design, individual applications are available within PASCE addressing either design/layout activities or engineering/analysis activities. The design/layout applications allow the user to construct and place plant components in logical (schematic) or spatial (physical) configurations and assign critical attribute data.

The engineering/analysis applications enable the user to evaluate and verify the adequacy of the schematic or physical design. These are linked to the appropriate design/layout application and include such engineering activities as pipe stress analysis and structural analysis program interfaces.

Each application uses elements of the foundation software to accomplish a specific task in the plant design process. The general capabilities of the applications are:

- Extract information from the design database.
- Modify or add to the data, using the discipline oriented functions provided
- Produce design documents, including drawings and reports.
- Generate the required construction documentation.
- Transmit design information to those responsible for related applications.



REFERENCE 5
SELECTED PAGES FROM THE REPORT

AL-DFC-07-06

REVIEW OF
COMPUTER MODELING
AT SARGENT & LUNDY

PREPARED BY

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NOVEMBER 2, 1987

REVIEW OF COMPUTER MODELING AT SARGENT & LUNDY

1.0 INTRODUCTION

This report is a review of the application of computer models to power plant design in Sargent & Lundy offices and a discussion of the future capabilities of computer modeling in general. The review is organized into five sections.

Section 2 contains a general description of the CAD and CAE equipment and software that are being used for computer modeling at this time and a review of the projects to which it is being applied. Over the past 3 years Sargent & Lundy has developed and implemented software to integrate the computer model with computer aided engineering and computer aided drafting. The objective of this development has been to increase cost effectiveness in order to secure the design quality benefits that the basic characteristics of computer models, CAD and CAE have to offer. Section 3 elaborates on the present capabilities of these tools, capabilities presently under development, capabilities that are planned for development and issues being researched.

Section 4 is a discussion of the primary design quality benefits that computer modeling, as it is presently used at Sargent & Lundy, has to offer. Each of these benefits directly relate to constructability. A short discussion on the mechanics of how the benefits arise is also included.

Section 5 is a description of the evolution of computer modeling in our offices. Section 6 contains a discussion of the factors that limit the speed at which computer model usage is expanding at present, and the root cause of those limits. Following that is a discussion of the new generation of CAD and CAE equipment being placed on the market. Over the next three to five years this equipment will gradually replace the present infrastructure of CAD and CAE equipment now in service in A/E offices. The discussion concludes with an assessment of the additional capabilities that the price/performance characteristics of this equipment have the ability to yield in the next five years.

2.0 COMPUTER MODEL APPLICATION TO DATE

Sargent & Lundy uses CAD equipment supplied by Intergraph Corporation for computer modeling and computer aided drafting. Figure 1 illustrates the arrangement of equipment presently in use. The CAD equipment shown on Figure 1 is interfaced with the company's UNISYS 1100 computer system. This computer system is used for design calculations, analysis work, and information management. Figure 2 illustrates its arrangement. The Interface between the two computer systems allows the results of design calculations that are done using computer aided engineering programs on the UNISYS system to be used as input for drafting and computer modeling work on the CAD system.

The interface also allows drawings and portions of computer models, which are 3D drawings, to be used as input to design calculations, analysis work or project information management operations on the UNISYS System.

Computer Modeling work is done using a software package that was developed in house, called the Plant Design System. The system was developed using the 3D drafting and data base management software supplied by Intergraph as building blocks. The Plant Design System package is a 3D design and drafting package. It permits the detailed computer model for a plant to develop as a by-product of routine computer aided drafting and design calculation work done on the project. Section 3 of this document explains the arrangement of the Plant Design System in more detail.

The development and implementation of the Plant Design System was planned as an evolution which began in early 1984. Since that time the primary elements of the Plant Design System were placed in service and used successfully on the five projects listed below.

- A reference design for a 350 MW pulverized coal unit
- 2 standard resource recovery plants
- A cogeneration unit turbine building
- An industrial power house

We are presently applying the Plant Design System to the preliminary design of nuclear units KNU 11&12. These are 1000 MW PWR units.

3.0 PRESENT CAPABILITIES AND DEVELOPMENT IN PROGRESS

3.1 Present Capabilities

Present capabilities at Sargent & Lundy can best be described by explaining the arrangement of the Plant Design System at present. Figure 3 illustrates the arrangement. The design of the system is organized around a central plant model which is used to maintain the design. To develop the design, engineers and designers use a set of design software and a set of computer-aided engineering interface software. The design software is used to develop the arrangement of the design. The CAE interface software is used to move descriptions of the design back and forth between the central plant model and a number of Computer Aided Engineering (CAE) systems which are used for design calculations and analysis work where required.

As the design develops, the drafting software is used to prepare the drawings necessary to present the design. The drawings are prepared using the plant model as input. A set of list system interface software is used to communicate with data base management systems that are used to prepare and maintain the engineering data lists, material lists, and configuration control lists used on the project.

Design Software

The design software is made up of three primary components:

- A set of arrangement menus
- A reference design library
- An interference checking program

The arrangement menus are specially designed workstation menus that are fitted to the front of color CAD workstations which the designers use to do their work.

Specially designed arrangement menus have been developed for each major category of layout work required to design a plant.

While working with the arrangement menus, the designer has access to a reference design library which resides on the CAD system. This library includes:

- 3D computer graphic models of reference generating station designs which are used as a starting point for design
- Predesigned plant modules
- Equipment representations
- Wire frame representations of standard hardware

Where visibility is difficult an interference checking program is used. If an interference is detected by the program, a paper output report and a drawing showing the interference are produced. The program considers all reserved spaces that are required for equipment removal, maintenance, access and egress and future designs while doing the interference check.

CAE Systems and CAE Interface

In the process of designing and providing field support for recently completed nuclear units, Sargent & Lundy developed and evolved a number of interactive computer aided engineering (CAE) programs for the labor intense areas of design. These being

- Structure Steel Design and Load Monitoring
- Piping Design and Drafting
- Piping Analysis
- Pipe Support Design and Drafting
- HVAC and Cable Tray Support Design and Drafting
- Cable Routing and Information Management

The CAE programs are operated using single screen graphic terminals or micro computers where appropriate. These are located at construction sites and throughout the home office.

Prior to the development of the Plant Design System, the CAE systems worked through the CAD equipment to assemble design drawings. The drawings were prepared by computer programs which receive the results of design calculations carried out using the CAE systems and convert them into drawings by assembling symbols and standard design details from a library. These programs were subsequently developed into the interface between CAE and the plant model. An overview of these CAE systems and this interface follows.

The interface between the CAE programs and the plant model consists of two types of computer programs.

- Submodel assembly programs
- Analytical model assembly programs

The submodel assembly programs receive detailed descriptions of designs that were developed using the CAE systems. They convert those descriptions into 3D model overlays. The overlays are included in the main plant model and subsequently used for interference checking and the preparation of drawings. The submodel assembly programs fully automate the installation of structural steel, and piping components in the plant model. These components make up a majority of a plant model (Approximately 90%).

The analytical model assembly programs are used to convert the plant model overlays into analytical model input data for the CAE systems. These programs are used to move the arrangements and design loadings for structural steel framing systems from the plant model to the CAE systems which are used for their analysis and design. This feature dramatically reduces the cost of developing those analytical models and inputting them to the CAE systems.

Drafting Software

As the design develops, two pieces of software are used to prepare drawings.

- An Automated Drafting Program
- A set of workstation menus called Drawing Production Menus

To prepare a drawing, a designer selects an area of the plant, or a portion of a plant system whose design he wishes to illustrate on the drawing. He also selects the views of the design he wishes to use and the drawing type. Using this input the automated drafting program cuts an appropriate slice from the plant model, activates the overlays that are required to show the design and its background, scales them as necessary and sets them up in a drawing title block.

The designer then uses a CAD workstation fitted with a Drawing Production Menu for final preparation and plotting of the drawing. In the process of setting up the drawing, the program applies the drawing content and drafting standards established for the project. Pipe support, HVAC Duct and cable tray support drawings have been fully automated.

List System Interface Software

The List System Interface Software is used to construct interfaces between the plant model and project information management and/or construction planning software that is selected for use on a project. Examples of this software are:

- Cost estimating packages
- Material control packages
- Procurement list software
- Engineering data list software
- Configuration control software
- Construction planning & scheduling packages

The interface software collects lists of plant components and materials which these programs use as input. The lists can be passed to these programs via a text file. These lists can be sorted by plant area, drawing, specification, system or subsystem before they are transmitted. The lists are time and date stamped or keyed to a specific revision of a drawing.

3.2 Capabilities Under Development

A number of new features are being developed at this time. The primary tasks in progress are:

- Automated pipe routing and support layout tools
- Cable routing directly on the plant model
- Detailed architectural design software which uses the plant model as input

The existing software is continuously being refined to increase its flexibility and effectiveness.

3.3 Capabilities Planned for Future Development

Development work on the Plant Design System and the implementation of its individual features is being carried out in accordance with a long range plan which was developed in 1984. Several capabilities originally scheduled in that plan remain to be developed. The primary capabilities remaining are:

- Phase II of a modernization and expansion plan for the company's engineering data list system. The end result will be a comprehensive procurement list and bill of material handling system connected with the plant model.
- Software features which facilitate the 3D design and drawing preparation for underground work in the plant yard. While present software permits this work to be done cost effectively, the features increase its effectiveness in this area.
- Software features for general site development work, earthwork planning calculations and the development of detailed civil engineering drawings for a project.
- Interactive CAE tools for detailed HVAC duct work engineering and drafting
- Interactive CAE tools for the structural engineering of combustion air and gas ducts on Fossil Units.

Development work on these capabilities is presently being held until the opportunity to apply them arises.

3.4 Capabilities Being Researched

A number of new issues connected with computer models are being pursued by an internal committee which is charged with the management of CAD development. These include:

- The implementation of the next generation of workstations for CAD and CAE work.
- The implementation of computer networking for CAD and CAE
- The translation of CAD drawings, which include computer models, between CAD systems supplied by different vendors.

These issues will be discussed in detail in Section 6 of this report.

4.0 PRIMARY BENEFITS AT PRESENT

The primary benefits offered by computer modeling as it exists today are construction cost savings. The savings are those that result from the following:

- Design and drafting quality improvement
- Improvements in bid package accuracy which promote better cost control and planning.





