5 CONTAINMENT SYSTEM

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5.1 STRUCTURAL DESIGN

5.1.1 GENERAL DESCRIPTION OF CONTAINMENT STRUCTURE

The reactor containment is a fully continuous reinforced concrete structure in the shape of a cylinder with a shallow domed roof and a flat foundation slab. The cylindrical portion is prestressed by a post-tensioning system consisting of horizontal and vertical tendons. The dome has a three-way post-tensioning system. Hoop tendons are placed in three 240 degree systems using three buttresses as anchorages, with the tendons staggered so that half of the tendons at each buttress terminate at that buttress. The foundation slab is conventionally reinforced with high-strength reinforcing steel. A continuous access gallery is provided beneath the base slab for installation and inspection of vertical tendons. A welded steel liner is attached to the inside face of the concrete shell to insure a high degree of leaktightness. The base liner is installed on top of the structural slab and will be covered with concrete. The structure will provide biological shielding for both normal and accident situations.

The reactor containment will completely enclose the entire reactor and reactor coolant system and insure that an acceptable upper limit for leakage of radioactive materials to the environment would not be exceeded even if gross failure of the reactor coolant system were to occur. The approximate dimensions of the reactor containment are: inside diameter, 116 feet; inside height, 206 feet; vertical wall thickness, 3-3/4 feet; dome thickness, $3\frac{1}{4}$ feet; and the foundation slab, 9 feet. The building encloses the pressurized water reactor, steam generators, reactor coolant loops and portions of the auxiliary and engineered safeguards systems. The internal net free volume is 1,900,000 cubic feet.

Full advantage is being taken in the design of this Reactor Building of the experience gained in the review of similar designs with the AEC for the Florida Power and Light Company's Turkey Point Plant, Consumers Power Company's Palisades Plant, Wisconsin-Michigan Power Company's Point Beach Plant and Duke Power Company's Oconee Nuclear Station, as well as containment designs by others which meet the same functional requirements.

Representative details of the construction that will be used are shown in Figures 5-1, 5-2, 5-3 and 5-3A. 17

The detailed design of the containment structure has resulted in the following revisions to Figure 5-1:

(a) The outer diameter of base slab has been reduced from 132'3" to 128'4". 14

(b) The location of the tendon gallery has been moved towards the center.

(c) One row of vertical tendon has been used instead of two rows. The tendons have an inward curvature at the base slab. 14

(d) One-inch resilient material has been used under the bottom slab of the access gallery instead of 3-inch. Compressible material has been eliminated under the vertical walls.

The dome will be a stiffened, double-curved, freestanding dome.

5.1.2 BASIS FOR DESIGN LOADS

The reactor containment will be designed for all credible conditions of loading, including normal loads, loads during loss of coolant accident, test loads, and loads due to adverse environmental conditions. The following loadings will be considered:

(a) The loadings caused by the pressure and temperature transients of the loss of coolant accident.

(b) Structure dead load.

(c) Live loads.

(d) Earthquake load.

(e) Wind force and tornado loads.

(f) Uplift due to buoyant forces.

(g) External pressure load.

The two critical loading conditions are those caused by the loss of coolant accident resulting from failure of the reactor coolant system and those caused by an earthquake.

5.1.2.1 Loss of Coolant Accident Load

The minimum design pressure and temperature of the containment will be equal to the peak pressure and temperature occurring as the result of any rupture of the reactor coolant system up to and including the severance of a reactor coolant pipe.

The supports for the reactor coolant system will be designed to withstand the blowdown forces associated with the sudden severance of the reactor coolant piping so that the coincidental rupture of the steam system is not considered credible.

Transients resulting from the loss of coolant accident and other, lesser, accidents are presented in Section 14 and serve as the basis for a containment design pressure of 59 psig.

The temperature gradient through the wall during the loss of coolant accident is shown in Figure 5-4. The variation of temperature with time and the expansion of the liner plate will be considered in designing for the thermal stresses associated with the LOCA.

5.1.2.2 Structure Dead Load

Dead load will consist of the weight of the concrete wall, dome, base slab, and any internal concrete. Weights used for dead load calculations will be as follows:

(a)	Concrete	148 lb/ft^3
(b)	Steel Reinforcing	489 lb/ft^3, using nominal cross-sectional areas of reinforcing as defined in ASTM for bar sizes and nominal cross-sectional areas of prestressing
(c)	Steel Lining	489 lb/ft^3, using nominal cross-sectional area of lining.

5.1.2.3 Live Loads

Live loads will include snow loads on the roof of the containment dome. The roof load will be 20 pounds per horizontal square foot.

Equipment loads will be those specified on the drawings supplied by the manufacturers of the various pieces of equipment.

Live loads will be assumed for the design of internal slabs consistant with the intended use of the slabs.

5.1.2.4 Earthquake Loads

Earthquake loading is predicated upon a design earthquake at the site having a horizontal ground acceleration of 0.10g. In addition, a maximum hypothetical earthquake having a ground acceleration of 0.20 g will be used to check the design to ensure no loss of functions. The seismic design spectrum curves are given in Appendix 5A. A vertical component two-thirds of the magnitude of the horizontal component will be applied in the load equations simultaneously. A dynamic analysis will be used to arrive at equivalent static loads for design.

5.1.2.5 Wind and Tornado Loads

Wind loading is 80 mph basic wind at 30 feet above grade, based on figure 1 (b) of ASCE Paper 3269, "Wind Forces on Structures." This wind load will not be considered for the containment design.

There are few reliable measurements of the pressure drop associated with a tornado funnel. The greatest drop recorded was equivalent to a bursting pressure of approximately 3 psi. This measurement, however, is highly questionable and is not regarded as authoritative. The greatest reliably measured pressure drops have been on the order of 1.5 psi or less.

The maximum design pressure difference will be 3 psi. It is 100 per cent greater than the greatest pressure ever reliably measured. This value is thought to be very conservative.

Because of the complexity of the airflow in a tornado, it has not been possible to calculate the velocity or trajectory of missiles that would truly represent tornado conditions. For design purposes, it is assumed that objects of low cross-sectional density such as boards, metal siding, and similar items may be picked up and carried at the maximum wind velocity of 300 mph.

The behavior of heavier, oddly shaped objects such as an automobile is less predictable. The design values of 50 mph for a 4000 pound automobile lifted 25 feet in the air is felt to be representative of what would happen in a 300 mph wind as the automobile was lifted, tumbled along the ground, and ejected from the tornado funnel by centrifugal force. These missile velocities are consistent with reported behavior of such items in previous tornadoes.

The structure will be analyzed for tornado loading (not coincident with accident or earthquake) on the following basis:

(a) Differential bursting pressure between the inside and outside of the containment structure is assumed to be 3 pounds per square inch positive pressure.

(b) Lateral force on the containment structure will be assumed as the force caused by a tornado funnel having a peripheral tangential velocity of 300 mph and a forward progression of 40 mph. The applicable portions of wind design methods described in ASCE Paper 3269 will be used, particularly for shape factors. The provisions for gust factors and variation of wind velocity with height do not apply.

(c) Tornado driven missiles equivalent to an airborne 4 inch by 12 inch by 12 foot plank traveling end-on at 300 mph, or a 4000 pound automobile flying through the air at 50 mph and at not more than 25 feet above the ground, will be assumed.

A discussion of the probability of tornado occurrence is presented in Seetion 2.

Except for local crushing at the missile impact area, the allowable stresses to resist the effects of tornadoes will be 90 per cent of the yield of the reinforcing steel and 85 per cent of the ultimate strength of the concrete.

5.1.2.6 Uplift Due to Buoyant Forces

Uplift forces which are created by the displacement of ground water by the structure will be accounted for in the design of the structures.

5.1.2.7 External Pressure Load

External pressure loading with a differential of $2\frac{1}{2}$ pounds per square inch from outside to inside will be considered.

The external design pressure is equivalent to having a barometric pressure rise to 31 inches of mercury after the containment was sealed at 29 inches of mercury. Therefore, operation of purge valves will not be required due to barometric changes during normal operation.

The external design pressure is also adequate to permit the containment to be cooled to 50 F from an initial maximum operating condition of 110 F. Therefore, operation of purge valves will not be necessary during this shutdown condition. Vacuum breakers are not required.

5.1.3 CONSTRUCTION MATERIALS

Basically four materials will be used for the foundation and the containment structure. These are:

(a) Concrete

(b) Reinforcing steel

(c) Steel prestressing tendons

(d) Steel liner plate

Detailed specifications and working drawings for these materials and their installation will be of such scope as to assure that the quality of work will be commensurate with the necessary integrity of the containment structure.

Basic specifications for these materials include the following:

5.1.3.1 Concrete

All concrete work will be in accordance with ACI 318-63, "Building Code Requirements for Reinforced Concrete" and to ACI-301, "Specifications for Structural Concrete for Buildings." Concrete will be a dense, durable mixture of sound coarse aggregate, fine aggregate, cement, and water. Admixtures will be added to improve the quality and workability of the fluid concrete during placement and to retard the set of the concrete. Maximum practical size aggregate, water reducing additives, and a low slump of two to three inches will be used to minimize shrinkage and creep. Aggregates will conform to "Standard Specifications for Concrete Aggregate" ASTM Designation C33. Fine aggregate will consist of sharp, hard, strong, and durable sand, free from adherent coatings, clay loam, alkali, organic material, or other deleterious substances.

Acceptability of aggregates will be based on the following ASTM Tests. These tests will be performed by a qualified commercial testing laboratory, and results submitted (1) to the owner, and (2) the constructor and his Quality Assurance Engineer.

Test	ASTM	
L. A. Rattler	C-131	
Clay Lumps Natural Aggregate	C-142	
Material Finer No. 200 Sieve	C-117	
Mortar Making Properties	C-87	
Organic Impurities	C-40	
Potential Reactivity (Chemical)	C-289	
Potential Reactivity (Mortar Bar)	C-227	(if necessary after performing C-289)
Sieve Analysis	C-136	
Soundness	C-88	
Specific Gravity and Absorption	C-127	
Specific Gravity and Absorption	C-128	
Petrographic	C-295	

Cement will be Type II low alkali cement as specified in "Standard Specifications for Portland Cement" ASTM Designation C150 and will be tested to comply with ASTM C-114.

Water for mixing concrete will be clean and free from any deleterious amounts of acid, alkali, salts, oil, sediment, or organic matter.

A water-reducing agent will be employed to reduce shrinkage and creep of concrete. Admixtures containing chlorides will not be used. The following types of agents willbe tested with the concrete materials selected for the containment structure:

Pozzolith No. 8

Pozzolith 100 R

Plastiment

Placewell LS

The agent selected will be the one providing the smallest shrinkage as determined by ASTM C-494, Type "D" Specifications for Chemical Admixtures for Concrete.

Concrete mixes will be designed in accordance with ACI 613 using materials qualified and accepted for this work. Only mixes meeting the design requirements specified for containment structure concrete will be used. Trial mixes will be tested in accordance with applicable ASTM Codes as indicated below:

Test	ASTM
Making and Curing Cylinder in Laboratory	C-192
Air Content	C-231
Slump	C-143
Bleeding	C-232
Compressive Strength Tests	C-39

Eight cylinders will be cast from each design mix for two tests on each of the following days: 3, 7, 28 and 90. The concrete in the containment base slab
will have a design compressive strength of 4,000 psi at 90 days instead of 17
28 days to improve shrinkage characteristics. The concrete in the containment wall and dome will have a design compressive strength of 5,500 psi at 90 days.

Test cylinders will be cast from the mix proportions selected for construction and the following concrete properties will be determined:

Uniaxial creep.

Modulus of elasticity and Poisson's ratio.

Autogenous shrinkage.

Thermal diffusivity.

Thermal coefficient of expansion.

Compressive strength.

The concrete technologist will participate in the preparation of concrete specifications, placement procedures, and field quality control and testing programs. He will make periodic site visits during construction.

The independent laboratory will test the concrete mixes. To maintain the quality of the mix used in the structure, the workability and other characteristics of the mixes will be ascertained before placement. A small concrete-control laboratory will be set up close to the batch plant. A batch plant inspector will be assigned and testing as shown below will be performed. Field control will be in accordance with the ACI Manual of Concrete Inspection as reported by Committee 611.

Aggregate testing will be carried out as follows:

(a) Sand Sample for Gradation (ASTM C-33 Fine Agg.)

(b) Organic Test on Sand (ASTM C-40)

(c) Three-Fourths inch Sample for Gradation (ASTM C-33 Size No. 67)

(d) One 1/2-inch Sample for Gradation (ASTM C-33 Size No. 4)

(e) Check for proportion of Glat and Elongated Particles.

Concrete samples will be taken from mix according to ASTM C-172, "Sampling Fresh Concrete." From these samples, cylinders for compression testing will be made. They will be stripped within 24 hours after casting and marked and stored in the curing room. These cylinders will be made in accordance with ASTM C-31, "Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field."

Slump, air content, and temperature measurements will be taken when cylinders are cast. Slump tests will be performed in accordance with ASTM C-143, "Standard Method of Test for Slump of Portland Cement Concrete." Air content tests will be performed in accordance with ASTM C-231, "Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method." Compressive strength tests will be made in accordance with ASTM C-39, "Method of Test for Compressive Strength of Molded Concrete Cylinders."

Evaluation of compression tests will be in accordance with ACI 214-65.

5.1.3.2 Reinforcing Steel

Reinforcing steel in the base slab of the containment structure and around penetrations in the cylinder will be deformed billet steel bars conforming to ASTM Designation 615 Grade 60. Deformed billet steel bars conforming to ASTM 615 Grade 60 will be used in the cylinder wall and the domed roof to control shrinkage and tensile cracks. 17

Mill test results will be obtained from the reinforcing steel supplier for each heat of steel to show proof that the reinforcing steel has the specified composition, strength, and ductility. Splices in reinforcing bar Sizes No. 11 and smaller will be lapped in accordance with ACI 318-63, and for bars larger than No. 11, Cadweld splices will be used.

Welding of reinforcing steel, if required, will be performed by qualified welders in accordance with AWS D12.1, "Recommended Practice for Welding Reinforcing Steel, Metal Inserts, and Connections in Reinforced Concrete Construction."

5.1.3.3 Steel Prestressing Tendons

This preliminary review is based on the tendons with the characteristics and test results documented in Appendix J. It is not intended, however, that this be the last design review of either tendon performance requirements for this plant or the characteristics of available prestressing systems. However, should future design reviews show the desirability for using other prestressing systems, the capabilities of that system will be given in a supplement to the PSAR. Further, tests will be made of the prestressing system using concrete as specified for this structure and detailed information will be submitted as it becomes available.

(a) Tendon Sizes.

One performance requirement is that tendons with proven integrity characteristics, be available in a range of strength capabilities. With this requirement satisfied, the basic tendon for the design can be chosen as the one with the largest strength compatible with the containment being designed and, should the need arise, smaller ones could be used if needed in special limited space situations.

This portion of the review examined the tendon compatibility with the structure size for the tendons listed in Appendix J. It was found that the range of tendon strengths are compatible with this structure, and the 170 wire to 180 wire strength capabilities are preferrable for this structure. Regardless of the tendon size selected, the following items will remain unchanged:

(1) The corrosion protection system.

(2) The structural test instrumentation system.

(3) The number of tendons subjected to the surveillance program.

(4) The procedure for development and demonstration of field equipment.

(5) The construction procedure of placing and stressing of tendons.

(6) The size of the tendon access gallery appears to be controlled by buttonheading space requirements. Any increase in size to accommodate the jack will be nominal, probably not to exceed one foot in width or height.

In the review, the following was considered:

(1) The nominal vertical center-to-center spacing of 90-wire circumferential tendons is less than 10 inches, while for the 170 to 184 wire tendon the spacing is less than 20 inches. Both nominal spacings are less than one-half of the 45-inch cylinder wall thickness and result in reasonably uniform prestressing force application to the cylinder. However, the 20-inch spacing results in a greater ease for concrete placement and lesser embedment congestion near penetrations. Further, the redundancy of the wires is not reduced by the use of the 170 to 184 wire tendons as compared to the 90-wire tendons since the total number of wires remains the same. As an illustration of the redundancy of tendons, three adjacent tendons could be removed without significantly affecting the structural integrity because of the stiffness of the shell between the remaining tendons.

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(2) The average bearing pressure against the tendon sheaths for this structure is approximately one-fourth that of that for the Ft. St. Vrain PCRV for which the 170-wire tendon was developed. This results from the differences of cylinder radius between the two structures. The average bearing pressure for this structure is one-fifth or less of that which occurred during tests of the 170-wire tendon with 180 degree curves with 10 foot radius. Even at the penetrations, the smallest radius of curvature for this containment, the bearing pressure under the sheath is smaller than that for the 10-foot radius tension test of the 170-wire tendon. Regardless of size of the individual tendon, the pattern of membrane stresses, bending stresses, and radial compression or tension stresses at the various penetrations are not expected to be materially affected due to the small ratios of the tendon spacing to wall thickness and the shell stiffness as cited above. Such aspects will be considered during the detailed design of the structure.

(3) The 90-wire tendon end anchors and bearing plates are slightly smaller than for the 170 to 184-wire tendon. Thus, the anchorage space for the 170 to 184-wire tendon on the buttresses, for example, would be sufficient for the 90-wire tendon with both tendon sizes resulting in bearing plate average concrete contact pressures within that allowed by ACI 318-63.

(4) Prestressing tendon system development for large tendons has been done primarily in support of PCRV work in France, England and the United States. For example, the Dungeness B nuclear power plant in England is using a system with about 160 7 mm (0.276 in.) diameter wires, which corresponds in force capacity to a tendon with 180 or more 0.25" diameter wires. The jack for this size tendon has been extensively tested as a part of the system development. The 170 wire tendon described in Appendix J has been developed for the PCRV for the Ft. St. Vrain plant and stressing equipment has provided 1000 cycles of load application, more than sufficient to stress all tendons on this containment, in one test series alone. Tendon utilization in construction is almost identical for all tendons described in Appendix J.

(b) End Anchors, Bearing Plates and Prestressing Steel.

The basic performance requirements for the end anchors are stated qualitatively by the Seismic Committee of the Prestressed Concrete Institute and published in their Journal of June, 1966 as follows:

" All anchors of unbonded tendons should develop at least 100% of the guaranteed ultimate strength of the tendon. The anchorage gripping should function in such a way that no harmful notching would occur on the tendon. Any such anchorage system used in earthquake areas must be capable of maintaining the prestressing force under sustained and fluctuating load and the effect of shock. Anchors should also possess adequate reserve strength to withstand any overstress to which they may be subjected during the most severe probable earthquake. Particular care should be directed to accurate positioning and alignment of end anchors. " 5

More quantitative performance requirements have been developed for this plant which include the requirements of the above quotation and are the basis for the comparisons with the tendon capabilities from Appendix J in this review. It is found that those tendon capabilities listed in Appendix A can satisfy the appropriate portions of the performance requirements. Confirmatory testing and completion of tests in progress will be required for any of the tendons used for this structure.

It is a performance requirement that the end anchors used develop 100% of the guaranteed minimum ultimate strength of the prestressing steel without permanent deformation which renders the end anchor unusable or results in significant slip of the prestressing steel relative to the end anchor. The test results in Appendix J give evidence that those end anchors can meet the performance requirement. For example, the button heads can develop the prestressing steel guaranteed minimum ultimate strength without failure or slip relative to the end anchor. Both the 90 and 170 wire end anchors at least met the deformation requirement.

Tendons having more than 90 and less than 170 wires are possible without undue future testing if only by using the 170 wire tendon end anchor with a fewer number of wires. Test results have not been provided with some of the tendon sizes listed but it appears that those tests needed would be confirmatory in nature, as is intended in any event.

Another performance requirement is that the end anchor be capable of maintaining integrity for 500 cycles of loads corresponding to an average axial stress variation between 0.7 and 0.75 f's at a repetition rate of one cycle in 0.1 seconds. This requirement of course sets minimum acceptable limits on fatigue effects due to notching by the end anchor and tendon performance in response to earthquake loads. The number of cycles was set by increasing to 500 from the 100 predicted. The stress variation was increased from a conservatively predicted 0.6 to 0.64 f's to the 0.7 to 0.75 f's. Further the number of cycles caused by earthquake loads is predicted as only 30 of the total of 100 and by using all those strong ground motions which exceed 1/2 of the peak ground motion for the earthquake. The predicted stress variation due to earthquake motion alone is predicted as being 10% of the total of 0.04 f's stress variation predicted. The 0.04 f's predicted stress variation in turn results from combinations of earthquake, wind and accident loadings. Analyses made during the investigation included con-
5 sideration of tendon excitation parallel and perpendicular to the tendon axis.

A comparison between performance requirements and tendon capabilities from Appendix J gives evidence that the end anchors can satisfy the performance requirements.

The bearing plate is included as a part of the prestressing system and at it's interface with the concrete there is one of the greater interactions with the structure. The average contact pressure between bearing plate and concrete is limited to those permissible by ACI-318-63 for the tendons listed in Appendix J. The maximum contact pressure exceeds the average at locations nearest where the end anchor contacts the bearing plate as is shown by tests in Appendix J. This results from a bending of the bearing plate. It is possible that the bending stress near the end anchor will reach yield since concrete differential creep will increase the bending of the plate from its initially loaded condition, and the largest bending stress in the bearing plate results from a yield moment for the plate. Although a difficult analytical problem, because of the inelastic nature of the materials and difficult to define boundary conditions, long experience and testing has shown that concrete reinforcing as used under column base plates and prestressing bearing plates, coupled with the bearing and base plate design approach, result in bearing and base plates that have not failed even though exposed to subzero temperatures in heavy industrial structures such as outdoor steel mill crane columns, power plant coal crusher structures and trestle columns. Also, communications with the chief engineer of an established prestressing

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company indicates that they have not experienced bearing plate failures when stressing tendons to 0.8 f's, the highest load planned to be imposed on the bearing plates, even while stressing in subzero weather. Since the bearing plates are designed and tested to proven standards; are not subjected to large cycling loads or repeated impact loads; and are used in a climate less extreme than those for which the standards have been proven, it appears that they can satisfy the performance requirments.

In determining the appropriateness of applying NDT requirements, consideration has been given to:

(1) The proven history, as cited above, for the use of both structural steel and post-tensioning systems under similar or worse environments to that of this application.

(2) The A-36 or similar steel used for the bearing plates is in general a better quality steel than the A-7 that has the proven history cited above.

(3) The fact that neither the AISC Structural Steel Code nor the ACI-318-63 has ever seen fit to incorporate such requirements in those codes.

The conclusion that is drawn from the above discussion is that brittle fracture is not a problem for post-tensioning bearing plates. 5

The prestressing steel specified in the information in Appendix J is produced to recognized quality standards. The test results in Appendix J show that the steel can meet its quality standards and the performance requirements. Further tests and usage for cold temperature service has shown that the steel can successfully perform in the comparatively good environment provided by this design.

(c) Corrosion Protection

Another tendon performance requirement is that suitable atmospheric corrosion protection be maintained for all exposure environments from the point of tendon manufacture to an including the installed locations. The corrosion protection to be furnished provides assurance that the tendon integrity will not be reduced, by atmospheric corrosion, below that needed.

Prior to shipment, the wire will be coated with a thin film of petrolatum containing rust inhibitors, such as Dearborn Chemical Company 490 R. The interior of the ungalvanized, spiral-wrapped semi-rigid corrugated sheathing will also be coated with the same material during manufacture. After tendon insertion in the sheathing and tensioning, the sheathing will be pumped full of a corrosion protection material which is at about 80 to 90 F and consists of a modified, thixotropic, refined petroleum oil base product such as Dearborn Chemical Company No -Ox-Id CM Casing Filler. The tendon and end anchors will be surrounded by the No-Ox-Id which in turn will be encapsulated by the sheathing and gasketed end caps which are sealed against the tendon bearing plate.

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No-Ox-Id contains no solvents but does contain certain proprietary chemical additives which inhibit corrosion of steel. It is thixotropic and is pumped in an essentially liquid form. On filling the sheaths and end caps it displaces air and water vapor before solidifying to a soft gel which surrounds the end anchors and the button heads.

Testing of No-Ox-Id has indicated that there are no significant amounts of chlorides, sulfides or nitrates. However, to verify that none are
5 present in the material used, samples will be taken from 10 per cent of each drum shipment with at least one sample per factory batch. The samples will be analyzed by an independent laboratory as follows:

Water soluble chloride (Cl) will be determined by ASTM Method D512-62T with a limit of accuracy of 0.5 ppm.

Water soluble nitrates (NO_3) will be determined by ASTM Method D992-52 with a limit of accuracy of 0.01 mg per liter. Water soluble sulfides (S) will be determined by ASTM Method D-1255 with a limit of accuracy of 1 ppm.

No significant trace of the impurities will be allowed. Further, the Dearborn Chemical Company has stability data going back 18 years which indicates that the material will not deteriorate during the 40 years life of the plant. The chemical composition of the material, being about 98% petrolatum jelly, indicates that it would possess the normal stability of liner hydrocarbons for the site temperature ranges.

5.1.3.4 Steel Liner Plates

The containment structure will be lined with welded steel plate conforming
to ASTM A-516, Grade 60, to insure low leakage. This steel has a minimum 14
yield strength of 32,000 psi and a minimum elongation in an 8-inch specimen
of 21 percent.

The design, construction, inspection and testing of the liner plate, which
acts as a leaktight membrane and is not a pressure vessel, is not covered
by any recognized code or specification. However, the liner plate will be 14
supplied to the requirements of ASTM A-516, Grade 60 "Carbon Steel Plates
for Pressure Vessels for Moderate and Lower Temperature Service" and ASTM
A-20, "Specification for General Requirements for Delivery of Rolled Steel
Plates of Flange and Firebox Qualities."

All components of the liner which must resist the full design pressure, such as penetrations, are selected to meet the requirements of Paragraph N-1211 of Section III, Nuclear Vessels, of the ASME Code. ASTM A-516 Grade 60 or 70 made to ASTM A-300 is typical of a steel which meets these requirements and will be used as a plate material for penetrations. The 516 material will satisfy NDT requirement of the ASME Boiler and Pressure Vessel Code Section III, Subsection N-330 and N-331. This material has excellent weldability characteristics and as much ductibility as is obtainable in any commercially available pressure vessel quality steel.

In accordance with ASME Code Case 1347, allowable stresses for A-516 Grade 60 and 70 are the same as those permitted for A-201 Grade B and A-212 Grade B, respectively.

The ASTM A-516 Grade 60 material was chosen on the basis that it has suffi-
cient strength as well as ductibility to resist the expected stresses from
design criteria loading and at the same time preserve the required leaktight- 14
ness of the containment. Its choice also allows the entire liner plate, in-
cluding penetrations, to be made out of the same material.

The liner plate is designed to function only as a leaktight membrane. It is not designed to resist the tension stresses from internal applied pressure which may result from any credible accident condition. The structural integrity of the containment is maintained by the prestressed, post-tensioned concrete. Since the principal applied stress to the liner plate membrane, from shrinkage and creep of the concrete, will be in compression and no significant applied tension stresses are expected from internal pressure loading, there is no need to apply special nil ductibility transition temperature criteria to the liner plate material. With the anticipated prestress level, this is true even for the condition created by 40° minimum containment spray impinging on the liner plate. On the other hand, all material for containment parts which must resist applied internal pressure stresses, such as penetrations, shall be impact tested in accordance with the requirements of Paragraph N-1211 of Section III, Nuclear Vessels, of the ASME Code.

A-516 steel is readily weldable by all of the commercially available arc 14
and gas welding processes.

A fundamental requirement for fabrication and erection of the liner plate is thatall welding procedures and welding operators be qualified by tests as specified in Section IX of the ASME Code. This Code requires testing of welded transverse root and face bend samples in order to verify adequate weld metal ductility. Specifically, Section IX of the Code requires that transverse root and face bend samples be capable of being bent cold 180 degrees to an inside radius equal to twice the thickness of the test sample. Satisfactory completion of these bend tests is accepted as adequate evidence of required weld metal and plate material compatibility.

Mill tests results will be obtained for the liner plate material. The plate will be visually checked for thickness, possible laminations and pitting. All surfaces of the liner plate in contact with concrete will not be coated. All exposed surfaces will receive sandblasting and will be treated with an inorganic zinc primer similar to Dimecote 5. Areas damaged by welding will be repaired to the above standards. Areas within reach of platforms and stairways will be treated with an epoxy gloss similar to Amercoat #66 to provide a surface which can be decontaminated. 17

5.1.3.5 Quality Assurance Program

Quality of both materials and construction of the containment structure will be assured by a continuous program of quality control and inspection by Bechtel Corporation, the Engineer-Constructor, and by the Applicants.

Qualified field supervisory personnel and inspectors will be assigned to the project to carry out the work in accordance with the specifications and drawings. Project design personnel will make frequent visits to the job site to coordinate the construction with the design. Inspectors will be experienced and thoroughly familiar with the type of work to be inspected, particularly in the field of prestressed concrete. The inspector will be given complete access to the work and will perform such examinations as are necessary to satisfy himself that the standards set forth in the applicable codes and specifications have been met.

Where material does not satisfy the standards, he will have the authority to stop work until the necessary alterations are made.

5.1.4 CONTAINMENT STRUCTURE DESIGN CRITERIA

Safety of the structure under extraordinary circumstances and performance of the containment structure at various loading stages are the main considerations in establishing the structural design criteria.

The two basic criteria are:

(a) The integrity of the liner plate shall be guaranteed under all loading conditions and,

(b) The structure shall have a low-strain elastic response such that its behaviour will be predictable under all design loadings.

The strength of the containment structure at working stress and over-all yielding will be compared to various loading combinations to insure safety. The containment structure will be examined with respect to strength, the nature and the amount of cracking, the magnitude of deformation, and the extent of corrosion to insure proper performance. The structure will be designed to meet the performance and strength requirements under the following conditions:

(a) Prior to prestressing

(b) At transfer of prestress

(c) Under sustained prestress

(d) At design loads

(e) At yield loads

Deviations in allowable stresses for the design loading conditions in the working stress method will be permitted if the yield capacity criteria are fully satisfied. All design will be in accordance with the ACI Code 318-63 unless otherwise stated herein.

No special design bases are required for the design and checking of the base slab. It will act primarily in bending rather than membrane stress. This condition is covered by the ACI Code 318-63. The loads and stresses in the cylinder and dome will be determined as described below.

5.1.4.1 Design Method

The structure will be analyzed using a finite element computer program for individual loading cases of dead load, live load, temperature and pressure. The computer output will include direct stresses, shear stresses, principal stresses, and displacement of each nodal point.

Stress plots which show the total stresses from appropriate combinations of loading cases will be made and areas of high stress will be identified. The modulus of elasticity will be corrected to account for the nonliner stress-strain relationship at high compression, if necessary. Stresses then will be recomputed if there are sufficient areas which require attention.

In order to consider creep deformations, the modulus of elasticity of concrete 5
under sustained loads such as dead load and prestress will be differentiated
from the modulus of elasticity of concrete under instantaneous loads such as
internal pressure and earthquake loads.

The forces and shears will be added over the cross-section and the total moment, axial force, and shear will be determined. From these values, the straight-line elastic stresses will be computed and compared to the allowable values. The ACI design methods and allowable stresses will be used for concrete and prestressed and non-prestressed reinforcing steel except as noted in these criteria.

5.1.4.2 Loads Prior to Prestressing

Under this condition the structure will be designed as a conventionally reinforced concrete structure. It will be designed for dead load, live loads (including construction loads), and a reduced wind load. Allowable stresses will be according to ACI 318-63 Code.

5.1.4.3 Loads at Transfer of Prestress

The containment structure will be checked for prestress loads and the stresses
compared with those allowed by the ACI 318-63 Code with the following exceptions:
ACI 318-63, Section 26, allows concrete stress of 0.60 f'_{ci} at initial transfer. 5
In order to limit creep deformation, the membrane compression stress will be
limited to 0.30 f'_{ci} whereas in combination with flexural compression the maximum 5
allowable stress will be limited to 0.60 f'_{ci} per the ACI 318-63.

For local stress concentrations with nonliner stress distribution as predicted
by the finite element analysis, o.75 f'_{ci} will be permitted when local rein- 5
forcing is included to distribute and control these localized strains. These
high local stresses are present in every structure but they are seldom identi-
fied because of simplifications made in design analysis. These high stresses
are allowed because they occur in a very small percentage of the cross-
section, are confined by material at lower stress and would have to be con-
siderably greater than the values allowed before significant local plastic
yielding would result. Bonded reinforcing will be added to distribute and 5
control these local strains.

Membrane tension and flexural tension will be permitted provided they do not 5
jeoperdize the integrity of liner plate. Membrane tension will be permitted to
occur during the post tensioning sequence but will be limited to occur during
the post tensioning sequence but will be limited to 1.0 f'_{ci}. When there is
flexural tension, but no membrane tension, the section will be designed in accord-
ance with section 2605(a) of the ACI Code. The stress in the liner plate due
to combined membrane tension and flexural tension, will be limited to 0.5 fy.
Shear criteria will be in accordance with the ACI 318-63 Code, Chapter 26 as
modified by the equations shown in paragraph 5.1.4.6, using a load factor of
1.5 for shear loads.

5.1.4.4 Loads Under Sustained Prestress

The conditions for design and the allowable stresses for this case will be the same as above except that the allowable tensile stress in non-prestressed reinforcing will be limited to 0.5 fy. The ACI limits the concrete compression to 0.45 f'_c for sustained prestress load. Values of 0.30 f'_c and 0.60 f'_c will be used as described above, which bracket the ACI allowable value. However, with these same limits for concrete stress at transfer of prestress, the stresses under sustained load will be reduced due to creep.

5.1.4.5 At Design Loads

This loading case is the basic "working stress" design. The containment vessel will be designed for the following specific loading cases:

(a) $D+F+L+T_O$

(b) $D+F+L+P+T_A$

Where:

D = Dead Load

L = Appropriate Live Load

F = Appropriate Prestressing Load

P = Pressure Load (varies with time from design pressure to no pressure)

T_O= Thermal loads due to operating temperature.

T_A= Thermal Loads Based on a Temperature Corresponding to a Pressure P (See figure 5-4)

Sufficient prestressing will be provided in the cylindrical and dome portions of the vessel to eliminate membrane tensile stress (tensile stress across the entire wall thickness) under design loads. Flexural tensile cracking will be permitted but will be controlled by bonded unprestressed reinforcing steel.

Under the design loads the same performance limits stated in 5.1.4.3 will apply with the following exceptions:

(a) If the net membrane compression is below 100 psi it will be neglected and a cracked section will be assumed in the computation of flexural non-prestressed reinforcing steel. Flexural tensile stresses in non-prestressed reinforcing of 0.5 fy will be allowed.

5 (b) When the maximum flexural stress does not exceed 6 $\sqrt{f'_c}$ and the extent of the tension zone is no more than 1/3 the depth of the section, non-prestressed reinforcing steel will be provided to carry the entire tension in the tension block. Otherwise, the non-prestressed reinforcing steel will be designed assuming a cracked section. When the bending moment tension is additive to the thermal tension, the allowable tensile
5 stress in the bonded reinforcing steel will be 0.5 fy minus the stress in reinforcing due to the thermal gradient as determined in accordance with the method of ACI-505.

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(c) The problem of shear and diagonal tension in a prestressed concrete structure should be considered in two parts: membrane principal tension and flexural principal tension. Since sufficient prestressing is used to eliminate membrane tensile stress membrane principal tension is not critical at design loads. Membrane principal tension due to combined membrane tension and membrane shear is considered under 5.1.4.6.

Flexural principal tension is the tension associated with bending in planes perpendicular to the surface of the shell and shear stress normal to the shell (radial shear stress). The present ACI 318-63 provisions of chapter 26 for shear are adequate for the design purposes with proper modifications as discussed under 5.1.4.6, using a load factor of 1.5 for shear loads. 5

Crack control in the concrete will be accomplished by adhearing to the ACI-ASCE Code Committee standards for the use of reinforcing steel. These criteria are based upon a recommendation of the Prestressed Concrete Institure and are as follows:

0.25 per cent reinforcing shall be provided at the tension face for small members

0.20 per cent for medium size members

0.15 per cent for large members

0.15 per cent mild steel reinforcing will be provided on the exterior faces of the wall and dome for proper crack control.

The liner plate is attached on the inside faces of the wall and dome. Since there is no tensile stress due to temperature on the inside faces, mild steel reinforcing is not necessary at the inside faces.

5.1.4.6 Loads Necessary to Cause Structural Yielding

The vessel will be checked for the factored loads and load combinations given below, and compared with the yield strength of the structure.

The load factors are the ratio by which loads will be multiplied for design purposes to assure that the load/deformation behavior of the structure is one of elastic, low-strain behavior. The load factor approach is being used in this design as a means of making a rational evaluation of the isolated factors which must be considered in assuring an adequate safety margin for the structure. This approach permits the designer to place the greatest conservatism on those loads most subject to variation and which most directly control the overall safety of the structure. It also places minimum emphasis on the fixed gravity loads and maximum emphasis on accident and earthquake or wind loads.

The final design of the containment structure satisfies the following load combination and factors;

(a) $Y = 1/\phi \quad (1.05D+1.5P+1.0T_A+1.0F)$

(b) $Y = 1/\phi \quad (1.05D+1.25P+1.0T_A+1.25H+1.25E+1.0F)$

(c) $Y = 1/\phi \quad (1.05D+1.25H+1.0R+1.0F+1.25E+1.0T_o)$

(d) $Y = 1/\phi \quad (1.05D+1.0F+1.25H+1.25W+T_o)$

5 (e) $Y = 1/\phi \quad (1.0D+1.0P+1.0T_A+1.0H+1.0E'+1.0F)$

(f) $Y = 1/\phi \quad (1.0D+1.0H+1.0R+1.0E'+1.0F+1.0T_o)$

Where Y = required yield strength of the structure as defined below.

ϕ = yield capacity reduction factor (defined in Section 5.1.4.7)

D = dead loads of structures and equipment plus any other permanent loading contributing stress, such as hydrostatic or soil. In addition, a portion of the live load is added when it includes items such as piping, cable and trays suspended from floors. An allowance is made for future additional permanent loads.

P = design accident pressure load

F = Effective prestress loads

R = Force or pressure on structure due to rupture of any one pipe

H = Force on structure due to thermal expansion of pipes due to design conditions

T_O = thermal loads due to the temperature gradient through wall during operating conditions

T_A = thermal loads due to the temperature gradient through the wall and expansion of the liner. It is based on a temperature corresponding to the factored design accident pressure.

E = design earthquake load

E' = maximum earthquake load

W = Tornado load

Equation (a) assures that the containment will have the capacity to withstand pressure loadings at least 50 per cent greater than those calculated for the postulated loss-of-coolant accident alone.

Equation (b) assures that the containment will have the capacity to withstand loadings at least 25 per cent greater than those calculated for the postulated loss-of-coolant accident with a coincident design earthquake or wind.

Equation (c) assures that the containment will have the capacity to withstand earthquake loadings 25 per cent greater than those calculated for the design earthquake coincident with rupture of any attached piping due to that earthquake.

Equation (d) assures that, the containment will have the capacity to withstand tornado loading 25% greater, than the design tornado.

Equations (e) and (f) assure that the containment will have the capacity to withstand either the postulated loss-of-coolant accident or the rupture of any attached piping coincident with the maximum hypothetical earthquake.

The load combinations, considering load factors given above, will be less than the yield strength of the structure. The yield strength of the structure is defined as the upper limit of elastic behavior of the effective load carrying structural materials. For steels (both prestress and non-prestress) this limit is taken to be the guaranteed minimum yield given in the appropriate ASTM specification. For concrete, it is the ultimate values of shear (as a measure of diagonal tension) and bond per ACI 318-63 and the 28 day ultimate compressive strength for concrete in flexure (f'_c). The ultimate strength assumptions of the ACI Code for concrete beams in flexure will not be allowed; that is, the concrete stress will not be allowed to go beyond yield and redistribute at a strain of 3 to 4 times that which causes yielding.

The maximum strain due to secondary moments, membrane loads and local loads exclusive of thermal loads will be limited to that corresponding to the ultimate stress divided by the modulus of elasticity (f'_c/E_c) and a straight-line distribution from there to the neutral axis assumed. For the above loads combined with thermal loads the peak strain will be limited to 0.003 inch/inch. For concrete membrane compression, the yield strength will be assumed to be 0.85 f'_c to allow for local irregularities, in accordance with the ACI approach. The reinforcing steel forming part of the load carrying system will be allowed to go to, but not exceed, yield as is allowed for ACI ultimate strength design.

A further definition of yielding is the deformation of the structure which will not cause strains in the steel liner plate to exceed 0.005 in/in. The yielding of non-prestress reinforcing steel will be allowed, either in tension or compression, if the above restrictions are not violated. Yielding of the prestress tendons will not be allowed under any circumstances.

Principal concrete tension due to combined membrane tension and membrane shear, excluding flexural tension due to bending moments or thermal gradients, will be limited to $3\sqrt{f'_c}$. Principal concrete tension due to combined membrane tension, membrane shear, and flexural tension due to bending moments or thermal gradients will be limited to $6\sqrt{f'_c}$. When the principal concrete tension exceeds the limit of $6\sqrt{f'_c}$, bonded reinforcing steel will be provided in the following manner:

(a) <u>Thermal flexural tension</u>- Bonded reinforcing steel will be provided in accordance with the methods of ACI-505. The minimum area of steel provided will be 0.15 per cent in each direction.

(b) <u>Bending moment tension</u> - Sufficient bonded reinforcing steel will be provided to resist the moment on the basis of cracked section theory using the yield stresses stated above with the following exception: When the bending moment tension is additive to the thermal tension, the allowable tensile stress in the reinforcing steel will be fy minus the stress in reinforcing due to the thermal gradient as determined in accordance with the methods of ACI-505.

Shear stress limits and shear reinforcing for radial shear will be in accordance with chapter 26 of ACI 318-63 with the following exceptions:

Formula 26-12 of the code shall be replaced by 5

$$V_{ci} = K\, b'd\sqrt{f'_c} + M_{cr}\left(\frac{V}{M'}\right) + V_i$$

Where

$$K = \left[1.75 - \frac{0.036}{np'} + 4.0\, np'\right]$$

but not less than 0.6 for $p' \geqslant 0.003$.

For $p' < 0.003$, the value of K shall be zero.

$$M_{cr} = \frac{I}{Y}\left[6\sqrt{f'_c} + f_{pe} + f_n + f_i\right]$$

f_{pe} = Compressive stress in concrete due to prestress applied normal to the corss-section after all losses (including the stress due to any secondary moment) at the extreme fiber of the section at which tension stresses are caused by live loads.

f_n = Stress due to axial applied loads, (f_n shall be negative for tension stress and positive for compression stress).

f_i = Stress due to initial loads at the extreme fiber of a section at which tension stress are caused by applied loads. (including the stress due to any secondary moment. f_i shall be negative for tension stress and positive for compression stress).

$$n = \frac{505}{\sqrt{f'_c}}$$

$$p' = \frac{As'}{bd}$$

V = Shear at the section under consideration due to the applied loads.

M' = Moment at a distance d/2 from the section under consideration, measured in the direction of decreasing moment, due to applied loads.

V_i = Shear due to initial loads (positive when initial shear is in the same direction as the shear due to applied loads.)

Lower limit placed by ACI-318-63 on V_{ci} as $1.7\, b'd\sqrt{fc'}$ will not be applied.

Formula 26-13 of the code shall be replaced by 5

$$V_{cw} = 3.5\, b'd \sqrt{fc'} \left[1 + \frac{f_{pc} + f_n}{3.5 \sqrt{f'_c}} \right]^{1/2} \qquad (2)$$

The term f_n is as defined above. All other notations are in accordance with chapter 26, ACI-318-63.

(1) This formula is based on the recent tests and work done by Dr. A. H. Mattock of the University of Washington.

(2) This formula is based on the commentary for Proposal Redraft of Section 2610-ACI-318 by Dr. A. H. Mattock, dated December, 1962.

When the above mentioned equations will show that allowable shear in concrete is zero, radial horizontal shear ties will be provided to resist all the calculated shear. 5

5.1.4.7 <u>Yield Capacity Reduction Factors</u>

The yield capacity of all load carrying structural elements will be reduced by a yield capacity reduction factor (ϕ) as given below. The justification for these numerical values is given in Appendix 5-E. This factor will provide for "the possibility that small adverse variations in material strengths, workmanship, dimensions, control and degree of supervision while individually

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within required tolerances and the limits of good practice, occasionally may combine to result in undercapacity" (refer to footnote on page 66 of ACI 318-63 Code.)

Yield Capacity Reduction Factors:

ϕ = 0.90 for concrete in flexure

ϕ = 0.85 for tension shear bond and anchorage in concrete

ϕ = 0.75 for spirally reinforced concrete compression members

ϕ = 0.70 for tied compression members

ϕ = 0.90 for fabricated structural steel

ϕ = 0.90 for reinforcing steel in direct tension

ϕ = 0.90 for welded or mechanical splices of reinforcing steel

ϕ = 0.85 for lap splices of reinforcing steel

ϕ = 0.95 for prestressed tendons in direct tension.

5.1.4.8 Prestress Losses

In accordance with the ACI Code 318-63, the design will provide for prestress losses caused by the following effects:

(a) Seating of anchorage

(b) Elastic shorterning of concrete

(c) Creep of concrete

(d) Shrinkage of concrete

(e) Relaxation of prestressing steel stress

(f) Frictional loss due to intended or unintended curvature in the tendons.

All of the above losses can be predicted with a reasonable degree of accuracy.

The environment of the prestress system and concrete is not appreciably different, in this case, from that found in numerous bridge and building applications. Considerable research has been done to evaluate the above items and is available to designers in assigning the allowances. Building code authorities consider it acceptable practice to develop permanent designs based on these allowances.

5.1.4.9 Liner Plate Criteria

The design criteria which will be applied to the containment liner to meet the specified leak rate under accident conditions are as follows:

(a) That the liner be protected against damage by missiles. (See Paragraph 5.1.4.10)

(b) That the liner plate strains be limited to allowable values that have been shown to result in leak tight vessels or pressure piping.

(c) That the liner plate be prevented from developing significant distortion.

(d) That all discontinuities and openings be well anchored to accommodate the forces exerted by the restrained liner plate, and that careful attention be paid to details of corners and connections to minimize the effects of discontinuities.

Pressure vessels, pressure piping, high pressure hydraulic tubing, and similar containers are made by cold forming, drawing, and dishing operations where strains may approach the elongation capacity of the material. (For mild steel at failure, this elongation varies 15 per cent to 30 per cent). These forming operations result in high strains both in tension and compression. Vessels and piping components manufactured by these methods have a history of high leak tight integrity proving that subjecting the steel material to high strain does not affect its leak tight integrity.

The best basis for establishing allowable liner plate strains is considered to be that portion of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels, Article 4. Specifically, the following sections have been adopted as guides in establishing allowable strain limits:

Para. N-412 (m)	Thermal Stress (2)
Para. N-414.5	Peak Stress Intensity
	Table N-413
	Fig. N-414, N-415 (A)
Para. N-412 (n)	
Para. N-415.1	

Implementation of the ASME design criteria requires that the liner material be prevented from experiencing significant distortion due to the thermal load and that the stresses be considered from a fatigue standpoint. (Para. N-412 (m) (2).)

The following fatigue loads will be considered in the design of the liner plate:

(a) Thermal cycling due to annual outdoor temperature variations. Daily temperature variations will not penetrate a significant distance into the concrete shell to appreciably change the average temperature of the shell relative to the liner plate. The number of cycles for this loading will be 40 cycles for the plant life of 40 years.

(b) Thermal cycling due to containment interior temperature varying during the startup and shutdown of the reactor system. The number of cycles for this loading will be assumed to be 500 cycles.

(c) Thermal cycling due to the LOCA will be assumed to be one cycle. Thermal load cyc'- -n the piping systems are somewhat isolated from the liner plate penetrations by the concentric sleeves between the pipe and the liner plate. The attachment sleeve will be designed in accordance with ASME Section III fatigue considerations. All penetrations will be reviewed for a conservative number of cycles to be expected during the plant life.

The thermal stresses in the liner plate fall into the categories considered in Article 4, Section III, Nuclear Vessels of the ASME Boiler and Pressure Vessel Code. The allowable stress in Figure N-415 (A) are for alternating stress intensity for carbon steels and temperatures not exceeding 700 F. In addition, the ASME Code further requires that significant distortion of the material be prevented.

In accordance with ASME Code Paragraph 412 (M) 2, the liner plate is restrained against significant distortion by continuous angle anchors and never exceeds the temperature limitation of 700 F and also satisfies the criteria for limiting strains on the basis of fatigue consideration.

Paragraph 412 (N) Figure N-415 (A) of the ASME Code has been developed as a result of research, industry experience, and the proven performance of code vessels. Because of the conservative factors it contains on both stress intensity and stress cycles, and its being a part of a recognized design code, Figure N-415 (A) and its appropriate limitations have been used as a basis for establishing allowable liner plate strains. Since the graph in Figure N-415 (A) does not extend below 10 cycles, 10 cycles is being used f r an LOCA instead of one cycle.

Establishing an allowable strain based on the one significant thermal cycle of the accident condition would permit an allowable strain (from Fig.N-415A) of approximately 2 per cent. The strain in the liner plate at proportional limit will be approximately 0.1 per cent. The liner plate will be allowed to go beyond proportional limit strains during the accident condition. Maximum allowable tensile or compressive strain has been conservatively set at 0.5 per cent (compared to 2 per cent shown above). The maximum predicted membrane strain in the liner plate during accident conditions has been found to be 0.25 per cent. The maximum combined membrane and flexural strain is predicted to be .45 per cent. 5

At the design accident pressure condition, there will be no tensile stress anywhere in the liner plate membrane. This is true both at the time of initial pressure release and under any later pressure temperature condition. The purpose of specifying an NDT temperature requirement is to provide protection against a brittle fracture or cleavage mode of failure. However, this type of failure is precluded by the absence of tensile stresses.

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No allowable compressive strain value has been set for the test condition because the value will be less than that experienced under the accident conditions. The maximum predicted compressive strain will be approximately 0.07 per cent.

The maximum allowable tensile strain will be 0.2 per cent under test conditions. The predicted value will be very nearly zero.

The stability of the liner plate will be ensured by the stiffening and anchoring of the plate to the prestressed concrete structure.

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5 The maximum compressive membrane strains are caused by accident pressure, thermal
loading, prestress, shrinkage and creep. The maximum strains will not exceed
.0025 in./in. and the liner plate will always remain in a stable condition.

The conservative design approach of the stiffening system used in the liner plate to prevent significant distortions at accident conditions, and stringent welding and weld inspection requirements will ensure that the leak tightness of the liner plate at accident conditions will not change from that at the test conditions.

In isolated areas the liner plate may have initial inward curvature due to
construction. The anchors will be designed to resist the forces and moments
5 induced when a section of the liner plate between anchors displaces inward due
to initial inward curvature and applied membrane loads.

5

The liner plate will be anchored at all discontinuities to eliminate excessive strains at the discontinuities. The forces in the liner plate at the discontinuities will be evaluated by use of the finite element computer program and the anchors will be designed to resist these forces.

At all penetrations the liner plate will be thickened to reduce stress concentrations in accordance with the ASME Boiler and Pressure Vessel Code 1965, Section III, Nuclear Vessels. The thickened portion of the liner plate will then be anchored to the concrete by use of anchor studs completely around the penetrations. For details of the penetrations see Figure 5 - 2. The sleeves, pipe cap, and all welds associated with the penetrations will be designed to resist all loads previously mentioned and also the prestress forces and internal design pressure.

5.1.4.10 <u>Missle Protection Criteria</u>

High pressure reactor coolant system equipment which could be the source of missiles is suitably screened either by the concrete shield wall enclosing the reactor coolant loops, by the concrete operating floor or by special missile shields to block any passage of missiles to the containment walls. Potential missile sources are oriented so that the missile will be intercepted by the shields and structures provided. A structure is provided over the control rod drive mechanism to block any missiles generated from fracture of the mechanisms.

Missile protection will be provided to comply with the following criteria:

(a) The containment and liner will be protected from loss of function due to damage by such missiles as might be generated in a loss-of-coolant accident for break sizes up to and including the double-ended severance of a main coolant pipe.

(b) The engineered safeguards system and components required to maintain containment integrity will be protected against loss of function due to damage by the missiles defined below.

During the detailed plant design, the missile protection necessary to meet the above criteria will be developed and implemented using the following methods:

(a) Components of the reactor coolant system will be examined to identify and to classify missiles according to size, shape and kinetic energy for purposes of analyzing their effects.

(b) Missile velocities will be calculated considering both fluid and mechanical driving forces which can act during missile generation.

(c) The reactor coolant system will be surrounded by reinforced concrete and steel structures designed to withstand the forces associated with double-ended rupture of a main coolant pipe and designed to stop the missiles.

(d) The structural design of the missile shielding will take into account both static and impact loads and will be based upon the state of the art of missile penetration data.

The types of missiles for which missile protection will be provided are:

(a) Valve stems

(b) Valve bonnets

(c) Instrument thimbles

(d) Various types and sizes of nuts and bolts

(e) External missiles defined in section 5.1.2.5

Protection is not provided for c[illegible] types of missiles for which postulated accidents are considered incredi[illegible] because of the material characteristics, inspections quality control during fabrication. and conservative design as applied to the particular component. Included in this category are missiles caused by massive, rapid failure of the reactor vessel, steam generator, pressurizer and main coolant pump casings. 5

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5.1.5 STRUCTURAL DESIGN ANALYSIS

The containment structure will be analyzed by a finite element computer program for individual loading cases of dead load, live load, temperature, and pressure as described in Section 5.1.4.1.

The ACI-318-63 code design methods and allowable stresses will be used for concrete and prestressed and non-prestressed reinforcing steel except as noted herein.

5.1.5.1 Critical Design Areas

Based on a recent design study of prestressed concrete containment structures, it has been substantiated that the main areas for design analysis are:

(a) The restraints at the top and bottom of the cylinder

(b) The restraints at the edge of the spherical sector dome

(c) The stresses around the large penetrations

(d) The behavior of the base slab relative to an elastic foundation

(e) The stresses due to transient temperature gradients in the liner plate and concrete

(f) Stresses within the ring girder

(g) Penetrations and concentrated loads

(h) Seismic loads

5.1.5.2 Analytical Techniques

The containment structure analysis will be performed by the finite element method developed by E. L. Wilson, under sponsorship of National Science Foundation Research Grant G18986. This program has been further developed to apply to axisymmetric structures. Such a method of analysis is normally used only for thick-walled structures where conventional shell analysis yiel[illegible] inaccurate results. Good correlation has been demonstrated between the fi[illegible] element analysis method and the test results for thick wall model vessels.

The design analysis for items a - f is done using the finite computer program because all of the conditions are axisymmetric. Items g and h are non-axisymmetric and are handled by techniques described in Sections 5.1.5.5 and 5.1.5.6.

The finite element technique is a general method of structural analysis in which the continuous structure is replaced by a system of elements (members) connected at a finite number of nodal points (joints). Conventional analyses of frames and trusses can be considered to be examples of the finite element method.

In the application of the method to an axisymmetric solid (e.g.,) a concrete containment structure, the continuous structure is replaced by a system of rings of triangular cross-section which are interconnected along circumferential joints. Based on energy principles, work equilibrium equations are formed in which the radial and axial displacements at the circumferential joints are unknowns of the system. A solution of this set of equations is inherent in the solution of the finite element system.

The finite element grid of the structure base slab will be extended down into the foundation material to take into consideration the elastic nature of the foundation material and its effect upon the behavior of the base slab.

The use of a finite element analysis will permit an accurate determination of the stress pattern at any location on the structure. The analysis method has been demonstrated on the following types of structures:

(a) Arch dams (including a portion of the foundation)

(b) Thick-walled prestressed concrete vessels

(c) Spacecraft heat shields

(d) Rocket nozzles

The computer program used in the analysis will handle the following inputs:

(a) Seven different materials

(b) Non-linear stress-strain curves for each material

(c) Any shape transient temperature curves

(d) Any shape axisymmetric loading

The program outputs will be:

(a) The direct stress and shear stress for each element

(b) The principal stresses and their directions for each element

(c) The deflections for each nodal point

An auxiliary computer program will plot stress curves based on the above analysis program outputs.

Additional information regarding this technique, the computer program employed, and a comparison of the results with other analytical methods is contained in Appendix 5-F.

5.1.5.3 Thermal Loads

The thermal loads are a result of the temperature differential within the structure. The design temperature gradients for this structure are shown on

Figure 5 - 4. The finite element analysis was prepared so that when temperatures are given at every nodal point, stresses are calculated at the center of each element. This way the liner plate was handled as an integral part of the structure, having different material properties, and not as a mechanism which would act as an outside source to produce loading on the concrete portion of the structure.

The liner plate is designed to have plastic deformation as a result of prestressing and high thermal stresses.

The finite element method includes this analysis too, by successive approximations, changing the modulus of elasticity of those elements which are subject to stresses higher than the proportional limit.

The output of the computer analysis shows the effect of the thermal loads on liner plate and concrete. The liner plate and the inside of the concrete are subject to compressive stress and the outside of the concrete section is subject to tension. These tension stresses balance the compressive stresses so that, except close to any discontinuity, there is no resultant membrane force. That is, all the compressive forces in the liner plate are carried by the prestressed concrete and reinforcement near the outside surface of the structure.

The compressive stresses in the liner plate exceed the proportional limit in the case of the design basis accident. An increased temperature would keep the liner plate in plastic condition, but only a negligible additional stress could develop, and thermal stresses would stay unchanged.

The small increase in containment temperature associated with the factored pressure is not significant in changing the temperature gradient through the concrete. Therefore, the temperature gradient for the factored pressure case is used for both the design accident and factored accident.

5.1.5.4 Tendon Failure Analysis

5 There will be approximately 180 vertical tendons and 600 hoops tendons using 90 wire system and 95 vertical tendons and 175 hoop tendons using 170 wire system. The hoop tendons will be placed in three 240° sections around the cylinder using three buttresses as anchorages. Therefore, failure of a hoop tendon or a series of adjoining tendons or spaced hoop tendons is limited between 240° segments of the containment vessel.

All prestressed tendons are subject to the most critical stress during initial tensioning. There will be a loss of prestress on the order of 15 per cent due to elastic and plastic losses, which will reduce the stress level. Even at the factored yield loads, the stress in the tendons will not be as high as during initial tensioning. Each of the tendons has been pre-tested at the time of initial jacking and the stress in the tendons under accident loading is only 80 per cent of this jacking stress. This means that the possibility of tendon failure under design accident loading is quite remote.

Although there is ample reserve capacity in the tendon and structure, the complex nature of the structural behavior makes it difficult to predict the effect of a hypothetical series of tendon failures until the final design is complete.

If two or three of the tendons fail during accident conditions, and if they are side by side or close together, this will not affect the integrity of the structure or the liner because the thick concrete walls will be sufficient to transmit the force from the adjoining tendons without resulting in any serious local stresses.

5.1.5.5 Stresses Near Equipment Openings

Analytical solutions for the determination of state of stress in the vicinity of equipment openings are obtained from reference to the following articles:

(a) "State of Stress in a Circular Cylindrical Shell with a Circular Hole," by A. C. Eringen, A. K. Naghdi, and C. C. Thiel - Welding Research Council Bulletin No. 102, January, 1965.

(b) Samuel Levy, A. E. McPherson and F. C. Smith, "Reinforcement of a Small Circular Hole in a Plane Sheet Under Tension," Journal of Applied Mechanics, June, 1948.

The analysis of the containment structure as a whole is first carried out without considering the openings in it. This analysis has been done by using the finite element program.

The containment structure with the opening in it is then analyzed in the following steps.

(a) Formulation of differential equations for the shell in complex variable form with the center of the hole as the origin (See reference a above)

(b) Solution of the differential equations (See reference a above)

(c) Evaluation of parameters in the solution (See reference a above)

(d) Formulation of the boundary conditions based on the stresses obtained from the vessel analysis above without the hole

(e) Calculation of membrane forces, moments, and shears around and at the edge of the opening

(f) The wall thickness around the opening will then be increased and reinforced to carry the higher forces, moment, and shears. The effect of the thickening on the stress concentration factors will be considered using reference (b) above.

(g) Evaluation of some of the effects of prestressing that are not handled in reference (a) above.

(h) Finally, the design will be checked to ensure that the strength of the reinforcement provided replaces the strength removed by the opening. This check is to maintain a good degree of compatibility between the general vessel shell and the area around the opening.

Details of the reinforcing and deflected strand pattern around the equipment hatch opening are shown on Figure 5- 3A 17

The deflection of the tendons does not significantly affect the stress con-
5 centrations. This is a plane stress analysis, and did not include the effect of the curvature of the shell; however, it gives an assurance of the correctness of the assumed membrane stress pattern caused by the prestressing around the opening.

The seismic load creates vertical membrane stress in the structure based on a cantilevered circular beam subjected to base accelerations. The membrane stresses at the opening are modified by appropriate stress concentration factors.

The temperature variation through the concrete wall creates a stress condition like one caused by a moment, constant in all directions on the continuous cylindrical or spherical surface. However, at any discontinuity, such as an opening, stress concentrations occur.

Using the center of the opening as the reference point to relate the directions of moments, the radial moment is zero at the edge of the opening, there being no resistance against radial rotation. The hoop moment is highly increased, the outside fiber being forced to take the shape of a larger circle, while the inside fiber takes the shape of a smaller circle.

Away from the edge of the opening both moments gradually reach the constant value on the undisturbed portion of the cylinder.

In the case of 1.5P (prestress fully neutralised) + 1.0T (accident temperature) the cracked concrete with highly strained tension reinforcement constitutes a shell with stiffness decreased but still constant in all directions. In order to control the increased hoop moment around the opening, the hoop reinforcement should produce strength about twice that of the radial one.

In the case of accident temperature combined with low internal pressure, very small or no tension develops on the outside, so the thermal strains will be built up without the relieving effect of the cracks. However, as has already been stated elsewhere, the liner plate will reach its yield stress, and so will the concrete at the inside corner of the penetration, thereby relieving once again the very high stresses, but still carrying the high moment in the state or redistributed stresses.

For the analysis of the thermal stresses around the opening the same method was used as for the other loadings.

At the edge of the opening a uniformly distributed moment equal but opposite to the moment existing on the rest of the shell was applied, and evaluated using the methods of the preceding reference and the effects were superimposed on the stresses calculated by the computer using the finite element method for axisymmetric solids.

The pattern of membrane stresses at design accident loading is not expected to be significantly different from the pattern of membrane stresses during the proof test, since the membrane stresses due to pressure are far more significant than those due to dead load or seismic load.

5.1.5.6 Seismic Analysis

The loads on the containment structure caused by earthquake will be determined as a result of a dynamic analysis of the structure. The dynamic analysis will be made on an idealized structure of lumped masses and weightless elastic columns acting as spring restraints. The analysis will be performed in two stages; the determination of the natural frequencies of the structure and its mode shapes, and the modal response of these modes to the earthquake by the spectrum response method. Appendix 5-A contains more details on the seismic design basis for this plant.

The natural frequencies and mode shapes are computed from the equations of motion of the lumped masses established in a stiffness of displacement method and are solved by iteration techniques by a fully tested digital computer program. The form of the equations is:

$$(K) \quad (\Delta) = \omega^2 \quad (M) \quad (\Delta)$$

(K) = Matrix of stiffness coefficients including the combined effects of shear, flexure, rotation and horizontal translation. 5

(M) = Matrix of concentrated masses

(Δ) = Matrix of mode shape

ω = Angular frequency of vibration

The results of this computation are the several values of ω_n and mode shapes $(\Delta)_n$ for n = 1, 2, 3 --- m where m is the number of degrees of freedom (i.e., lumped masses) assumed in the idealized structure.

The response of each mode of vibration to the design earthquake is then computed by the response spectrum technique, as follows:

(a) The base shear contribution of the n^{th} mode

$$V_n = W_n S_{an}(\omega_n \gamma)$$

Where:

W_n = Effective weight of the structure in the n^{th} mode computed from:

$$W_n = \frac{(\Sigma_x \Delta_{xn} W_x)^2}{\Sigma_x (\Delta_{xn})^2 W_x}$$ where the

subscript x refers to levels throughout the height of the structure.

ω_n = Angular frequency of the n^{th} mode

$S_{an}(\omega_n, \gamma)$ = Spectral accelaration of a single degree of freedom system with a damping coefficient of γ, obtained from the response spectrum.

(b) The horizontal load distribution for the n^{th} mode is then computed as:

$$F_x = V_n \left(\frac{\Delta_{xn} W_x}{\Sigma_x \Delta_{xn} W_x} \right)$$

The several mode contributions are then combined to give the final response of the structure to the design earthquake.

(c) Additional Considerations:
The number of modes to be considered in the analysis will be determined at the time of final design to adequately represent the structure being analyzed. Since the spectral response technique yields the maximum value of response for each mode, and these maxima do not occur at the same time, the response of the modes of vibration will be combined by taking the square root of the sum of the squares of model values. 5

8 The standard modal analysis procedure, as described above, takes into account structural rocking, lateral translation and the shearing and flexural distortion of the structure. The answer for question 11.2.16 in Supplement No. 4 gives further explanation of the analytical method and Fig. 11.2.16-1 shows the analytical model. In computing the spring constants for the rocking motion, the experimental elastic properties of the rock will be utilized.

The following values of damping and ground acceleration will be used in the analysis together with the natural periods to obtain spectral accelerations.

Ground Acceleration	% Damping	Ground Acceleration	% Damping
0.20	5%	0.10	2%

5.2 DESIGN, CONSTRUCTION, AND TESTING OF PENETRATIONS

5.2.1 TYPES OF PENETRATIONS

All penetrations will be pressure resistant, leak-tight, welded assemblies designed, fabricated and tested in accordance with the ASME Nuclear Vessel Code, Section III.

5.2.1.1 Electrical Penetrations

Canister type penetrations are used for all electrical conductors passing through the containment. The penetration canister is a hollow cylinder closed on both ends with insulated bushing or connector assembly. This canister is provided with a test plug to allow test pressurization of the penetration assembly. Figure 5-2 shows typical electrical penetrations. The method used to seal the joint between the canister end plate and the conductor depends upon the type of cable and connector assembly involved. In general, there are three types used:

(a) Type 1 - High voltage power, 4160 volts and 6900 volts

(b) Type 2 - Power and control, 600 volts and below

(c) Type 3 - Instrumentation, thermocouple leads, coaxial, and other special wires.

Type 1 penetrations will be high voltage insulated copper rods with copper braid. These insulated rods will be connected between the insulated bushings at each end plate of the canister. High voltage insulating bushings and seals may be used to provide the barrier.

Type 2 penetrations will be single or multiconductor insulated cable. This cable will be connected between the connector assembly at each end of the penetration canister. Hermetically sealed contact assembly which is sealed in the canister end plates will be used.

Type 3 penetrations will be the same as Type 2 except the conductors will be thermocouple material, coaxial cable, or special wires. The sealing methods will be the same as for Type 2 penetrations.

5.2.1.2 Piping Penetrations

Single barrier piping penetrations are provided for all piping passing through the containment. The closure of the pipe to the liner plate is accomplished with a pipe reducer welded to the pipe and to the liner plate reinforcement. In the case of piping carrying hot fluid, the pipe will be insulated and cooling may be required to reduce the concrete temperature. Figure 5-2 shows typical hot and cold pipe penetrations. The modes of isolating the piping penetrations are covered in Section 6.

The anchorage of penetration closure connecting pipes to the containment wall will be designed as Class I structures to resist all forces and moments caused by a postulated pipe rupture. The design conditions will include the maximum pipe reactions, and pipe rupture forces.

The following design criteria for typical piping penetrations is used to ensure the integrity of the liner penetration junction at the piping.

(1) The penetration assembly consisting of pipe reducer and pipe sleeve section and the assembly welds and welds to the liner plate will be full penetration welds. The assembly is anchored into the wall concrete and designed to accomodate all forces and moments due to pipe rupture and thermal expansion.

(2) The design criteria will be that the pipe penetration will be the strongest point in the system when a pipe break is postulated. Pipe stops, increased pipe thickness or other means will be used to attain this. Part of this criteria will also be that the operation of closure valves will not be impaired by any postulated pipe break.

5.2.1.3 Equipment and Personnel Access Hatches

An equipment hatch fifteen feet in diameter is provided as shown on Figure 5-3 which is fabricated from welded steel and furnished with a double gasketed flange and bolted dished door. Equipment up to and including the size of the reactor vessel O-ring seal can be transferred into and out of the containment building through this hatch.

Two personnel locks are provided. One of these is for emergency access only. Each personnel lock is a double door, welded steel assembly. A quick-acting type, equalizing valve connects the personnel lock with the interior and exterior of the containment vessel for the purposes of equalizing pressure in the two systems when entering or leaving the containment.

The two doors in each personnel lock are interlocked to prevent both being opened simultaneously and to ensure that one door is completely closed before the opposite door can be opened. Remote indicating lights and annunciators situated in the control room indicate the door operational status. Provision is made to permit by-passing the door interlocking system to allow doors to be left open during plant cold shutdown. Each door lock hinge is designed to be capable of independent, three-dimensional adjustment to assist proper seating. An emergency lighting and communication system operating from an external emergency supply is provided in the lock interior.

5.2.1.4 Special Penetrations

(a) Fuel Transfer Penetration

A fuel transfer penetration is provided for fuel movement between the refueling transfer canal in the reactor containment and the spent fuel pit. The penetration consists of a 30 inch stainless steel pipe installed inside a 42 inch pipe. The inner pipe acts as the transfer tube and is fitted with a double gasketed blind flange in the refueling canal and a standard gate valve in the spent fuel pit. This arrangement prevents leakage through the transfer tube in the event of an accident. The outer pipe is welded to the containment liner and provision is made by use of a special seal ring for test pressurizing all welds

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essential to the integrity of the penetration during plant operation. Figure 5-2 shows a sketch of the fuel transfer tubes.

(b) Containment Supply and Exhaust Purge Ducts

The ventilation system purge duct is equipped with two tight- seating valves to be used for isolation purposes. The valves are remotely operated for containment purging as described in Section 9.7.

5.2.2 DESIGN OF PENETRATIONS

5.2.2.1 Design Criteria

Penetrations will conform to the applicable sections of ASA N6.2-1965, "Safety Standard for the Design, Fabrication and Maintenance of Steel Containment Structures for Stationary Nuclear Power Reactors." All personnel locks and any portion of the equipment access door extending beyond the concrete shell will conform in all respects to the requirements of ASME Section III Nuclear Vessels Code.

Each line which penetrates the containment and contains high pressure and high temperature fluids (main steam and feedwater) will have structural restraints such that: the fracture of any one line will not jeopardize any other line whose fracture would then constitute a loss of coolant accident. Electrical penetrations will be protected or separated such that they will not be damaged by the whipping of any pipe. 5

Further protection of each line, necessary to preclude pipe rupture between penetration and first valve, is accomplished by shortening the exposed length of pipe and installing the first valve as close as possible to the containment internal or external wall, dependent upon valve operating and maintenance clearances. Criteria which apply to the provision of automatic and manual isolation valves in the penetration lines are contained in Section 5.4.

5.2.2.2 Code of High-Temperature Penetrations

The main high temperature piping consists of two penetrations for feedwater and two penetrations for main steam which have a maximum operating temperature range between 450 F and 562 F. Thermal insulation is provided on the outside diameter of each line and separate coolant circulation, with instrumentation suitable for flow monitoring, in the air gap between insulation and penetration liner sleeve. The combination of insulation and coolant circulation is designed to restrict maximum temperature rise in the concrete to 150 F.

For the condition of loss of penetration coolant circulation, the maximum steady state temperature in the concrete will be 300 F at the penetration surface and decrease to 120 F at a maximum depth of 48 inches in the containment wall. Actual peak temperatures in the penetrations resulting from accident conditions are expected to subside within six hours. A maximum temperature of 390 F may be tolerated for 120 days (1) without appreciable deterioration of the concrete.

The basis for limiting strains in the penetration steel will be the ASME Boiler and Pressure Vessel Code for Nuclear Vessels, Section III, Article 4, 1965, and therefore, the penetration structural and leak tightness integrity will be maintained. Local heating of the concrete immediately around the penetration will develop compressive stress in the concrete adjacent to the penetration and a negligible amount of tensile stress over a large area. The mild steel reinforcing added around penetrations will distribute local compressive stresses for overall structural integrity.

5.2.2.3 Penetration Materials

The materials for penetrations including the personnel and equipment access hatches together with the mechanical and electrical penetrations will be carbon steel and and will conform with the requirements of the ASME Nuclear Vessel Code. As required by the Nuclear Vessel Code, the penetration materials shall meet the necessary Charpy V-notch impact values at a temperature 30 F below the lowest service temperature.

(a) Piping Penetration Materials

Materials specifications are listed below:

Piping Penetration Material	Specification
Penetration Sleeve	ASTM - A333
Penetration Reinforcing Rings	ASTM - A516
Penetration Sleeve Reinforcing	ASTM - A516
Bar Anchoring Rings and Plates	ASTM - A516
Rolled Shapes	ASTM - A36

(b) Electrical Penetration Materials

The penetration sleeves to accommodate the electrical penetration assembly canisters will be 10 inch, Schedule 80 carbon steel pipe, except where otherwise noted.

(c) Access Penetration Materials

The equipment and personnel access hatch materials will be as follows:

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(1) Davis, Harold S., "Thermal Considerations in Design of Concrete Shields," ASCE Proceedings, September, 1958

Access Penetration Material	Material Specification
Equipment Hatch Insert	
Equipment Hatch Flanges	All ASTM A516 made to ASTM A300
Equipment Hatch Head	
Personnel Hatch	

5.2.3 INSTALLATION OF PENETRATIONS

The qualification of welding procedures and welders will be in accordance with Section IX, "Welding Qualifications," of the ASME Boiler and Pressure Vessel Code. The repair of defective welds will be in accordance with Para. N-528 of Section III, "Nuclear Vessels" of the above Code.

5.2.4 TESTABILITY OF PENETRATIONS

Some lines which penetrate the containment are not open to the containment atmosphere. Where these lines are located outside the missile barrier, they are considered to be closed systems, not subject to rupture following a loss of coolant accident. The main steam lines, the feedwater lines, and the service water lines which provide cooling water to the coolers in the ventilation air handling units fall within this category.

Any leakage through these closed lines will be detected as part of the pre-operational integrated leak test of the containment.

Some lines which penetrate the containment are part of the closed piping systems located outside the containment vessel and isolation is accomplished as shown in Section 5.4. The following lines fall within this category:

(a) The letdown cooler cooling water supply line

(b) The reactor coolant pump seal water supply lines

(c) The decay heat removal loop inlet and outlet lines

The first three of these lines are in systems which are normally water filled and normally operate at positive pressures. Any significant leakage from these lines will be detected during plant operation.

The decay heat removal loop is part of the safety injection and post-loss-of-coolant recirculation flow path which is discussed in detail in Section 6.

Provisions for Isolation Valves

Those containment penetrations which communicate directly between the containment atmosphere and the outside environment are provided with normally closed isolation valves or blind flanges.

5.3 CONTAINMENT ACCESSIBILITY CRITERIA

The containment is designed for purging during operation to allow accessibility into certain areas of the containment building for necessary maintenance. The purging rate will be limited by monitors and together with the filters shown in Figure 5-6, will prevent radioactive release exceeding acceptable limits. Particulate matter will be removed from the purge gas before gas release to the atmosphere through the purge vent.

5.4 ISOLATION SYSTEM

5.4.1 DESIGN BASES

The general design basis governing isolation valve requirements is:

> Leakage through all fluid penetrations, not serving accident-consequence-limiting systems, is to be minimized by a double barrier so that no single, credible failure or malfunction of an active component can result in loss of isolation or intolerable leakage. The installed double barriers take the form of closed piping systems, both inside and outside the Reactor Building, and various types of isolation valves.

Reactor Building isolation occurs on a signal of approximately 4 psig in the Reactor Building. Valves that isolate penetrations which are directly open to the Reactor Building, such as the Reactor Building purge valves and sump drain valves, will also be closed on a high radiation signal.

The isolation system closes all fluid penetrations not required for operation of the engineered safeguards in order to prevent leakage of radioactive materials to the environment. Fluid penetrations serving engineered safeguards also meet this design basis.

All remotely operated Reactor Building isolation valves are provided with position limit indicators in the control room.

5.4.2 SYSTEM DESIGN

The fluid penetrations that require isolation after an accident may be classed as follows:

Type I. Each line connecting directly to the reactor coolant system has two Reactor Building isolation valves. One valve is external, and the other is internal to the Reactor Building. These valves may be either a check valve and a remotely operated valve, or two remotely operated valves depending on the direction of normal flow.

Type II. Each line connecting directly to the Reactor Building atmosphere has two isolation valves. At least one valve is external, and the other may be internal or external to the Reactor Building.

These valves may be either a check valve and a remotely operated valve, or two remotely operated valves depending on the direction of normal flow.

Type III. Each line not directly connected to the reactor coolant system or not open to the Reactor Building atmosphere has one valve, either a check valve or a remotely operated valve. This valve is located external to the Reactor Building.

Type IV. Lines that penetrate the Reactor Building and are connected to either the building or the reactor coolant system, but which are never opened during reactor operation, have provisions for locking in a closed position.

There are additional subdivisions in each of these major groups. The individual system flow diagrams show the manner in which each Reactor Building isolation valve arrangement fits into its respective system. For convenience, each different valve arrangement is shown in Table 5-1 and Figure 5-6 of this section. The symbols on these figures are identified on Figure 9-1. This table lists the mode of actuation, the type of valve, its normal position, and its position under Reactor Building isolation conditions. The specific system penetrations to which each of these arrangements is applied are also presented. Each valve will be tested periodically during normal operation or during shutdown conditions to insure its operability when needed.

The accident analysis for failure or malfunction of each valve is presented with the respective system evaluation of which that valve is a part, for example, chemical addition and sampling system, etc.

There is sufficient redundancy in the instrumentation circuits of the safeguards actuation system to minimize the possibility of inadvertent tripping of the isolation system. This redundancy and the instrumentation signals that trip the isolation system are discussed further in Section 7.

The system abbreviations in column three of Table 5-1 are defined as follows:

MU	Makeup and Purification System
DH	Decay Heat Removal System
RB	Reactor Building Cooling System
SF	Spent Fuel Cooling System
WD	Waste Disposal System
CA	Chemical Addition and Sampling System
BS	Reactor Building Spray System
IC	Intermediate Cooling System
SW	Service Water System
CW	Auxiliary Cooling Water System
SP	Secondary Plant

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Tabl
Reactor Building Isola

Pene-tration No.	Service	System	Flow Direc-tion	Valve Arrgt.	Location Referred to R.B.	Valv Type
1	Pressurizer and Reactor Coolant Sample Lines	CA	Out	5	Inside	Gate Gate
					Outside	Gate
2	Reactor Bldg Sump Drain	WD	Out	3	Inside	Gate
					Outside	Gate
3	Let Down Line to Purification Demineralizers	MU	Out	5	Inside	Gate Gate
					Outside	Gate
4	Reactor Coolant Pump & Control Rod Drive, Seal Return Line	MU	Out	5	Inside Inside Outside	Gate Gate Gate
5	Reactor Coolant Pump Seal Water Supply	MU	In	1	Inside	Stop
					Outside	Globe Globe
6	Normal Makeup to the Reactor Coolant System	MU	In	2	Inside	Check
					Outside Outside	Globe Globe
7a, 7b, 7c, 7d	High Pressure Injection Lines	MU	In	7	Inside	Check
					Outside	Gate
8	Fuel Transfer Tube	SF	In/Out	8	Inside	Speci Clos
					Outside	Gate
9	Reactor Bldg Spray Inlet Line	BS	In	7	Inside	Check
					Outside	Gate

* All valves with electric motor operators are also equipped with hand wheels.
** Post-accident reactor coolant system pressure causes valve to close.

e 5-1
ion Valve Information

e	Line Size, in.	Method of Actuation	Signal	Normal Valve Position	Position Indication	Post-Accident Position
	3/8	EMO*	ES	Closed	Yes	Closed
	3/8	EMO	ES	Closed	Yes	Closed
	3/8	Air	ES	Closed	Yes	Closed
	4	EMO	ES	Closed	Yes	Closed
	4	Air	ES	Closed	Yes	Closed
	1-½	EMO	ES	Open	Yes	Closed
	1-½	EMO	ES	Closed	Yes	Closed
	1-½	Air	ES	Open	Yes	Closed
	4	EMO	ES	Open	Yes	Closed
	1-½	EMO	ES	Open	Yes	Closed
	4	Air	ES	Open	Yes	Closed
Ck.	1	---	--	Open	No	Closed
	4	Air	--	Throttled	Yes	Closed**
	4	Manual	--	Closed	No	Closed
	2 1/2	---	--	Open	No	Open
	2 1/2	Air	--	Throttled	Yes	Open
	2 1/2	Manual	--	Closed	No	Closed
	2 1/2	---	--	--	No	Open
	2 1/2	EMO	ES	Closed	Yes	Open
ial ure	30	---	--	Closed	--	Closed
	30	Manual	--	Closed	No	Closed
	8	---	--	--	No	Open
	8	EMO	ES	Closed	Yes	Open

Table 5-1

Pene-tration No.	Service	System	Flow Direc-tion	Valve Arrgt.	Location Referred to R.B.	Valve Type
10	Reactor Bldg Spray Inlet Line	BS	In	7	Inside	Check
					Outside	Gate
11	Decay Heat Coolant Return	DH	In	7	Inside	Check
					Outside	Gate
12	Decay Heat Coolant Return	DH	In	7	Inside	Check
					Outside	Gate
13	Decay Heat Coolant Let-Down	DH	Out	9	Inside	Gate Gate (
					Outside	Gate
14	Reactor Bldg Sump Recir-culation Line	DH	Out	10	Outside	Gate
15	Reactor Bldg Sump Recir-culation Line	DH	Out	10	Outside	Gate
16	Reactor Coolant Drain Tank Vent	WD	Out	14	Outside	Gate
17	Reactor Bldg Inlet Purge Line	--	In	11	Inside	Butter
					Outside	Butter
18	Reactor Bldg Outlet Purge Line	--	Out	12	Inside	Butter
					Outside	Butter
19-20	Reactor Coolant Pump Motors and Lub Oil Coolers	SW	In/Out	6	Outside	Gate
					Outside	Gate

Cont'd)

	Line Size, in.	Method of Actuation	Signal	Normal Valve Position	Position Indication	Post-Accident Position
	8	---	--	--	No	Open
	8	EMO	ES	Closed	Yes	Open
	12	---	--	Closed	No	Open
	12	EMO	ES	Closed	Yes	Open
	12	---	--	Closed	No	Open
	12	EMO	ES	Closed	Yes	Open
	10	Manual	--	Closed	No	Closed
)	10	EMO	Remote Manual	Closed	Yes	Closed
	10	EMO	Remote Manual	Closed	Yes	Closed
	18	EMO	Remote Manual	Closed	Yes	Open
	18	EMO	Remote Manual	Closed	Yes	Open
	2	Air	ES	Closed	Yes	Closed
'ly	36	EMO	ES	Closed	Yes	Closed
'ly	36	Air	ES	Closed	Yes	Closed
'ly	36	EMO	ES	Closed	Yes	Closed
'ly	36	Air	ES	Closed	Yes	Closed
	6	EMO	ES	Open	Yes	Closed
	6	EMO	ES	Open	Yes	Closed

Penetration No.	Service	System	Flow Direction	Valve Arrgt.	Location Referred to R.B.	Valve Type
21-23	Reactor Bldg. Air Coolers	SW	In/Out	6	Outside	Gate
24-26					Outside	Gate
27-28	Feedwater Lines	--	In	13	Outside	Stop C
29-30	Steam Lines	--	Out	13	Outside	Gate
31-32	Steam Generator Sample Line	CA	Out	3	Inside	Gate
					Outside	Gate
33-34	Core Flooding Tank Fill & Nitrogen Supply Line	DH	In	4	Inside	Check
					Outside	Check
35	Reactor Coolant System Drain Line	WD	Out	5	Inside	Gate
					Inside	Gate
					Outside	Gate
36-37	Intermediate Cooling System	IC	In	4	Inside	Check
					Outside	Check
			Out	3	Inside	Gate
					Outside	Gate
38	Control Rod Drive Seal Water Supply	MU	In	1	Inside	Check
					Outside	Globe
						Globe
39	Fuel Transfer Canal Recirculation Line	SF	Out	15	Inside	Gate
					Outside	Gate
						Gate
40	Core Flooding Tank Sample & Bleed Line	DH	Out	5	Inside	Gate
						Gate
					Outside	Gate

(Cont'd)

	Line Size, in.	Method of Actuation	Signal	Normal Valve Position	Position Indication	Post-Accident Position
	8	EMO	ES	2-Open 1-Closed	Yes	Open
	8	EMO	ES	2-Open 1-Closed	Yes	Open
heck	18	Air	--	Open	No	Closed
	30	Hydr.	ES	Open	Yes	Closed
	3/8	EMO	Remote Manual	Open	Yes	Open
	3/8	EMO	ES	Open	Yes	Closed
	2	---	--	Closed	No	Closed
	2	---	--	Closed	No	Closed
	2-½	EMO	ES	Closed	Yes	Closed
	2-½	EMO	ES	Closed	Yes	Closed
	4	Air	ES	Closed	Yes	Closed
	6	---	--	Open	No	Closed
	6	---	--	Open	No	Closed
	6	EMO	ES	Open	Yes	Closed
	6	AIR	ES	Open	Yes	Closed
	1-½	---	--	Open	No	Closed
	1-½	Air	--	Throttled	Yes	Closed **
	1-½	Manual	--	Closed	No	Closed
	8	Manual	--	Closed	No	Closed
	8	Manual	--	Closed	No	Closed
	4	Manual	--	Closed	No	Closed
	1/2	Solenoid	Remote Manual	Closed	Yes	Closed
	1/2	Solenoid	Remote Manual	Closed	Yes	Closed
	1/2	Solenoid	ES	Closed	Yes	Closed

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5.5 VENTILATION SYSTEM

5.5.1 DESIGN BASES

5.5.1.1 Governing Conditions

The Reactor Building normal ventilation system utilizes the cooling units and removes normal heat loss from equipment and piping in the Reactor Building. A separate system purges the Reactor Building with fresh air whenever desired.

5.5.1.2 Sizing

To provide for access to the Reactor Building, the normal ventilation system will be sized to control the interior air temperature to 110 F during operation and a minimum of 60 F during shutdown.

5.5.2 SYSTEM DESIGN

A flow diagram of the normal ventilation and purge systems is shown in Figure 5.6.

The normal cooling system will utilize the fan-cooler units located in the building outside the secondary shielding. The coolers will use chilled water 17
supplied by a chiller as the heat removal medium and will discharge the cooled air through ducts to provide adequate distribution for the equipment and areas. In addition, air will circulate through the reactor cavity.

During any accident including the M.H.A., the coolers will use low pressure service water through separate cooling coils to reduce the pressure by removing heat from the reactor building atmosphere.

The purge system will consist of a supply fan with a heater and a filter and a discharge fan-filter unit with a prefilter and absolute filter. All of the purge system, except interior ducts, and two isolation valves will be located outside the Reactor Building. Ducts will be provided inside the Reactor Building for adequate distribution.

The purge system discharge to the station vent will be monitored and alarmed to prevent release exceeding acceptable limits.

5.5.2.1 Isolation Valves

As the normal cooling system is contained completely within the Reactor Building, it will not include provisions for any isolation valves other than on cooling water lines. The purge system will be provided with double automatic isolation valves to close in 5 seconds in both the supply and discharge ducts. These valves will be normally closed and will be opened only for the purging operation. They will be electrically actuated inside the Reactor Building and pneumatically actuated outside the Reactor Building.

5.6 LEAKAGE MONITORING SYSTEM

No continuous leakage monitoring system will be provided.

The barrier to leakage in the Reactor Building is the one-quarter inch steel liner plate. All penetrations of whatever type are continuously welded to the liner plate before the concrete in which they are embedded is placed. These penetrations, shown on Figures 5-2 become an integral part of the liner and are so designed, installed and tested.

The steel liner plate is securely attached to the prestressed concrete Reactor Building and is an integral part of this structure. This Reactor Building is conservatively designed and rigorously analyzed for the extreme loading conditions of a highly improbable hypothetical accident, as well as for all other types of loading conditions which could be experienced. Thorough control will be maintained over the quality of all materials and workmanship during all stages of fabrication and erection of the liner plate and penetrations and during construction of the entire Reactor Building.

The comprehensive program for preoperational testing, inspection and post-operational surveillance is described in detail in Section 5.9, "Tests and Inspection," and is summarized in the following paragraphs.

During construction, the entire length of every seam weld in the liner plate is leak tested. Individual penetration assemblies are shop tested. Welded connections between penetration assemblies and the liner plate are individually leak tested after installation. Following completion of construction, the entire Reactor Building, the liner and all its penetrations are tested at 115 per cent of the design pressure to establish structural integrity. The initial leak rate test of the entire Reactor Building is conducted at 100 per cent of the design pressure and at successively lower pressures to demonstrate vapor tightness and to establish a reference for periodic leak testing for the life of the station. Multiple and redundant systems based on different engineering principles are provided as described in 6, "Engineered Safeguards," to provide a very high degree of assurance that the accident conditions will never be exceeded and that the vapor barrier of the containment will never be jeopardized.

Under all normal operating conditions and under accident conditions including the worst loss-of-coolant accident, no possibility exists that any leakage could occur or that the integrity of the vapor barrier could be violated in any way that would be significant to the public health and safety or to that of the station personnel. Adequate administrative controls will be enforced to minimize the possibility of human error. Station operators will be trained and licensed in accordance with regulations. Safety analyses are presented in Section 14.

Penetrations such as the permanent equipment and personnel access hatches cannot be opened except by deliberate action and are interlocked and alarmed by fail-safe devices such that the Reactor Building will not be breached unintentionally. The liner plate over the foundation slab is protected by cover concrete. Wherever access to the liner plate is blocked by interior concrete, means will be provided so that weld seams can be tested for leakage. The liner plate will be protected against corrosion by suitable coatings and by cathodic protection. Walls and floors for biological and missile shielding, and for access and operating purposes, also provide compartmentation which constitutes protection for the liner during operating as well as accident conditions.

Once the adequacy of the liner has been established initially, there is no reason to anticipate progressive deterioration during the life of the station which would reduce the effectiveness of the liner as a vapor barrier. Inside the Reactor Building, the atmosphere is subject to a high degree of temperature control. The outside of the liner is protected by 3-3/4 feet of prestressed concrete which is exceptionally resistant to all weather conditions.

Inspection on a periodic basis, as necessary, will be conducted in all spaces accessible under full power operation. Biological shielding is provided to reduce radiation to limits which make occupancy of spaces adjacent to the liner permissible with a frequency exceeding that of most previous stations. An intensive visual inspection of the Reactor Building inside and outside will be conducted at every regularly scheduled shutdown for fuel replenishment.

All penetrations except the following are grouped and are in penetration areas. Any leakage that might occur from these penetrations will be collected and exhausted through the station vent, as described in 6.5. In this manner, leakage which might occur from these groups of penetrations will be isolated from leakage which might occur through the containment vessel itself.

1. Permanent Equipment Hatch
2. Personnel Access Hatch
3. Main Steam and Feedwater Lines
4. Emergency personnel Hatch

Should there be any indications of abnormal leakage, the source of excessive leakage will be located and such corrective action as necessary will be taken. This will consist of repair or replacement. Appropriate action will also be taken to minimize the possibility of reoccurrence of excessive leakage, including such redesign as might prove to be necessary to protect public health and safety. Leak testing will be continued until a satisfactory leak rate has again been demonstrated.

A considerable background of operating experience is being accumulated on containments and penetrations. Full advantage of this knowledge will be taken in all phases of design, fabrication, installation, inspection, testing and operation. Four stations with similar containment designs will immediately precede this station. Practical improvements in design and details will be incorporated as they are developed, where applicable.

For the foregoing reasons, it has been concluded that a continuous monitoring system is unnecessary. Since there is no such system provided, there can be no misoperation or malfunction which in itself might constitute a hazard. The steel-lined Reactor Building is self-sufficient, and other than valves and hatch doors, there are no operating parts. The containment boundary is extended only by listed penetrations and further described and tabulated in 5.4, "Isolation System" and 5.5, "Ventilation System."

5.7 SYSTEM DESIGN EVALUATION

This containment system is not dependent upon the operation of a system such as a continuous leakage monitoring system for the entire containment, or a continuous leakage surveillance system for containment penetrations and seals, hence neither of these systems is be' furnished. Therefore, no analyses of the capability of these systems are ecessary.

A full evaluation of the containment system which is provided is included in 5.6, "Leakage Monitoring System 'n justification of the omission of such a monitoring system. The React. Building with the appurtenant engineered safeguards systems will prevent uncontrolled release of radioactivity to plant and surrounding areas during normal operating and accident conditions, as well as for lesser accidental conditions. Containment integrity is maintained whenever, simultaneously, the reactor coolant system is pressurized above 300 psig, when the reactor coolant temperature is 200 F or above and when there is nuclear fuel in the core.

5.8 CONSTRUCTION PRACTICES AND QUALITY ASSURANCE

5.8.1 APPLICABLE CONSTRUCTION CODES

The following codes of practice will be used to establish standards of construction procedure:

ACI 301 - Specification for Structural Concrete for Buildings (proposed)

ACI 318 - Building Code Requirements for Reinforced Concrete

ACI 347 - Recommended Practice for Concrete Framework

ACI 605 - Recommended Practice for Hot Weather Concreting

ACI 613 - Recommended Practice for Selecting Proportions for Concrete

ACI 614 - Recommended Practice for Measuring, Mixing and Placing Concrete

ACI 315 - Manual of Standard Practice for Detailing Reinforced Concrete Structures

Part UW - Requirements for Unfired Pressure Vessels Fabricated by Welding of Section VIII of the ASME Boiler and Pressure Vessel Code.

AISC - Steel Manual, Code of Standard Practice

PCI - Inspection Manual

AWS - Code for Welding in Building Construction (D 1.0-66)

AWS - Recommended Practices for Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction (D 12.1-61)

In every instance the construction procedure for the containment will equal or exceed the recommendations set forth in the foregoing publications. The extent to which each detailed process will exceed standard requirements cannot be described without incorporating all applicable job specifications and anticipating [illegible] conditions. In general, however, wherever the applicable codes specify minimum and ideal criteria, the ideal will be incorporated into the specifications.

5.8.2 QUALITY ASSURANCE PROGRAM

5.8.2.1 General

A formal quality assurance organization and reporting system will be employed to assure that critical structures will be built in accordance with the specifications. The Quality Assurance Engineer with surveillance responsibilities will be thoroughly familiar with design drawings, specifications, applicable codes, and quality control requirements. 14

The number of Construction Department field inspectors assigned at any one time will depend upon the requirements of the variable inspection work load and construction schedule. However, one man will be assigned with the responsibility for inspection in each are of activity, i.e., civil, electrical and mechanical. They will be thoroughly familiar with the design engineer's specifications, design drawings, applicable codes, and sampling and testing procedures pertaining to their areas of responsibility. They will be graduate engineers or have equivalent professional experience.

As the inspection work load increases additional, equally qualified, field inspectors will be assigned to perform inspection duties. They will report on inspection matters directly to the Quality Assurance Engineer.

5.8.2.2 Participation of Containment Design Group

The senior engineers of the engineering design groups and engineering specialists such as the Supervising Materials Engineer and Senior Metallurgical Engineers will be at the site during critical periods of construction and testing. They will also be in constant contact with the Quality Assurance Engineer.

Bechtel's rotational program assigns responsible field personnel to the engineering office to gain experience in the design of facilities. This procedure develops field engineers who are well-founded in design and construction practices and are well-qualified to perform inspection assignments. Moreover, they have at their command Bechtel's technical specialists who are called upon to support their organization. Among these are included the soils mechanics and geology, concrete, metallurgical, and welding sections.

The Quality Control organization, which differs little from that of normal projects, will provide an effective inspection and quality control program for the construction of the project.

5.8.2.3 Responsibility of Inspection Group

The field inspection group will be permanently located at the job site. Inspection of materials sources in other parts of the United States will be by Bechtel's normal inspection group with assistance from the design group. They will report any deviations from design or specification requirements directly to the Quality Assurance Engineer. The Quality Assurance Engineer will have the authority to stop work (on construction site only) and assure rectification of the deviation in materials and workmanship quality. In addition, he will report directly to the Bechtel Project Engineer (Home Office.) 14

Independent testing labora ories will be used for quality control testing and reporting of the concrete materials and for the user's testing of reinforcing steel, liner plate and tension material.

The independent testing laboratories report to the Project Field Engineer. 14

The Quality Assurance Engineer will have direct access to all phases of the construction work, and will continuously monitor the field inspector's work. He will report directly to the Project Engineer (Home Office) and will be completely independent of the construction organization.

5.8.3 CONSTRUCTION MATERIALS INSPECTION AND INSTALLATION

Materials to be used in the containment structure include concrete, concrete materials, reinforcing steel, prestressing system materials, and steel liner plate. The user inspection and testing of each material will be as follows:

5.8.3.1 Concrete Materials

(a) Cement

In addition to the tests required by the cement manufacturers, the following user tests will be performed:

ASTM C 114 - Chemical Analysis

ASTM C 115 - Fineness of Portland Cement

ASTM C 151 - Autoclave Expansion

ASTM C 191 - Time of Set

ASTM C 109 - Compressive Strength

ASTM C 190 - Tensile Strength

The purpose of the above tests is to ascertain conformance with ASTM Specification C 150. In addition, tests ASTM C 191 and ASTM C 109 will be repeated periodically during construction to check storage environmental effects on cement characteristics. The tests will supplement visual inspection of material storage procedures.

(b) Water Reducing Agents

A concrete testing laboratory will be engaged to perform the necessary strength and shrinkage tests on various water reducing agents to establish the particular additive with the most desirable characteristics for this application.

(c) Aggregates

User tests of concrete aggregate include the following:

Test			
ASTM No.	Name	Basis For	Results to be Achieved
C 131	Los Angeles Abrasion	ASTM Spec C-33	To conform with specification

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Test ASTM No.	Test Name	Basis For	Results to be Achieved
C 142	Clay Lumps	ASTM Spec C-33	To conform with specification
C 117	Material Finer than #200 Sieve	ASTM Spec C-33	To conform with specification
C 87	Mortar Making Properties	ASTM Spec C-33	To conform with specification
C 40	Organic Impurities	ASTM Spec C-33	To conform with specification
C 289	Potential Reactivity (Chemical)	ASTM Spec C-33	To conform with specification
C 136	Sieve Analysis	ASTM Spec C-33	To conform with specification
C 88	Soundness	ASTM Spec C-33	To conform with specification
C 127	Specific Gravity and Absorption	ASTM Spec C-33	Mix Design Calculations
C 128	Specific Gravity and Absorption	ASTM Spec C-33	Mix Design Calculations
C 295	Petrographic	ASTM Spec C-33	To conform with specification

In addition to the foregoing initial user's tests, a daily inspection control program will be carried on during construction to ascertain consistency in potentially variable characteristics such as gradiation and organic content.

(d) Water

Water to be used in concrete mixing will be sampled and analyzed by a qualified testing laboratory to assure conformance with specifications.

5.8.3.2 Concrete

(a) Design Mix

Design mixes and the associated tests will be provided by a qualified concrete testing laboratory. The design of mixes will be in accordance with ACI 613 to obtain material proportions for the specified concrete. During construction the field inspection personnel will make any minor modifications that may be necessitated by variations in aggregate gradation or moisture content.

(b) Compressive Strength

Concrete strength, a slump, and temperature inspections will be performed. The purpose of the test and inspection is to ascertain conformance to

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specifications. The basis for the proposed inspection procedure is ACI Manual of Concrete Inspection with upgraded modifications to meet the more stringent requirements of this application.

5.8.3.3 Reinforcing Steel

(a) Material

All reinforcing steel will be user-tested in accordance with ASTM specifications. Tests will include one tension and one bend test per heat or per mill shipment, whichever is less, for each diameter bar. Test samples will be obtained at the fabrication plant. High strength bars will be clearly identified prior to shipment to prevent any possibility of mix-up with lower strength reinforcing bars.

(b) Mechanical Splices

The "Cadweld" inspection program is detailed in Appendix 5-C. Ordinary welded splices will not be used for main bars in the containment structure, as stated in 5.1.3.3.

(c) Fabrication

Visual inspection of fabricated reinforcement will be performed to ascertain dimensional conformance with specifications and drawings.

(d) Placement

Visual inspection of in-place reinforcement will be performed by the placing inspector to assure dimensional and location conformance with drawings and specifications.

5.8.3.4 Prestress System

(a) Wires

Sampling and testing of the tendon material used in construction will conform to ASTM Standard A-421 or ASTM A-416. The following procedure will be used:

a) Buttonhead rupture tests from each reel of wire will be made.

b) Each size of wire from each mill heat and all strands from each manufactured reel to be shipped to the site shall be assigned an individual lot number and tagged in such a manner that each such lot can be accurately identified at the job site. Anchorage assemblies shall likewise be identified. All unidentified prestressing steel or anchorage assemblies received at the job site will be subject to rejection.

c) Random samples as specified in the ASTM Standards stated above will be taken from each lot of prestressing steel to be used in the work. With each sample of prestressing steel wire or strand that is tested, there shall be submitted a certificate stating the manufacturer's minimum guaranteed ultimate tensile strength of the sample to be tested. Stress-strain curves will be plotted and the yield and tensile strength verified. For the prefabricated tendons, one completely fabricated prestressing test specimen 5 feet in length including anchorage assemblage, will be tested for each size of tendon contained in an individual manufacturing run. The anchorages will develop the minimum guaranteed ultimate strength of the tendon and the minimum elongation of the tendon material as required by the applicable ASTM specification.

Field inspection will ensure that there are no visible mechanical or metallurgical notches or pits in the tendon material.

(b) Installation

All prestressing installation work shall be continuously inspected by a qualified inspector. All measuring equipment used for installation will be calibrated and certified by an approved independent testing laboratory. During stressing operations, records will be kept by Bechtel for use in comparing force measurements with elongation for all tendons. The resultant cross-reference will provide a final check on measurement accuracy. Measurement accuracy and rejection allowances will be in accordance with ACI-318, Chapter 26.

(c) Grease

Grease will be sampled after delivery and submitted to a qualified testing laboratory for chemical analysis to establish conformance with specifications.

5.8.3.5 Containment Liner

(a) Steel Plate

Steel plate will be tested at the mill in full conformance to the applicable ASTM specifications. Certified mill test reports will be supplied for review and approval by the design group in the Project Engineer's office.

There will be no impact testing done on the liner plate material. The purpose of impact testing is to provide protection against brittle failure. The possibility of a brittle fracture of the liner plate is precluded because at the design accident pressure condition there will not be any tensile stress anywhere in the liner plate. This is true whether there is instantaneous release of pressure or there is some time lag in temperature load application. Therefore, the NDT temperature of the liner plate loses significance.

(b) Fabrication and Installation

Welding inspection will conform to the quality control inspection procedure described in detail by Appendix 5-G.

Dimensional tolerances will be checked by an installation inspector to prevent unanticipated installation deformations.

5.8.4 SPECIFIC CONSTRUCTION TOPICS

5.8.4.1 Bonding of Concrete Between Lifts

Horizontal construction joints will be prepared for receiving the next lift by wet sandblasting, by cutting with an air-water jet, or by bush hammering. Surface set retardant compounds will not be used.

When wet sandblasting is to be employed, it will be continued until all laitance, coating, stains, debris, and other foreign materials are removed. The surface of the concrete will be washed thoroughly to remove all loose material.

When air-water cutting is to be used, it will be performed after initial set has taken place but before the concrete has taken its final set. The surface will be cut with a high pressure air-water jet to remove all laitance and to expose clean, sound aggregate, but not so as to undercut the edges of the larger particles of aggregate. After cutting, the surface will be washed and rinsed as long as there is any trace of cloudiness of the wash water. Where necessary to remove accumulated laitance, coatings, stains, debris, and other foreign material, wet sandblasting will be used before placing the next lift, to supplement air-water cutting.

Horizontal surfaces will be wetted and covered with one-quarter inch to one-half inch of mortar of the same cement-sand ratio as used in the concrete, immediately before the concrete is placed.

Vertical joints will also be sandblasted or bush hammered, cleaned, and wetted before placing concrete.

5.8.4.2 Prestressing Sequence

The detailed stressing sequence will be based on the following general requirements to minimize unbalanced loads and differential stresses in the structure.

(a) No significant amount of horizontal or dome stressing will be permitted until sufficient vertical stressing is completed. The required minimum vertical stressing will be determined as part of the final design. The vertical stressing is effective in partially resisting meridianal moments and must precede dome and horizontal stressing. Vertical prestressing will be done by a minimum of six jacks spaced evenly about the circumference. Stressing positions will be alternated to prevent concentrations of multiple stressed tendons adjacent to multiple unstressed tendons.

(b) Dome stressing will follow vertical stressing but will precede horizontal stressing. It will also be done with a minimum of six jacks, with two jacks working on a single tendon in each of the three systems oriented at 120 degrees. The dome stressing will be alternated to prevent large concentrations of stressed tendons.

(c) Horizontal tendons will also be stressed from both ends. A minimum of six jacks will operate to stress a complete ring of tendons prior to moving to another level. Stressing operations will progress from the top to the bottom, taking every fourth or fifth tendon on each successive trip.

The procedure for prestressing will be carefully worked out with the post-tensioning vendor.

All procedures will be subject to the approval of Bechtel Corporation.

Bechtel will provide to the vendor prestressing force requirements anticipated concrete elastic, shrinkage, and creep prestress losses, and the maximum prestress forces for each stage of prestressing. The vendor will incorporate all this information along with any steel relaxation, friction, and anchorage losses to establish the initial jacking force for each sequential operation.

Force and stress measurements will be made by measuring the elongation of the prestressing steel and comparing it with the force indicated by the jack-dynamometer or pressure gage. The gage will indicate the pressure in the jack within plus or minus two per cent. Force-jack pressure gage or dynamometer combinations will be calibrated against known precise standards just before application of prestressing forces begins and all calibrations will be so certified prior to use. Pressure gages and jacks so calibrated will always be used together.

During stressing, records will be kept of elongations as well as pressure obtained. Jack-dynamometer or gage combinations will be checked against elongation of the tendons and the cause of any discrepancy exceeding plus or minus five per cent of that predicted by calculations (using average load elongation curves) will be corrected, and if caused by differences in load-elongation from averages will be so documented. Calibration of the jack dynamometer or pressure gage combinations will be maintained accurately within above limits.

5.9 CONTAINMENT SYSTEM INSPECTION, TESTING, AND SURVEILLANCE

5.9.1 TESTS TO ENSURE LINER INTEGRITY

As the structure is constructed and after it is complete with liner, concrete structures, and all electrical and piping penetrations, equipment hatch, and personnel locks in place, the following tests will be performed.

(a) Construction Tests: These take place during the erection of the containment structure liner.

(b) Pre-operational Tests: These are performed after the erection of the structure is complete but before reactor operation.

5.9.1.1 Tests on Liner During Construction

Inspection procedures to be employed during construction for the liner seam welds, liner fastening, and around penetrations will consist of visual inspection, vacuum box soap bubble testing, radiography, and dye penetrant testing.

(a) Visual Inspection of Welds

All of the welding will be visually examined by a technician responsible for welding quality control. The criteria for workmanship and visual quality of welds will be as follows:

Each weld will be uniform in width and size throughout its full length. Each layer of welding shall be smooth and free of slag, cracks, pinholes, and undercut, and shall be completely fused to the adjacent weld beads and base metal. In addition, the cover pass shall be free of coarse ripples, irregular surface, non-uniform bead pattern, high crown, and deep ridges or valleys between beads. Peening of welds will not be permitted.

Butt welds shall be of multipass construction, slightly convex, of uniform height, and have full penetration.

Fillet welds shall be of the specified size, with full throat and legs of uniform length.

(b) Soap Bubble Tests

All of the welding which will be covered by concrete or otherwise inaccessible after construction will be vacuum box soap bubble tested. In this test a vacuum box containing a window is placed over the area to be tested and is evacuated to produce at least 5 psi pressure differential. Before the vacuum box is placed over the test area, a soap solution is applied to the weld and any leaks will be indicated by bubbles observed through the window in the box. The soap solution consists of equal parts of corn syrup, liquid detergent, and glycerin. The solution shall be prepared not more than 24 hours preceding the test and its bubble formation properties shall be checked with a sample leak every half hour during the test.

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(c) Radiography

Radiography will be used as an aid to quality control. The primary purpose of the liner plate and the welds therein is to provide leak tightness integrity to the post-tensioned concrete containment vessel. Structural integrity of the containment is provided by the post-tensioned concrete and not by the liner plate.

Radiography is not recognized as an effective method for examining welds to assure leak tightness. Therefore, the only benefit which can be expected from radiography in connection with obtaining leak tight welds is an aid to quality control. Random radiography of each welder's work will provide structural verification that the welding is or is not under control and being done in accordance with the previously established and qualified procedures. Additionally, employing random radiography to inspect each welder's work has been proved by past experience to have a positive psychological effect on improving overall welding workmanship.

The criterion for radiographic techniques shall be in accordance with Paragraph UW-51 of Section VIII of the ASME Code. At least one spot radiograph shall be taken in the first 10 feet of welding completed in the flat, vertical, horizontal, and overhead positions by each welder.
5 Thereafter, approximately 10 per cent of the welding will be spot examined on a random basis, in such manner that an approximately equal number of spot radiographs will be taken from the work of each welder.

(d) Dye Penetrant

Dye penetrant inspection will also be used as an aid to quality control. The field welding inspectors will use dye penetrant inspection to closely examine welds judged to be of questionable quality on the basis of the initial visual inspection. Also, dye penetrant inspection will be used to confirm the complete removal of all defects from areas which have been prepared for repair welding. Dye penetrant inspection of liner plate welds will be in accordance with Appendix VIII, "Methods for Liquid Penetrant Examination," of Section VIII of the ASME Boiler and Pressure Vessel Code.

(e) Initial Leak Test for Base Slab Liner Plate Welds

The welds for each section of base slab liner plate will be vacuum box soap bubble tested immediately upon installation. After successfully passing this leakage test, they will be covered with test channels and the particular welds associated with that section of liner plates will be pressure tested for a period of at least 15 minutes with no drop in pressure. Any repairs will be carried out utilizing the same high standards and control exercised in the initial construction.

5.9.1.2 Pre-operational Integrated Leak Test

The design leak rate will not be more than 0.2 per cent by volume of the contained atmosphere in 24 hours at 59 psig. It has been demonstrated that, with good quality control during erection, this is a reasonable requirement. 3

The basis of the leak rate test is the reference volume method. Every effort is made to demonstrate the leak tightness of the reference volume system. The entire reference volume system is pressurized to a minimum of 100 psig with air containing 20 weight per cent Freon. All reference volume joints are bagged with plastic and the system held at this pressure for 48 hours. The reference volume system, especially the joints, is checked with a halogen leak detector to demonstrate integrity.

In addition to the usual calculation of leak rate as a function of pressure differential, air is returned to the reactor containment at the conclusion of the test through a precision gas meter until the differential pressure is returned to its original condition. This provides a check on the calculated leak rate. Reactor containment ambient temperature and humidity are also measured during the course of the test to provide further backup information.

The initial leak rate test consists of establishing a leak rate at 59 psig. Because the containment is a thick-walled concrete structure, short-term temperature or meteorological variations should not have any appreciable effect on the containment ambient temperature and pressure. It should, therefore, be possible to establish meaningful leak rates in shorter term test than might be required on a bare steel vessel. The containment will be held at each test pressure for a minimum of 24 hours.

5.9.2 STRENGTH TEST

A pressure test will be made on the completed building using air at 68 psig. This pressure will be maintained on the building for a period of one hour. During this test, measurements and observations as described in Appendix 5-H will be made to verify the adequacy of the structure design. 5

5.9.3 IN-SERVICE TENDON SURVEILLANCE PROGRAM

The in-service surveillance program for the containment structure consists of evaluating the tendon system performance and the corrosion protection system performance. Further, the containment structure is a passive type system where mechanical operational failures are non-existent, thus only requiring that the system remain in status quo and available to perform its function in the unlikely event that it will be required. It is the intent of the surveillance programs to provide sufficient in-service historical evidence necessary to maintain the confidence that the integrity of the containment structure is being preserved.

To accomplish the surveillance program, the following quantity of tendons will be made available for inspection and lift-off readings.

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5 Horizontal - Three 240° tendons comprising two complete hoop systems.

Vertical - Three tendons spaced approximately 120° apart.

Dome - Three tendons spaced approximately 120° apart.

The surveillance program for structural integrity and corrosion protection will consist of the following operations being performed during each inspection.

(a) Lift-off readings will be taken for all nine tendons.

(b) One tendon of each directional group will be relaxed and three wires or one strand removed as samples for inspection.

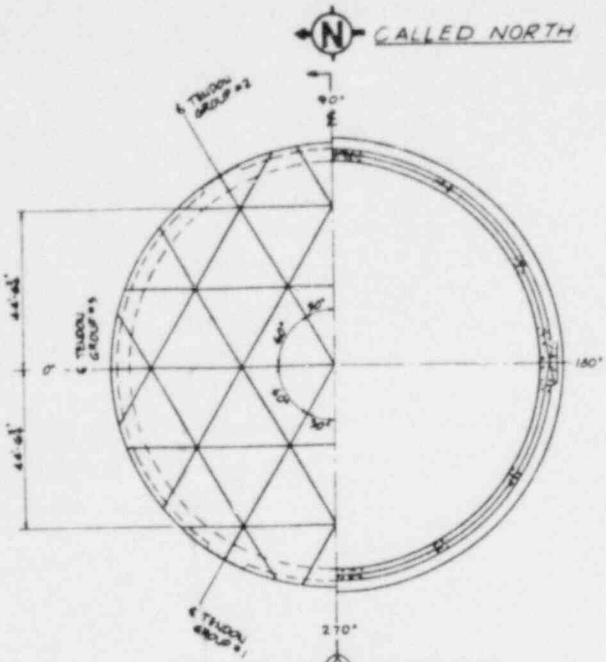
(c) After the inspection the tendons will be retensioned to the stress level measured at the lift-off reading, and then checked by a final lift-off reading.

(d) Should the inspection reveal any significant corrosion (pitting, or loss of area), further inspection of the other two sets will be made to determine the extent of the corrosion and its significance to the load-carrying capacity of the structure. Samples of corroded wire or strand will be tested to failure to evaluate the effects of any corrosion.

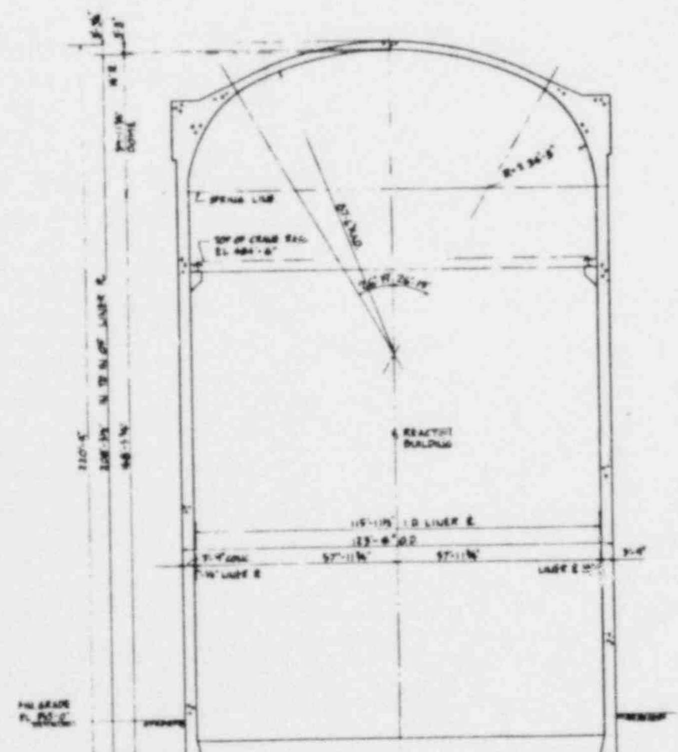
Inspection requirements for containment, as well as those for other systems, will be a part of the technical specifications for the plant and will be included in the operating license application. Changes in these inspection requirements or their elimination at any time during plant life will be subject to AEC regulations governing technical specifications and will require review and approval by the AEC after justification by the applicant.

A conservative testing frequency will be established at the operation license stage and nothing in the design of the containment will preclude the testing of tendons or pneumatic testing of the containment at any time in its life.

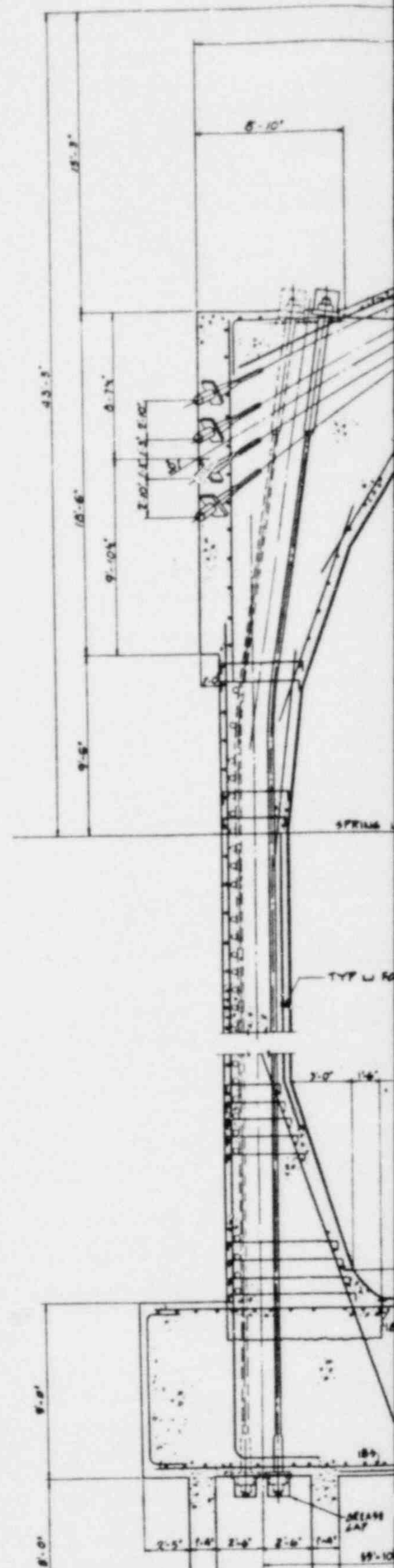
It is expected that experience gained in surveillance testing of the containment structure as well as from other sources during the life of the plant will show that testing frequency can be relaxed subject to AEC review and approval.

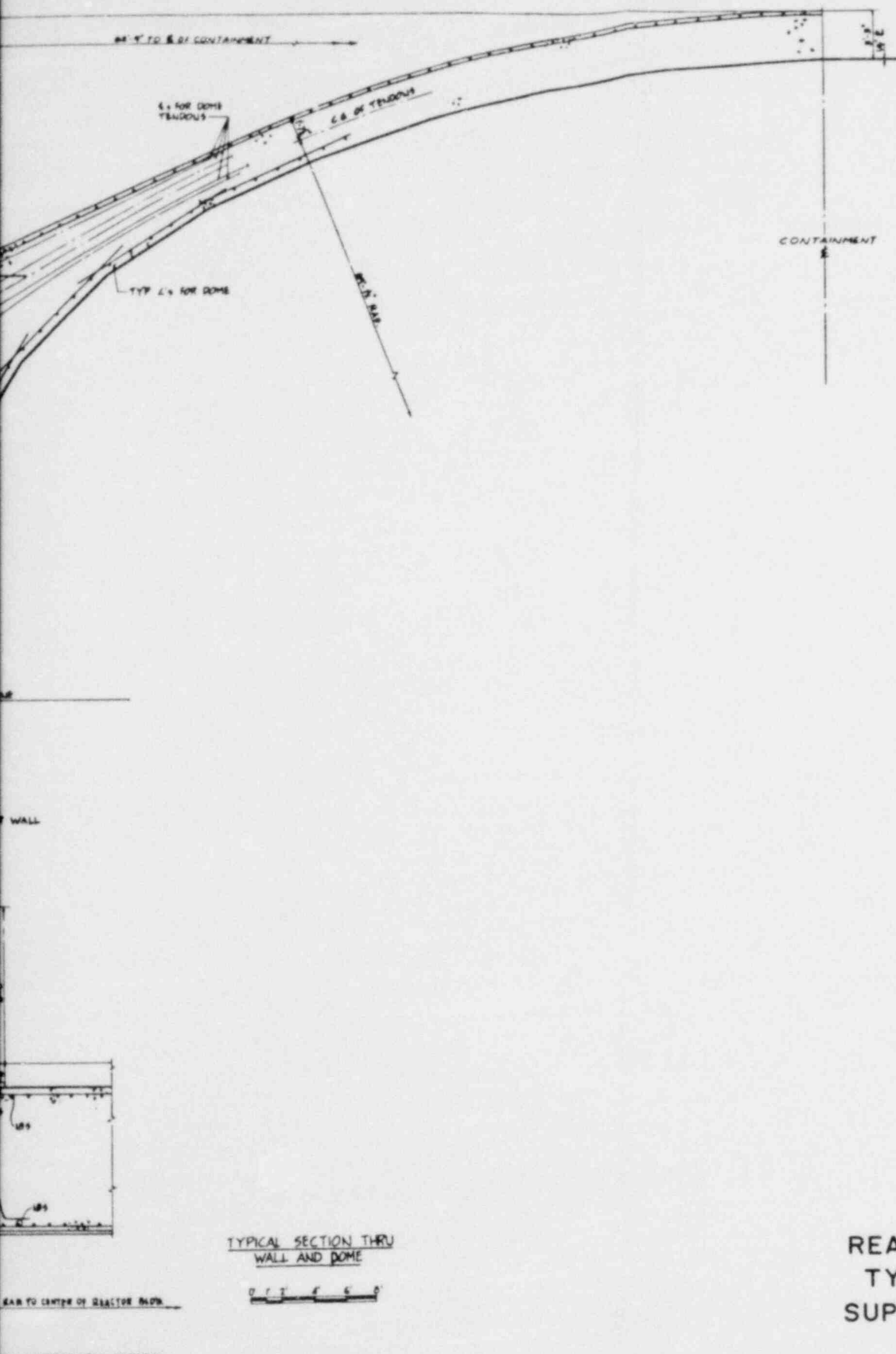


ROOF PLAN FLOOR PLAN

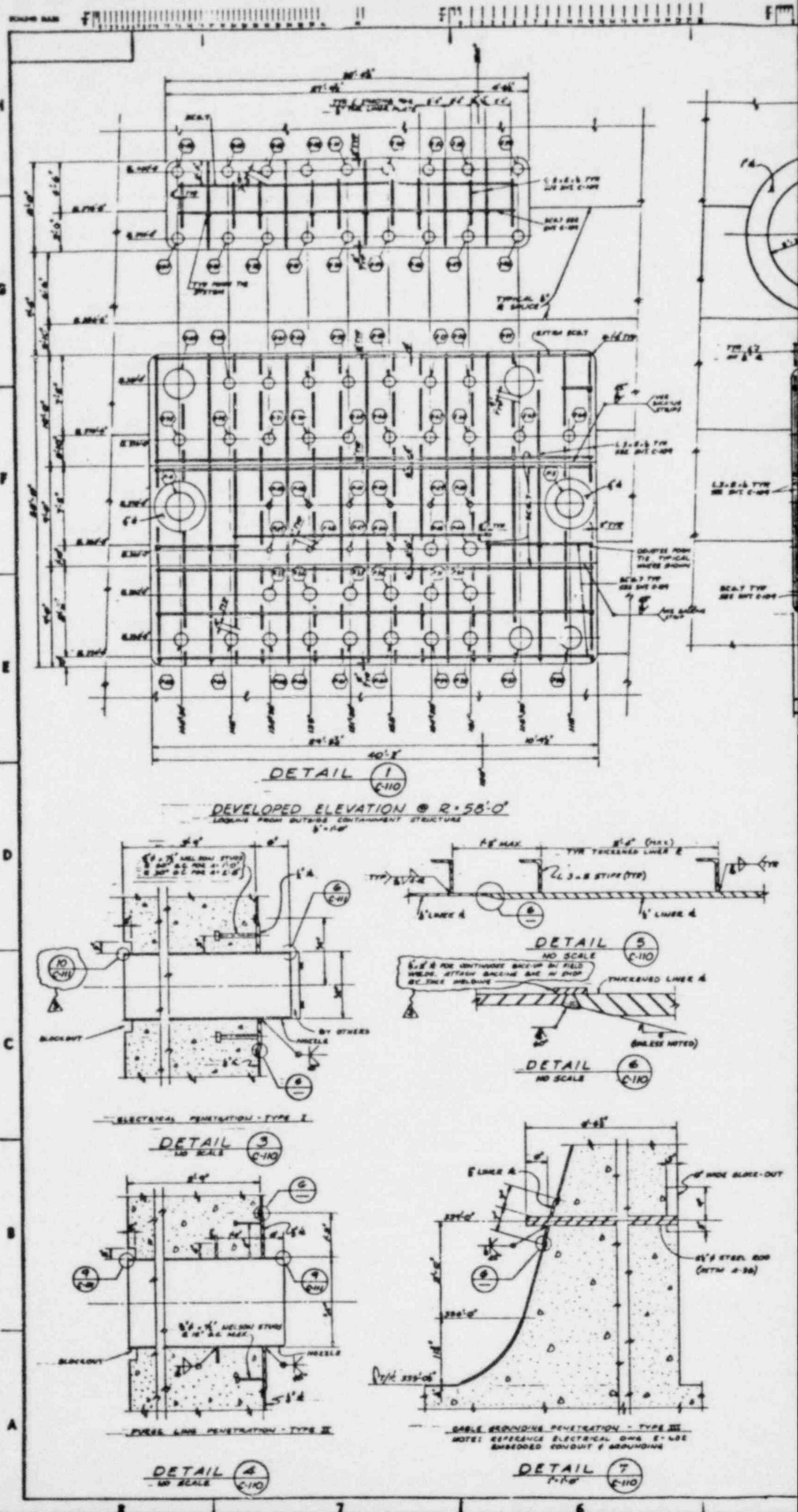


SEC. A





REACTOR BUILDING
TYPICAL DETAILS
SUPPLEMENT No. 5
Figure 5-1


DETAIL 1 C-110
DEVELOPED ELEVATION @ R=58'-0"
LOOKING FROM OUTSIDE CONTAINMENT STRUCTURE
DETAIL 5 NO SCALE C-110
THICKENED LINER
DETAIL 6 NO SCALE C-110
BLOCKOUT
BY OTHERS
NOZZLE
ELECTRICAL PENETRATION - TYPE I
DETAIL 3 NO SCALE C-110
PURGE LINE PENETRATION - TYPE II
DETAIL 4 NO SCALE C-110
CABLE GROUNDING PENETRATION - TYPE III
DETAIL 7 C-110
H
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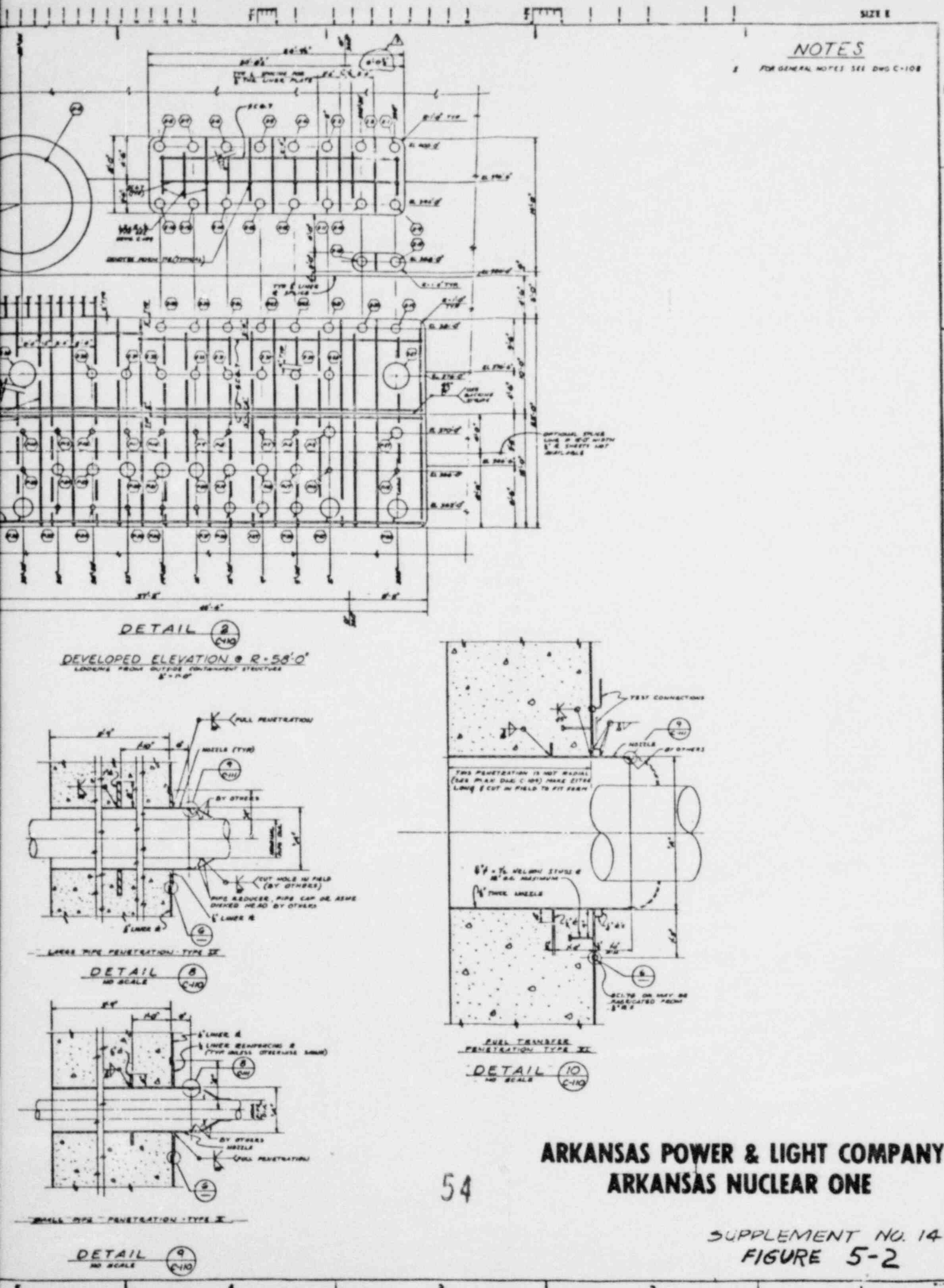
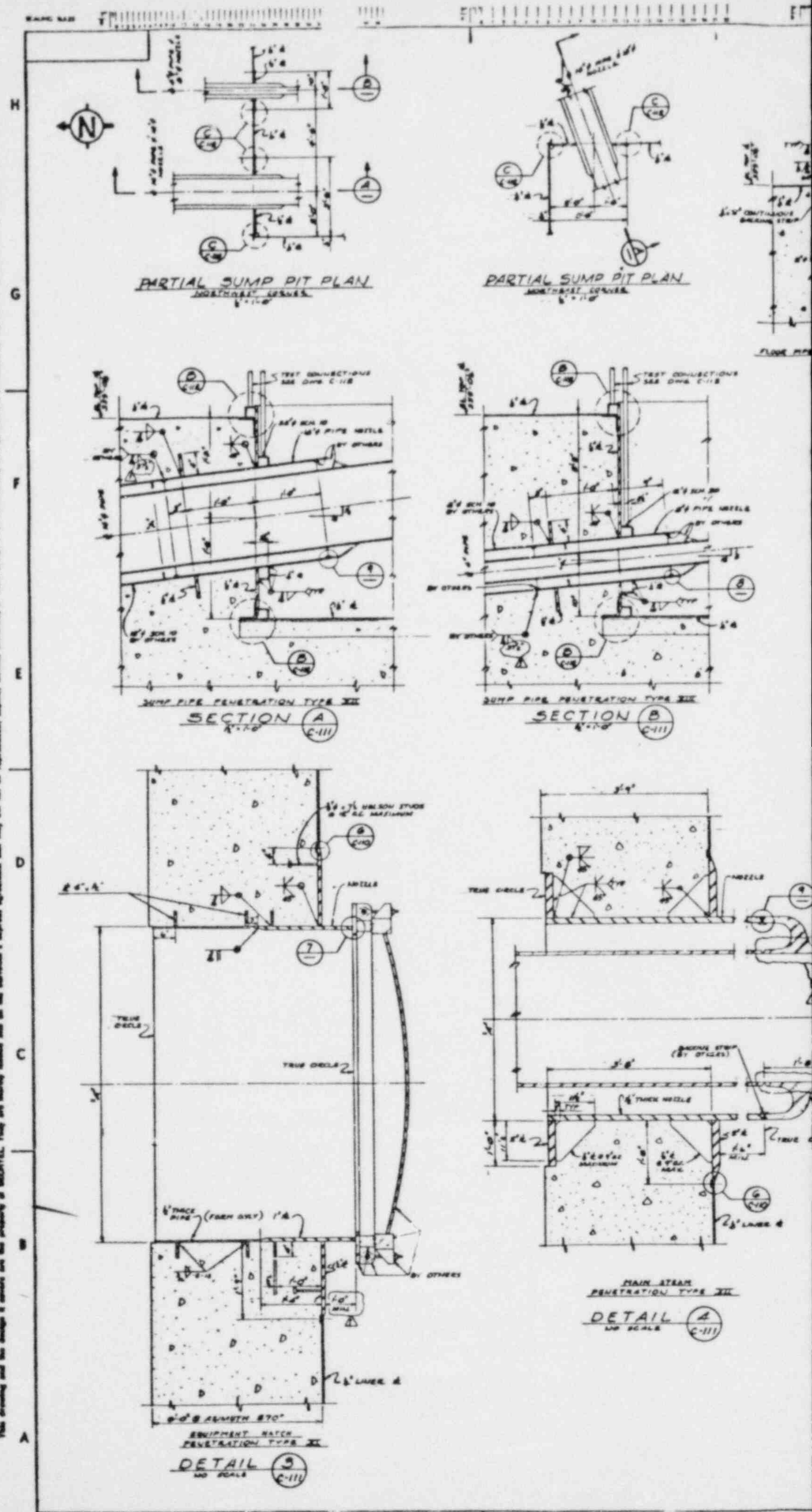


ARKANSAS POWER & LIGHT COMPANY
ARKANSAS NUCLEAR ONE

SUPPLEMENT NO. 14
FIGURE 5-2


PARTIAL SUMP PIT PLAN
PARTIAL SUMP PIT PLAN
TEST CONNECTIONS SEE DWG C-118
BY OTHERS
SECTION A C-111
SECTION B C-111
TRUE CIRCLE
NOZZLE
BY OTHERS
DETAIL 3 C-111
NO SCALE
MAIN STEAM
DETAIL 4 C-111
NO SCALE

55

SIZE E

NOTES

1. FOR GENERAL NOTES SEE DWG. E-108
2. SPIDERS AND/OR SUPPORTS SHALL BE SUPPLIED DURING FABRICATION, STRESS RELIEVING, SHIPPING & ERECTION TO MAINTAIN THE SPECIFIED NOZZLE TOLERANCES & INSIDE DIAMETERS
3. NOZZLE TOLERANCES

3.1 THE FOLLOWING INFORMATION PERTAINS TO THE INSIDE END OF ALL NOZZLES EXCEPT IT SHALL PERTAIN TO BOTH ENDS FOR THE TYPE I & X PENETRATIONS.

3.2 THE FOLLOWING INFORMATION SHALL BE USED FOR ALL TYPE I, X & XI PENETRATIONS.

THE PERMISSIBLE VARIATION OF THE DIAMETER OF THE NOZZLE SHALL NOT EXCEED THE FOLLOWING:

(A) OUTSIDE DIAMETER – BASED ON CIRCUMFERENTIAL MEASUREMENT ±.5% OF THE SPECIFIED DIAMETER

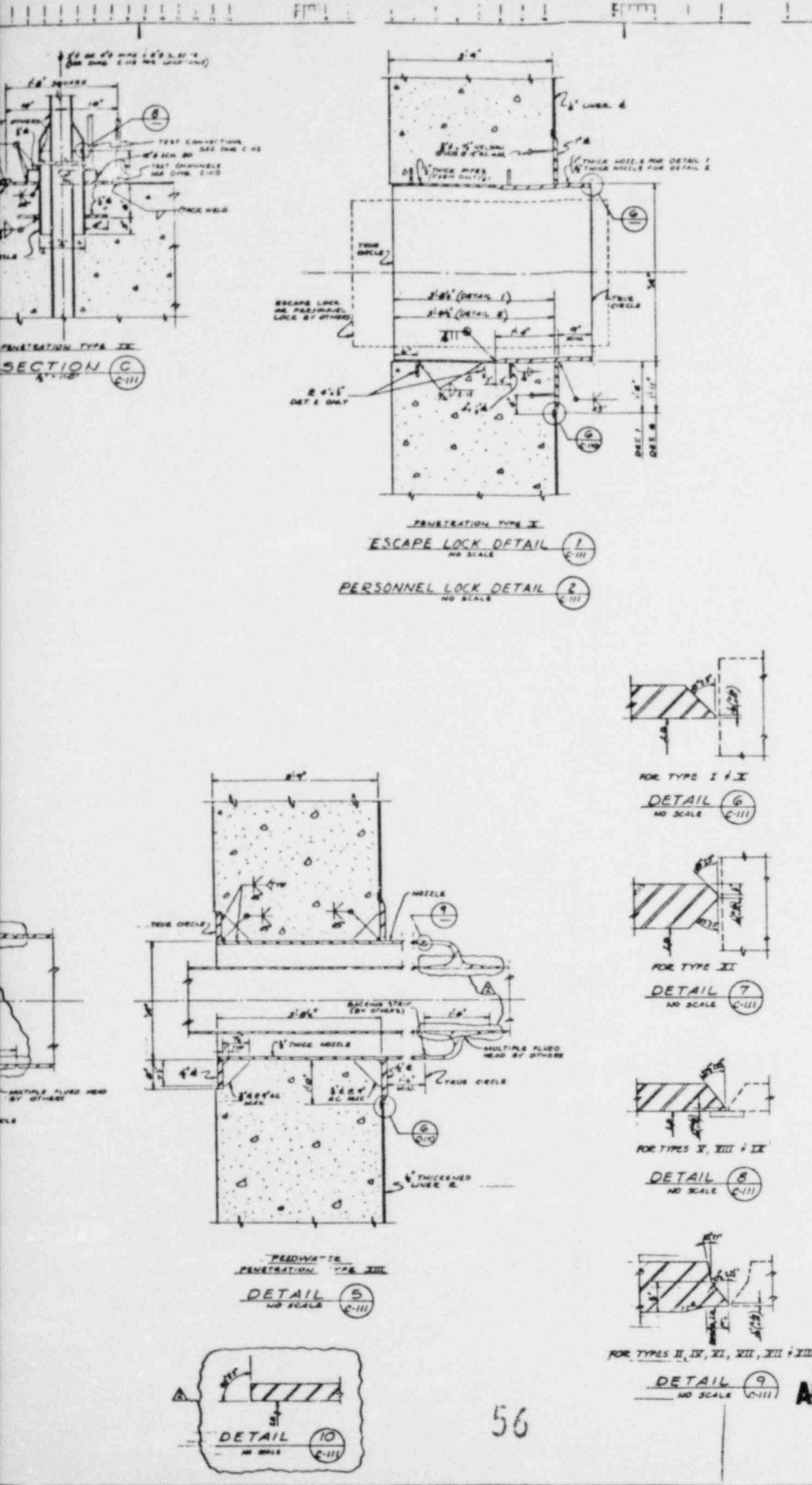
(B) OUT OF ROUNDNESS – THE DIFFERENCE BETWEEN THE MAJOR AND MINOR INSIDE DIAMETERS, 1.0%

3.3 FOR ALL TYPE IV, V, XII, XIII & IX PENETRATIONS THE PERMISSIBLE VARIATIONS IN WEIGHT & DIMENSIONS SHALL CONFORM TO THE VALUES GIVEN IN ASTM A-106

3.4 THE FOLLOWING TOLERANCES IN TABLE I SHALL PERTAIN TO THE PENETRATION TYPES LISTED.

TABLE I

TYPE	NOM DIA	INSIDE DIAMETER (in)	NOM THICKNESS (in)	MIN THICKNESS (in)
IV	1'-8"	18.646 ±.09	.330	[illegible]
IV/XII	1'-6"	16.646 ±.09	.750	[illegible]
IV	2'-0"	22.757 ±.05	.687	.60
XIII	3'-0"	34.90 ±.0625	.750	.750
XI	4'-0"	47.00 ±.0625	.90	.90
II	4'-6"	53.00 ±.0625	.90	.90
XII	4'-6"	51.00 ±.0625	1.50	1.50



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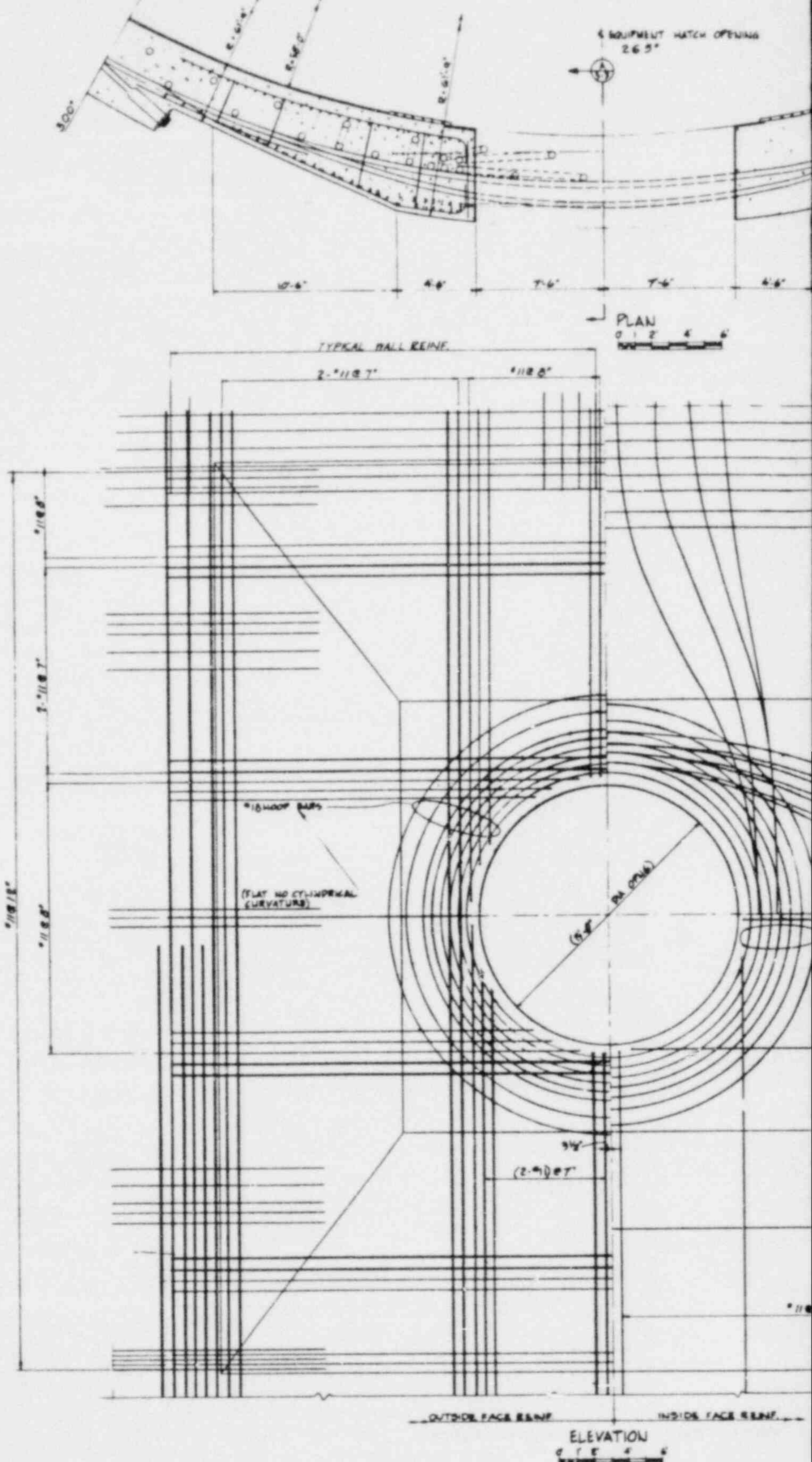
ARKANSAS POWER
& LIGHT COMPANY
ARKANSAS NUCLEAR ONE

SUPPLEMENT NO. 14
FIGURE 5-3



℄ EQUIPMENT HATCH OPENING
265°
300°
10'-6"
4'-6"
7'-6"
7'-6"
4'-6"
PLAN
TYPICAL WALL REINF.
ELEVATION
OUTSIDE FACE REINF.
INSIDE FACE REINF.

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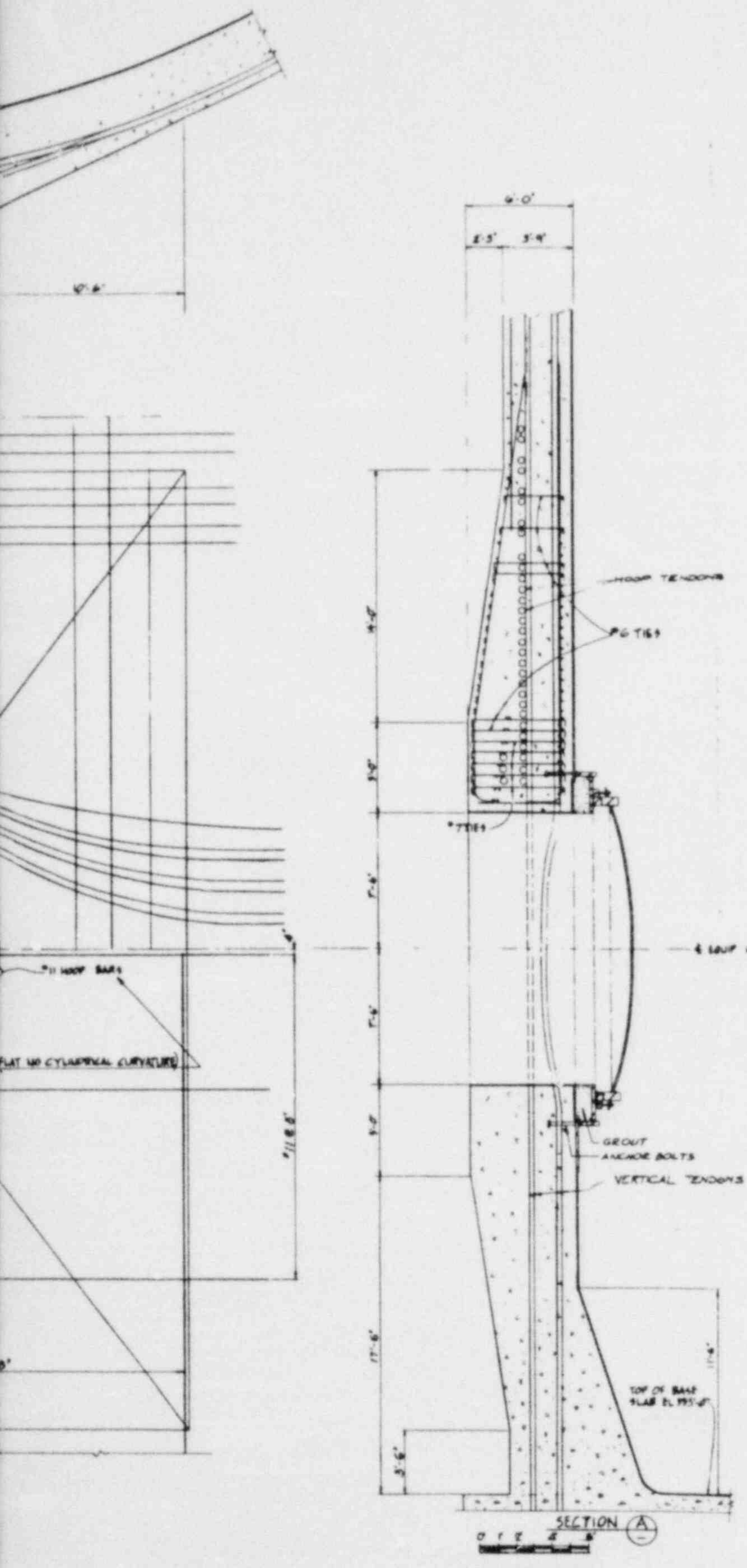
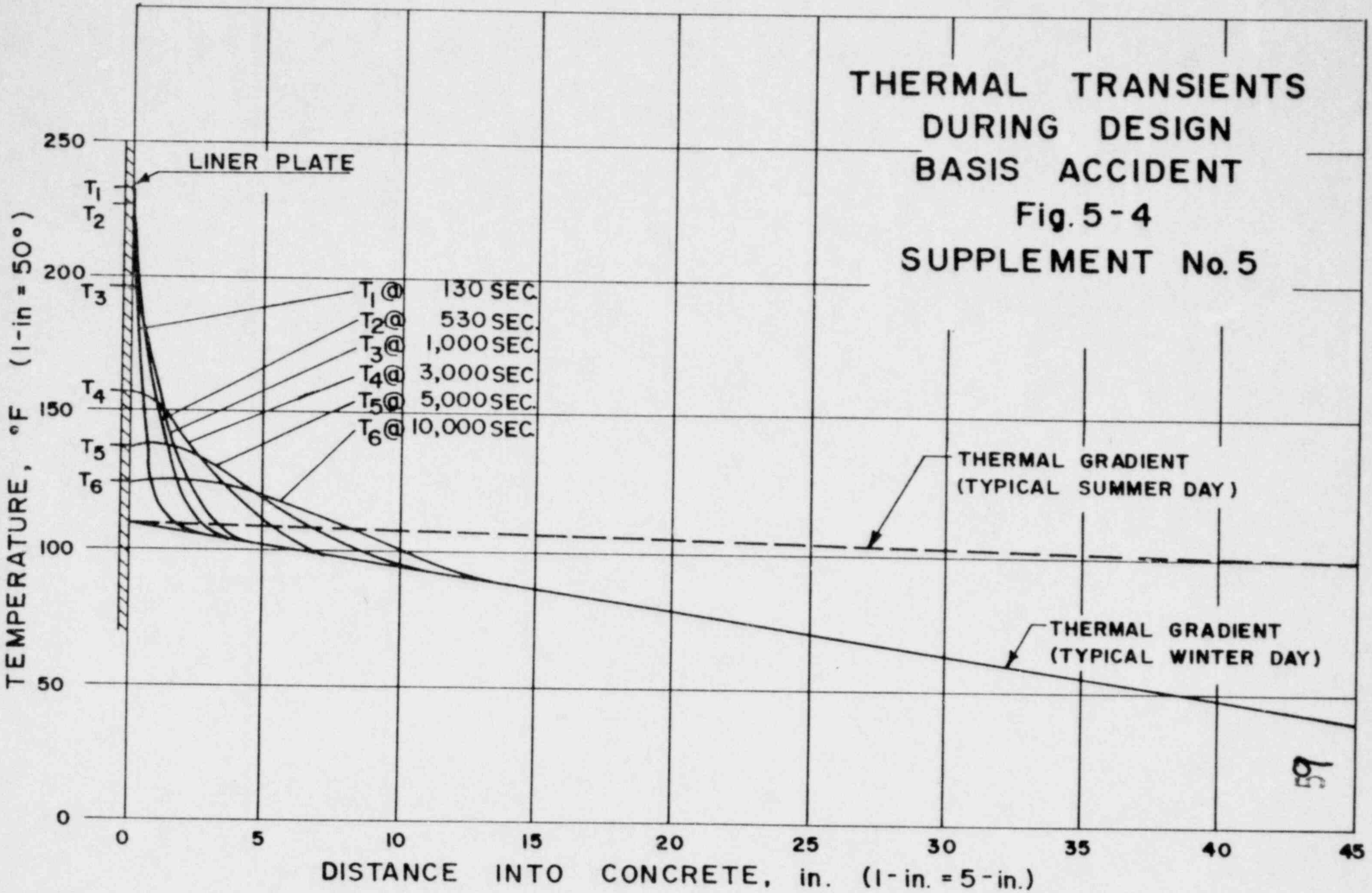
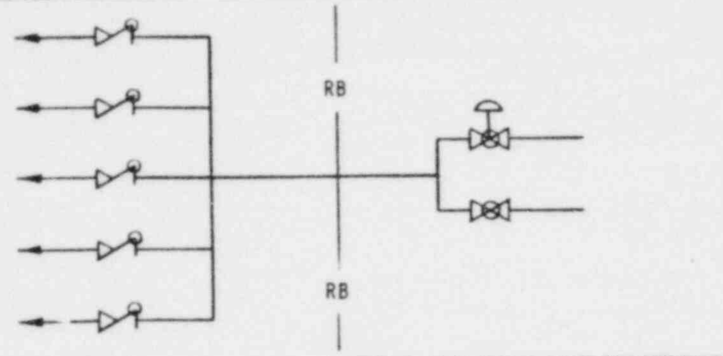
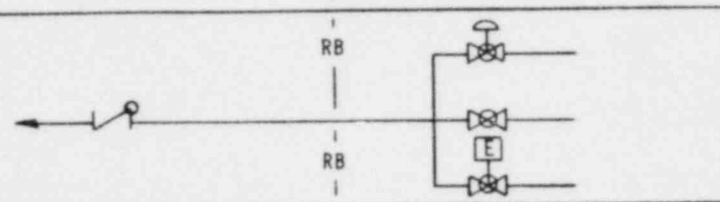
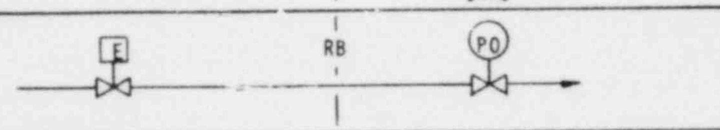
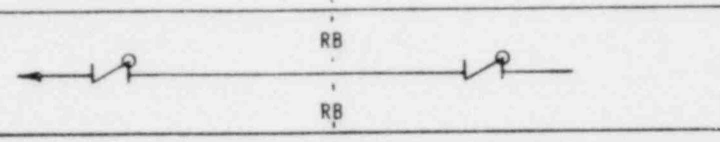
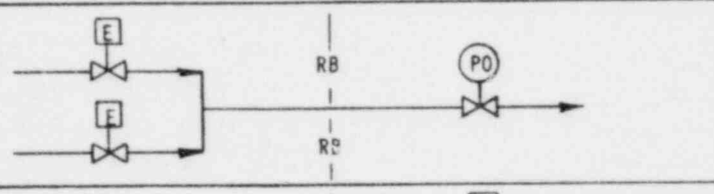
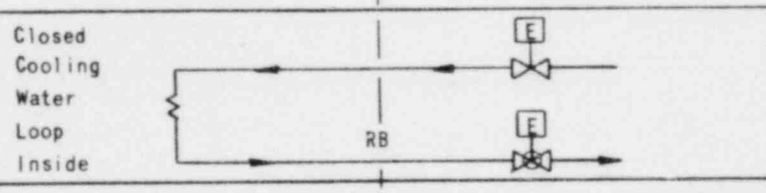
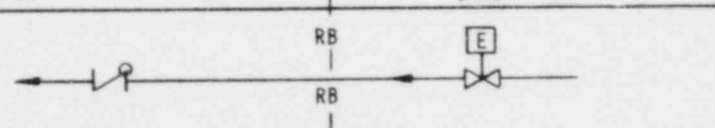
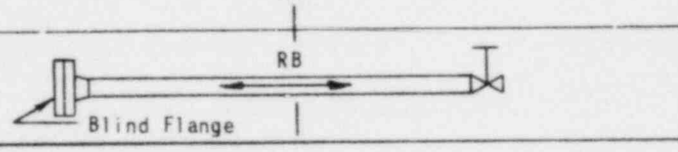


DETAILS OF EQUIPMENT HATCH
REACTOR BUILDING
SUPPLEMENT No. 17
Figure 5-3A



THERMAL TRANSIENTS
DURING DESIGN
BASIS ACCIDENT
Fig. 5-4
SUPPLEMENT No. 5
LINER PLATE
T_1 @ 130 SEC.
T_2 @ 530 SEC.
T_3 @ 1,000 SEC.
T_4 @ 3,000 SEC.
T_5 @ 5,000 SEC.
T_6 @ 10,000 SEC.
THERMAL GRADIENT
(TYPICAL SUMMER DAY)
THERMAL GRADIENT
(TYPICAL WINTER DAY)
TEMPERATURE, °F (1-in = 50°)
DISTANCE INTO CONCRETE, in. (1-in. = 5-in.)
0
50
100
150
200
250
5
10
15
20
25
30
35
40
45
59

<table>
<tr><th>VALVE ARRGT</th><th>INSIDE REACTOR BUILDING</th><th>OUTSIDE REACTOR BUILDING</th><th>PENE-TRATION NO. AND TYPE</th></tr>
<tr><td>1</td><td colspan="2"></td><td>5, 38
(TYPE I)</td></tr>
<tr><td>2</td><td colspan="2"></td><td>6
(TYPE I)</td></tr>
<tr><td>3</td><td colspan="2"></td><td>2
(TYPE II)
31,32,37
(TYPE III)</td></tr>
<tr><td>4</td><td colspan="2"></td><td>33, 34
(TYPE I)
36
(TYPE III)</td></tr>
<tr><td>5</td><td colspan="2"></td><td>1,3,4,40
(TYPE I)
35
(TYPE III)</td></tr>
<tr><td>6</td><td colspan="2"></td><td>19-26 INCL.
(TYPE III)</td></tr>
<tr><td>7</td><td colspan="2"></td><td>7a,7b,7c,7d
11,12
(TYPE I)
9,10
(TYPE II)</td></tr>
<tr><td>8</td><td colspan="2"></td><td>8
(TYPE IV)</td></tr>
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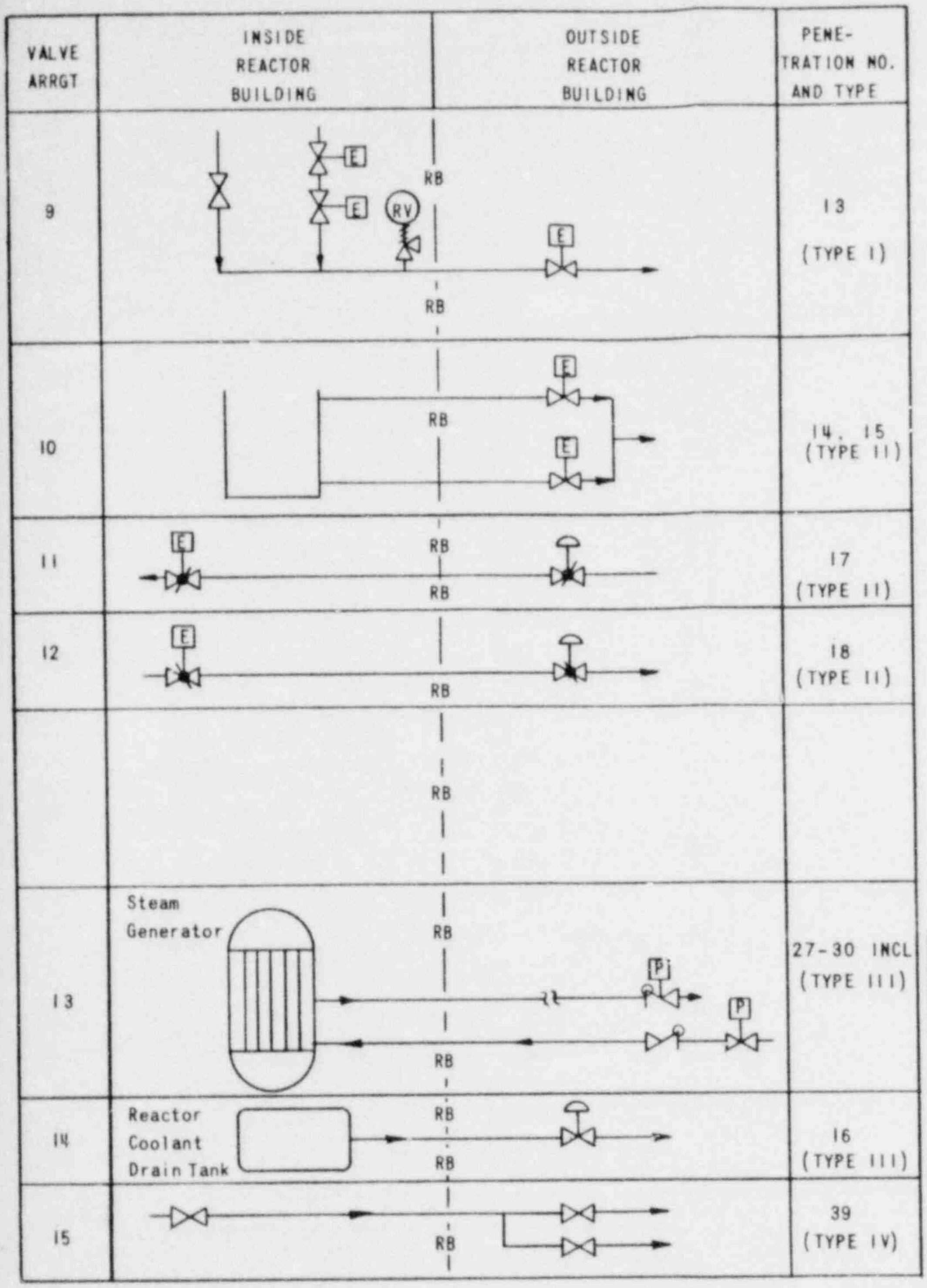
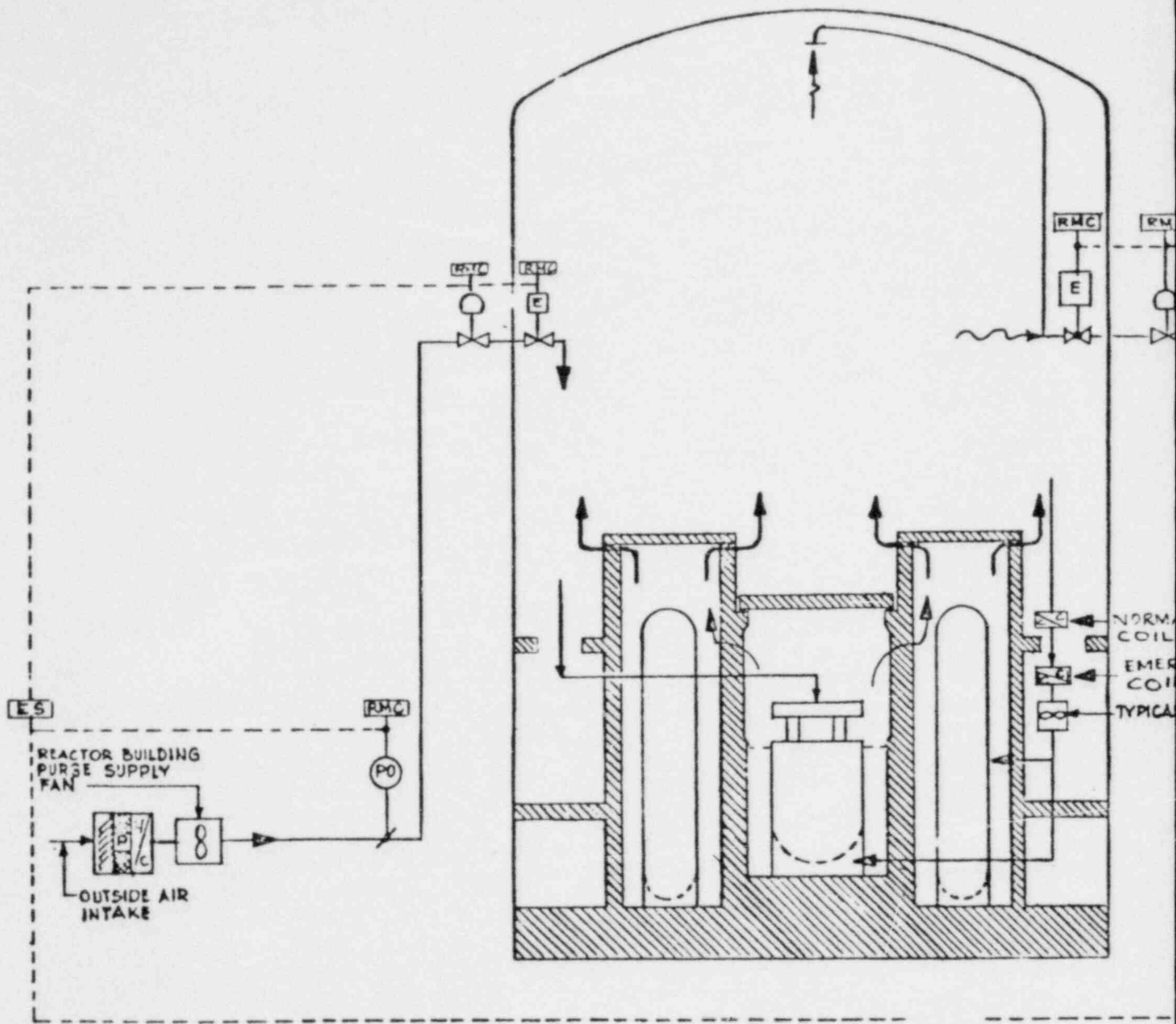


REACTOR BUILDING ISOLATION VALVE ARRANGEMENT

FIGURE 5-5

REVISED 2-8-68



LEGEND

LOUVER

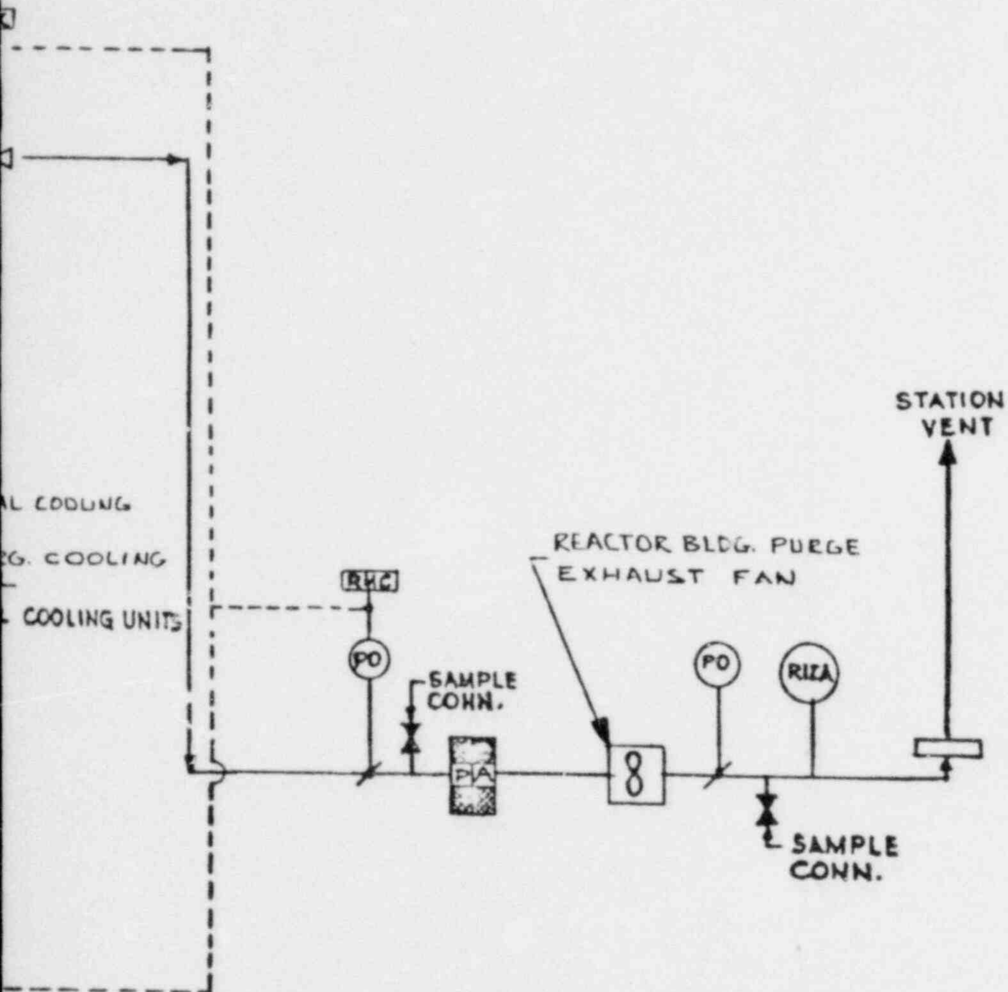
H/C HEATING COIL

C/C COOLING COIL

RMC REMOTE - MANUAL CONTROL

NOTE

FOR LEGEND NOMENCLATURE SEE FIGURE 9-1



VENTILATION SYSTEM

REACTOR BUILDING

Figure 5-6

SUPPLEMENT NO. 17