3.8 Design of Category I Structures

3.8.1 Concrete Containment

3.8.1.1 Description of the Containment

3.8.1.1.1 Basic Configuration

The containment encloses the reactor vessel, steam generators, reactor coolant loops, and portions of the auxiliary and engineered safety features systems. The containment provides reasonable assurance that leakage of radioactive material to the environment does not exceed the acceptable dose limit as defined in 10 CFR 50.34 (Reference 1) even if a loss-of-coolant accident (LOCA) occurred.

The internal structures are physically independent of the containment, except at the supporting foundation basemat. The connections of operating and intermediate floors to the containment wall are described in Subsection 3.8.3.1.10.

The containment shares a common basemat with the auxiliary building. The auxiliary building wraps around the containment with a seismic isolation gap of 50 mm (2 in).

The reactor containment building basemat has a continuous tendon gallery that provides access to the vertical tendons below the wall-basemat junction.

The containment is a prestressed concrete structure composed of a right circular cylinder with a hemispherical dome and is founded on safety-related common basemat. The entire structures are lined on the inside with steel plate that acts as a leak-tight membrane. The cylindrical portion of the containment is prestressed by a post-tensioning system consisting of horizontal and inverted "U" vertical tendons. There are three buttresses equally spaced around the containment wall, and each horizontal tendon is anchored at buttresses 240 degrees apart, bypassing the intermediate buttress. The dome portion is prestressed by a post-tensioning system consisting of horizontal tendons up to a 45-degree vertical angle and of two groups of inverted "U" vertical tendons oriented 90 degrees to each other. The inverted "U" tendons are carried through the cylindrical wall and anchored at the tendon gallery.

The general configuration and dimensions of the containment structure are shown in Figures 3.8-1 and 3.8-2. Local areas at the equipment hatch and two personnel airlock areas are thickened as shown in Figure 3.8-3.

The containment has the following dimensions:

a. Inside diameter of containment: 45.72 m (150 ft)

b. Inside height of containment: 76.66 m (251.5 ft) from the top of base slab to the ceiling of dome apex

c. Thickness of containment wall: 1.37 m (4 ft 6 in)

d. Dome thickness: 1.22 m (4 ft)

3.8.1.1.2 Foundation Basemat

A description of the foundation basemat is given in Subsection 3.8.5.

Appendix 3.8A shows the reinforcement details of the intersection where the containment wall intersects with nuclear island (NI) common foundation basemat.

3.8.1.1.3 Containment Shell

3.8.1.1.3.1 General

The cylindrical containment shell has a constant thickness of 1.37 m (4 ft 6 in) from the top of the foundation basemat to the springline. The shell is thickened locally around the equipment hatch, two personnel airlocks, feedwater, and main steam line penetrations. The containment reinforcing consists primarily of hoop and meridional steel. Prestressing tendons are also arranged in hoop and meridional directions. The tendons in the meridional directions extend over the dome to form an inverted “U” shape.

3.8.1.1.3.2 Reinforcing Bar Layout

Continuous hoop and meridional reinforcements are placed at the outside layers of the cylindrical wall. Similar reinforcements are also provided at the inside layers. Additional reinforcing bars are provided around major penetrations in the shell as required. Shear ties are provided where radial shear reinforcing as required.

3.8.1.1.3.3 Prestressing Tendon Layout

The cylindrical wall is post-tensioned with 165 hoop tendons at 305 mm (12 in) center. Each hoop tendon is anchored at the buttresses located 240 degrees apart, bypassing the intermediate buttress. Thus, three hoop tendons make two complete rings. Vertical post-tensioning for the cylindrical wall is provided by two sets of equally spaced 50 orthogonal inverted “U” vertical tendons.

The spacing of the hoop tendons and inverted “U” vertical tendons in the cylindrical wall is shown in Figure 3.8-4.

3.8.1.1.3.4 Liner Plate Details and Anchorage

The 6.0 mm (0.25 in) liner plate is attached to inside of the cylindrical wall by vertical angles embedded in cylindrical wall as shown in Figure 3.8-5. Horizontal stiffeners are provided for the liner plate to serve as an inside formwork for the cylindrical wall during concrete placement.

3.8.1.1.3.5 Penetrations

Access to the interior of the containment is provided through two personnel airlocks. An equipment hatch permits transfer of equipment into and out of the containment. In addition to these access openings, other major penetrations provided in the containment wall are for the main steam, feedwater, and HVAC lines. The containment wall is also penetrated by various process pipelines (Figure 3.8-6), electrical penetration assemblies (Figure 3.8-7), and the fuel transfer tube penetration. Descriptions are provided in Subsections 3.8.2.1.3.1.1 and 3.8.2.1.3.1.2.

The penetration sleeves through the containment are fabricated of steel, anchored to the concrete structure, and seal welded to the containment liner plate. The type, size, and location of the penetration, as well as any load that is imposed on the cylindrical wall by the penetration, determine whether any additional reinforcing is required in the wall around the penetration. Post-tensioning tendons are deflected around the penetrations, if required. Minimum bend radius of all deflected tendons is 9.15 m (30.0 ft) between tangent points. Portions of the containment pressure boundary that are steel and not backed by concrete, such as the equipment hatch, personnel airlocks, and Class MC penetration assemblies including the fuel transfer tube penetration sleeve, are designed in accordance with *[ASME Section III, Division 1, Subsection NE]** (Reference 2), as described in Subsection 3.8.2.

3.8.1.1.3.5.1 Personnel Airlocks

Access to the containment is provided through two personnel airlocks with a diameter of 3.4 m (11 ft 2 in). The personnel airlocks are located at the plant grade level (Az. 280 degrees and elevation 103 ft 9 in) and the operating floor level (Az. 234 degrees and elevation 159 ft 9 in). The containment wall around the personnel airlocks is thickened, and additional reinforcement is provided for stress concentrations due to the opening, as shown in Figure 3.8-3. The post-tensioning tendons are deflected around the penetrations.

3.8.1.1.3.5.2 Equipment Hatch

The equipment hatch with a diameter of 7.92 m (26 ft) is located at Az. 280 degrees and elevation 167 ft 6 in. The containment wall around the equipment hatch is thickened, and additional reinforcement is for stress concentrations due to the opening provided around the opening. The post-tensioning tendons are deflected around the opening.

3.8.1.1.3.6 Polar Crane Bracket

The polar crane brackets are spaced equally and embedded in the cylindrical wall to support the polar crane girder. Forces acting on the wall due to bracket loads are accommodated by additional reinforcement in the wall. A thickened liner plate is provided in the bracket areas. The spacing of the vertical liner stiffener in the vicinity of thickened liner plates is designed to limit excessive strain in the adjoining 6.0 mm (0.25 in) liner plate.

3.8.1.1.4 Containment Dome

3.8.1.1.4.1 General

The roof of the containment is a hemispherical dome. The inside of the dome is lined with a steel liner plate to provide leak-tightness. The buttresses are extended up to 48 degrees into the dome to provide anchorage for the dome hoop tendons.

3.8.1.1.4.2 Reinforcing Bar Layout

The containment dome is reinforced using the same arrangements as the dome tendons. Orthogonal reinforcing is the continuation of the vertical reinforcing in the cylindrical wall. Hoop reinforcing is also provided up to 45 degrees above the springline to complete the system. Radial ties are also provided over the entire dome to account for radial tension due to the curvature of the prestressing tendons.

3.8.1.1.4.3 Prestressing Tendons

Post-tensioning for the dome is provided by the orthogonal inverted “U” vertical tendons and 30 hoop tendons at 1.5 degrees on the center up to 45 degrees above the springline. The spacing of hoop tendons in the dome is shown in Figure 3.8-4.

3.8.1.1.4.4 Liner Plate Details and Anchorage

Radial and hoop stiffeners are provided for attaching the 6.0 mm (1/4 in) liner plate to the concrete dome. However, in the central portion, stiffeners are placed to form a rectangular grid. The liner serves as inside formwork for placing the concrete.

3.8.1.2 Applicable Codes, Standards, and Specifications

The following regulations, codes, standards, and specifications are used in the design of the concrete containment.

3.8.1.2.1 Design Codes, Standards, Specifications, and Regulations

The design codes, standards, specifications, and regulations are listed in Table 3.8-1. The primary design code for concrete containment is *[ASME Section III, Division 2, Subsection CC]** (Reference 3).

3.8.1.2.2 NRC Regulatory Guides

Conformance to each NRC Regulatory Guide (RG) is described in Section 1.9. The applicable NRC RGs to the design of the concrete containment are NRC RG 1.35 (Reference 4), NRC RG 1.35.1 (Reference 5), NRC RG 1.136 (Reference 6), and NRC RG 1.7 (Reference 7).

3.8.1.2.3 Industry Standards

Internationally recognized industry standards published by ASTM are used whenever possible to define material properties, testing procedures, and fabrication and construction methods.

3.8.1.3 Loads and Load Combinations

The containment is designed to resist the loads given in *[Article CC-3000 of the ASME Code]** and NRC RG 1.136 with the exceptions listed below.

a. The post-LOCA flooding combined with the safe shutdown earthquake (SSE) is more severe than the post-LOCA flooding combined with the operating basis earthquake (OBE) set at one third or less of the SSE for the plant. Therefore, only the post-LOCA flooding SSE combination is considered in the design.

b. *[Subarticle CC-3720 of the ASME Code]** is satisfied when the containment structure is exposed to the load combination listed below. As a minimum design condition, the pressure ($P_{g1} + P_{g2}$) is not less than 310 kPa (45 psig).

$$D + F + T + P_{g1} + P_{g2}$$

Where:

D = Dead load

F = Prestress

T = Temperature load

P_{g1} = Pressure resulting from an accident that releases hydrogen generated from 100 percent fuel clad metal-water reaction

P_{g2} = Pressure resulting from uncontrolled hydrogen burning

A description of load categories and definition of loads are given in Subsections 3.8.1.3.1 and 3.8.1.3.2.

3.8.1.3.1 Load Category

The load categories include any condition encountered during construction and testing, and in the normal operation of a nuclear power plant, as well as the conditions resulting from extreme environmental conditions postulated during the life of the facility and certain combinations thereof.

The design loads are defined as service load category and factored load category depending on the frequency of their occurrence.

3.8.1.3.1.1 Service Loads

Service loads are any loads encountered during construction and in the normal operation of a nuclear power plant and include loads such as any anticipated transient or test loads during normal and emergency startup and shutdown of the nuclear steam supply, safety and auxiliary systems, and the severe environmental loads that may be anticipated during the life of the facility.

Construction

The construction condition considers events and loads during construction, including the various stages of prestressing but excluding those during testing. Contraction loads for buildings and other structures are developed in accordance with Table 3.8-2 and with SEI/ASCE 37-02 (Reference 8).

Testing

The testing condition includes a consideration of events and loads applied during the containment structural integrity or leak rate testing and pre-operational tests such as hydrostatic testing of equipment. Each testing event is considered to be mutually exclusive of other testing events.

Normal

The normal condition includes a consideration of events and loads that are reasonably expected during the operation, shutdown, and normal maintenance of the power plant.

3.8.1.3.1.2 Factored Loads

Factored loads include loads encountered infrequently, such as severe environmental, extreme environmental and abnormal loads.

Severe Environmental

The severe environmental condition includes a consideration of the loads due to infrequent site-related environmental events such as operating basis earthquake, design basis wind, and design basis flood or precipitation during the plant life.

Extreme Environmental

The extreme environmental condition includes a consideration of the loads due to site-related environmental events that are credible but highly improbable. These events include the SSE, design basis tornado/hurricane and its associated missiles, probable maximum precipitation, probable maximum water level, and the site-related accidents to be postulated but not included in the abnormal loading category.

Abnormal

The abnormal condition includes a consideration of the loads due to design basis events. They include pressure, temperature, blast, pipe whip, jet impingement, flooding, and pipe reactions due to postulated pipe breaks for design basis accidents. This loading condition also includes plant related non-environmental missiles. The loads from each postulated accident event are considered to be mutually exclusive of other postulated accidents.

Abnormal/Severe Environmental

The abnormal/extreme condition includes a consideration of the loads due to the highly improbable simultaneous occurrence of abnormal and severe environmental loading conditions. Only the specified combinations of these conditions are considered.

Abnormal/Extreme Environmental

The abnormal/extreme condition includes a consideration of the loads due to the extremely improbable simultaneous occurrence of abnormal and extreme environmental loading conditions. Only the specified combinations of these conditions are considered.

3.8.1.3.2 Design Loads

The design loads pertaining to the design of containment are as follows:

a. Dead load (D)

   Dead loads, including hydrostatic and permanent equipment loads

b. Live load (L)

   Live loads, including any movable equipment loads and other loads that vary with intensity during each occurrence such as soil pressures

c. Prestress (F)

   Loads resulting from the application of prestress, including effects resulting from the construction sequence used to post-tension the tendon

d. Operating temperature (T_o)

Thermal effects and loads during normal operating conditions, based on the most critical transient or steady-state condition; the combination of internal and external temperatures that produce the maximum effects is considered.

e. Pipe reaction (R_o)

Pipe reaction during normal operating or shutdown conditions, based on the most transient or steady-state condition

f. External pressure (P_v)

Pressure loads resulting from pressure variation either inside or outside the containment

g. Test pressure (P_t)

Pressure during the structural integrity and leak rate tests

h. Test temperature (T_t)

Thermal effects and loads during the structural integrity and leak rate tests

i. Wind load (W)

Loads generated by the design wind specified for the plant site

j. Seismic load (E_o)

OBE loads are not applicable to the containment design for the APR1400 because an OBE level is one third of the SSE.

k. Seismic load (E_s)

Loads generated by the SSE; only the actual dead loads and live loads are considered in evaluating seismic response forces.

l. Tornado load (W_t)

Tornado or hurricane loading including the effects of missile impact

m. Internal flooding (H_a)

Load resulting from internal flooding other than from pipe breaks

n. Accident pressure (P_a)

Design pressure load within the containment generated by the design basis accident, based on the calculated peak pressure with an appropriate margin

o. Accident temperature (T_a)

Thermal effects and loads generated by the design basis accident including operating temperature (T_o)

p. Pipe reaction (R_a)

Pipe reaction from thermal conditions generated by the design basis accident including pipe reaction at normal operating or shutdown conditions (R_o)

q. Pipe break load (R_r)

Local effects due to the design basis accident normally include all postulated high energy system ruptures. These loads include an appropriate dynamic load factor to account for the dynamic nature of the load. This load category includes:

1) Pipe break reaction load (Y_r)

Y_r is defined as the equivalent static load on the structure generated by the reaction of the high-energy pipe during the postulated break.

2) Pipe break jet impingement load (Y_j)

Y_j is defined as the jet impingement equivalent static load on the structure generated by the postulated break.

3) Pipe break missile impact loads (Y_m)

Y_m is defined as the missile impact equivalent static load on the structure generated by or during the postulated break, such as pipe whipping.

r. Flooding load (Y_f)

Y_f is the load within or across a compartment or building due to flooding generated by a postulated pipe break. These loads are calculated considering the design basis flood heights.

s. Other Loads

Other loads refer to postulated events or conditions that are not included in the design basis. These loading conditions and effects are evaluated without regard to the bounding conditions under which SSCs perform design basis functions. This load category includes:

1) Aircraft hazard (A)

Aircraft hazard refers to loads on a structure resulting from the impact of an aircraft. The evaluation of this loading condition is considered as part of the plant safeguards and security measures.

2) Combustible gas (P_{g1}, P_{g2})

Combustible gas loads are pressure loads that result from a fuel-clad metal-water reaction followed by an uncontrolled hydrogen burn during a post-accident condition in the containment inerted by carbon dioxide. NRC RG 1.136, Regulatory Position C.5 provides the loads and load combinations acceptable for analysis and design of containment when exposed to the loading conditions associated with combustible gas. The loads and load combinations for combustible gas are provided in Subsection 3.8.1.3.

t. Missile loads other than hurricane generated or tornado-generated missiles

There are no missile loads on the containment resulting from activities of nearby military installations, turbine failures, or other causes.

3.8.1.3.3 Design Load Combinations

The applicable load combinations and load factors for the design of a concrete containment conform to the requirements of *[Article CC-3000 of the ASME Section III, Division 2.]** Table 3.8-2 lists the load combinations used in the design of the containment.

3.8.1.3.4 Liner Plate Loads and Load Combinations

The load combinations shown in *[Table CC-3230-1 of the ASME Code]** are applicable to the liner, except that load factors for all load cases are taken as equal to 1.0. Strains associated with construction-related liner deformations are excluded when calculating liner strains for the service and factored load combinations.

3.8.1.4 Design and Analysis Procedures

3.8.1.4.1 General

The design and analysis procedures are in compliance with the requirements of *[Article CC-3000 of the ASME Section III, Division 2.]**

Throughout the analysis special attention is given to, the following areas of the containment:

a. Intersection between the basemat and the cylinder

b. Intersection between the cylinder and the dome

c. Areas around large penetrations

d. Areas around polar crane brackets

e. Behavior of the base slab relative to the underlying foundation material

f. Stresses due to transient temperature in the liner plate and concrete

g. Penetrations and points of concentrated loads

h. Buttresses

3.8.1.4.2 Containment Structure

The ANSYS (Reference 9) computer program is used to analyze the containment for the loads defined in Subsection 3.8.1.3.2. The analysis results of these load case analyses are combined and factored using the loading combinations defined in Subsection 3.8.1.3.3.

The analysis model of the containment consists of the dome, cylindrical wall, and a part of the basemat. No other structures are physically connected to the containment structure; therefore, the basemat is the only interfacing part in the containment model. Subsection 3.8.5 describes the modeling of the common basemat structure.

A three-dimensional, eight-node solid element that is suitable for moderately thick shell structures is used to model the containment concrete dome and cylindrical wall. Five layers of solid elements through the thickness are used to model the dome and cylindrical wall. The buttresses and thickened areas around the large penetrations are included in the ANSYS model.

Post-tensioning tendon forces are included in the containment structural analysis. Forces for each tendon in the cylindrical wall and dome are averaged along their routing lengths in the containment model. Post-tensioning forces are transferred to the concrete by imposing initial stresses along the lengths of the modeled tendons which are embedded in the concrete model. The tendons are modeled using two-node three dimensional type elements. The prestress losses are explicitly included in the initial stress values.

Additional descriptions of the containment computer model are provided in Appendix 3.8A.

3.8.1.4.3 Assumptions on Boundary Conditions

The boundary condition is applied at the bottom of the basemat and at vertically cut faces inside and outside the basemat. The cut faces are fixed radially and circumferentially, whereas the bottom face is fixed only vertically so that unimportant parts can be cut and removed.

3.8.1.4.4 Axisymmetric and Non-axisymmetric Loads

The containment is modeled in its entirety as a three-dimensional structure. The loads described in Subsection 3.8.1.3.2 are applied in the locations and directions appropriate for each load. Overall pressure is applied uniformly to the interior surface of the containment structure.

Localized loads, such as penetration dead loads, hydrostatic pool water loads, live loads, and pipe rupture loads are applied to specific portions of the structural model as appropriate. Post-tension loads are applied to each tendon in its specific location. Localized loads at buttress locations that are caused by the offset of the tendons with respect to the shell are accounted for in the modeling. Response spectrum analysis is applied for the two horizontal and one vertical seismic load directions using the methodology described in Subsection 3.7.2.

3.8.1.4.5 Transient and Localized Loads

3.8.1.4.5.1 Analysis of Areas of Containment Wall Supporting Polar Crane Brackets

The containment wall around the crane brackets is analyzed considering the effects of crane bracket reactions. To account for potential difference in the timing between containment construction and polar crane installation, two models are used for the analyses: the overall containment full model and a partial model with only the containment cylinder.

3.8.1.4.5.2 Thermal Stress Analysis

To analyze the containment for thermal gradients, the nonlinear temperature profile across the containment wall thickness is obtained through the transient heat analysis using the ANSYS program. The resultant forces and moments from the thermal stresses are applied to each design section along with other appropriate axial forces and moments due to mechanical loads acting simultaneously with the thermal loads.

The stresses in the concrete and reinforcing steel are checked, taking into account the self-limiting effects of thermal moments due to concrete cracking.

3.8.1.4.6 Creep and Shrinkage Analysis

The effects of concrete creep, shrinkage, elastic shortening, and tendon steel relaxation are included in the computations for prestress losses in the tendons.

a. Concrete creep strain

   1) Vertical direction = 592×10^{-6} mm/mm (in/in)

   2) Horizontal direction = 930×10^{-6} mm/mm (in/in)

b. Concrete shrinkage strain = 120×10^{-6} mm/mm (in/in)

c. Poisson’s ratio = 0.17

d. Elastic modulus

   1) Containment external concrete wall = 30,441.74 MPa (4.415 × 10^6 psi)

   2) Containment internal concrete structure = 30,441.74 MPa (4.415 × 10^6 psi)

   3) Containment concrete basemat = 27,789.38 MPa (4.031 × 10^6 psi)

   4) Prestressing steel material = 193,053.20 MPa (2.8 × 10^7 psi)

e. Elastic shortening of concrete

   1) Vertical direction = 124 × 10^{-6} mm/mm (in/in)

   2) Horizontal direction = 194 × 10^{-6} mm/mm (in/in)

f. Tendon relaxation = 6 %

3.8.1.4.7 Tangential Shear

The design and analysis procedures for tangential shear are in accordance with *[ASME Section III, Division 2]** and NRC RG 1.136.

Tangential shear is resisted by the vertical reinforcement and the horizontal hoop reinforcement in the containment wall.

3.8.1.4.8 Variations in Physical Properties

In the design and analysis of the containment, consideration is given to the effects of possible variations in the physical properties of materials on the analytical results. The properties used for analysis purposes were established based on engineering experience with similar construction and materials. The values that were used are delineated in Subsection 3.8.1.4.6. Additional reviews of materials and their effects on the analysis and design of the containment will be included in design specification development and materials selection.

Losses due to elastic shortening, concrete creep and shrinkage, and relaxation of the post-tensioning cables were accounted for in the analysis. Subsection 3.8.1.4.6 summarizes parameters to consider time-dependent losses such as shrinkage, creep, and tendon relaxations.

When designing the structure under service and factored load conditions, allowable stress levels are used based on the minimum strength of the concrete and reinforcing materials used in construction of the containment to account for variations in physical properties.

3.8.1.4.9 Analysis of Areas around Large Penetrations

Large penetrations can cause stress concentrations. Increased thickness of the containment shell around these areas preserves the overall shell stiffness, compensates for the effects of stress and strain concentrations, and provides space for post-tensioning tendons and reinforcing bars.

The local structural behaviors at large, thickened penetration regions are investigated using the three-dimensional finite element full model.

3.8.1.4.10 Steel Liner Plate and Anchors

Design of the liner plate includes a consideration of construction loads, internal pressure, prestress, creep, shrinkage, and thermal effects. The design of the containment liner complies with the allowable stress and strain values in Subarticle CC-3720 of Section III of the ASME Code.

The liner plate is not assumed as a structural member in the design other than during construction. Loads caused by thermal growth of the liner plate are considered in the concrete containment design.

The liner plate is anchored to the concrete so that the liner stain does not exceed the allowable strain given in the code. The anchorage system is designed so that progressive failure of the anchors or massive bucking of the liner does not occur.

The liner anchorage system is analyzed, which includes calculating the force and deflection at anchorage points. The design of the liner anchorage complies with the force and displacement allowables in Subarticle CC-3730 of Section III of the ASME Code.

3.8.1.4.11 Ultimate Pressure Capacity

The ultimate pressure capacity (UPC) of the containment is evaluated based on the design results of the structure. The UPC is estimated based on attaining a maximum global membrane strain away from discontinuities of 0.8 percent. This strain limit is applied to the tendons, rebars, and liner. When the pressure capacity contribution is calculated from the tendons, the above-specified strain limit is applied to the full range of strain. The UPC analysis is performed considering material nonlinear behaviors for the reinforced concrete.

The stress-strain curves for the reinforcing steel and tendon are based on the code-specified minimum yield strength. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendon, respectively. The stress-strain curves are developed for the design-basis accident temperature.

The ultimate pressure capacity of the containment is a pressure of 1.269 MPa (184 psi) at which the maximum strain of the liner plate and horizontal tendon is approximately 0.8 percent.

3.8.1.4.12 Severe Accident Capability

The safety of the containment under severe accident conditions is assessed and demonstrated to comply with the allowable values in Subarticle CC-3720 of the ASME Code.

Based on the results of the analyses, all of the tendons and rebars are still in the elastic stage. At the maximum pressure loading level of the critical severe accident scenario, the liner plate strains at the cylindrical wall base, mid-height wall, and penetration regions do not reach the limit strain of the allowable values.

3.8.1.4.13 Design Summary Report

A design summary report for the containment structures is presented in Appendix 3.8A where the design of representative critical sections of the structures is described.

The evaluation considering the deviations of as-procured or as-built construction to the design is performed with the acceptance criteria described in Subsection 3.8.1.5.

3.8.1.5 Structural Acceptance Criteria

The allowable stresses, strains, forces, displacements and temperatures for the containment structures including the liner are defined based on the requirements given in Article CC-3000 of the ASME Code. When the containment structure is subjected to the load combinations described in Table 3.8-2, the allowable stresses, strains, forces or displacements specified below are not exceeded in order that:

a. The containment is essentially elastic under service load conditions.

b. General yielding of the reinforcing steel does not develop under factored primary load conditions.

c. The leak-tight integrity of the liner is maintained.

3.8.1.5.1 Acceptance Criteria for Service Load Conditions

The acceptance criteria under service load conditions are given below:

3.8.1.5.1.1 Concrete

Compression

The allowable stresses for the service load combinations defined in Table 3.8-2 are as follows:

a. Primary membrane stress: 0.30 f'_c

b. Primary membrane plus flexural stress: 0.45 f'_c

c. Primary plus secondary membrane stress: 0.45 f'_c

d. Primary plus secondary membrane plus flexural stress: 0.60 f'_c

Tension

Concrete tensile strength is not relied on to resist flexural or membrane tension.

Radial Shear

The allowable concrete stress and the limiting maximum stress for radial shear are in accordance with Subarticle CC-3431.3 of the ASME Code.

Tangential Shear

The allowable concrete stress and the limiting maximum stress for tangential shear are in accordance with Subarticle CC-3431.3 of the ASME Code.

Peripheral Shear

The allowable concrete stress and the limiting maximum stress for peripheral shear are in accordance with Subarticle CC-3431.3 of the ASME Code.

Torsional Shear

The allowable concrete stress and the limiting maximum stress for torsional shear are in accordance with Subarticle CC-3431.3 of the ASME Code.

3.8.1.5.1.2 Prestressing System

Tendon

The tendon stresses during stressing and anchoring and the tendon stresses used for the design do not exceed the following:

a. Because of prestressing tendon jacking force, the tendon tensile stress does not exceed 0.96 f_{py} but is not greater than the lesser of 0.80 f_{pu} and the maximum value recommended by the manufacturer of prestressing steel or anchorage devices.

b. Immediately after anchoring, the tensile stress at the anchor point does not exceed 0.81 f_{py} or 0.73 f_{pu}, and the average tensile stress at the anchorage point of the tendon group after anchoring does not exceed 0.70 f_{pu}.

c. For the purpose of design, the effective prestress is based on tendon stresses not exceeding those calculated to occur immediately after anchoring minus all applicable losses.

End Anchor

Compression under the tendon end anchor bearing plates is in accordance with the requirements of Subarticle CC-3431.1 of the ASME Code.

Prestress Losses

To determine the effective prestress, the prestress losses are considered in accordance with Subarticle CC-3542 of the ASME Code. The wobble friction coefficient and curvature friction coefficient are determined experimentally and verified during stressing operations. In addition, NRC RG 1.35.1 is used to establish the upper bound and lower bound of prestress losses at the time of 60-year design life.

3.8.1.5.1.3 Reinforcement Steel

Tension

a. The average tensile stress in reinforcing steel does not exceed 0.5 $f_{y.}$

b. The values given in a. above may be increased by 33.3 percent when the following loads are combined with other loads in the load combination:

   1) Temporary loads from prestressing, which decrease after completion of prestressing (considered in construction load combination)

   2) Secondary loads due to concrete volume change such as creep, shrinkage, and thermal growth

e. The values given in a. above may be increased by 50 percent when the temporary pressure loads during the test condition are combined with other loads in the load combination.

Compression

a. For load resisting purposes, the compressive stress in reinforcing steel does not exceed 0.5 f_y.

b. The values given in a. above may be increased by 33.3 percent when the following loads are combined with other loads in the load combination.

   1) Temporary loads from prestressing, which decrease after completion of prestressing (considered in construction load combination)

   2) Temporary test pressure loads (considered in test condition)

   3) Secondary loads due to concrete volume change such as creep, shrinkage, and thermal growth

Radial Shear

The radial shear reinforcement for service loads is provided in accordance with Subarticle CC-3522 of the ASME Code.

Tangential Shear

The tangential shear reinforcement for service loads is provided in accordance with Subarticle CC-3522 of the ASME Code.

Peripheral Shear

The peripheral shear reinforcement for service loads is provided in accordance with Subarticle CC-3522 of the ASME Code.

Torsional Shear

The torsional shear reinforcement for service loads is provided in accordance with Subarticle CC-3522 of the ASME Code.

Radial Tension Reinforcement

Radial tie reinforcement is provided to resist radial tensile forces from curved tendons in portions of the containment with double curvature in accordance with Subarticle CC-3545 of the ASME Code.

End Anchor Reinforcement

Tendon end anchor reinforcement oriented perpendicular to the direction of applied force is provided to control cracking in the end anchor zone in accordance with Subarticle CC-3543 of the ASME Code.

3.8.1.5.2 Acceptance Criteria for Factored Load Conditions

The acceptance criteria under factored load conditions are given below.

3.8.1.5.2.1 Concrete

The allowable stresses for the factored load combinations defined in Table 3.8-2 are as follows:

a. Primary membrane stress: 0.60 f'_c

b. Primary membrane plus flexural stress: 0.75 f'_c

c. Primary plus secondary membrane stress: 0.75 f'_c

d. Primary plus secondary membrane plus flexural stress: 0.85 f'_c

Tension

Concrete tensile strength is not relied on to resist flexural or membrane tension.

Radial Shear

Radial shear is a transverse shear and is similar to shear in beam analysis. It occurs in the vicinity of discontinuities in shell flexural or membrane behavior. The allowable shear stress in prestressed concrete is determined in accordance with Subarticle CC-3421.4 of the ASME Code.

Tangential Shear

Tangential shear is a membrane shear in the plane of the containment shell resulting from lateral load such as earthquake, wind, hurricane or tornado loading. The allowable shear stress in prestressed concrete is determined in accordance with Subarticle CC-3421.5 of the ASME Code.

Peripheral Shear

Peripheral shear stress is a transverse shear and is similar to punching shear in slab analysis. It is the shear resulting from a concentrated force or reaction acting transverse to the plane of the wall. The peripheral shear stress carried by concrete is in accordance with Subarticle CC-3421.6 of the ASME Code.

Torsional Shear

Torsional shear stress is a local, in-plane shear stress induced in the containment wall due to torsional moment (from pipe penetrations or attachments) applied about an axis normal to the containment wall. The torsional shear stress carried by concrete is in accordance with Subarticle CC-3421.7 of the ASME Code.

3.8.1.5.2.2 Prestressing System

Tendons

The maximum axial tensile capacity of the tendon is 90 percent of the yield strength in accordance with Subarticle CC-3423 of the ASME Code.

Prestressing Losses

To determine the effective prestress, allowance for the following loss of prestress is considered.

a. Slip at anchorage

b. Elastic shortening of concrete

c. Creep of concrete

d. Shrinkage of concrete

e. Stress relaxation of tendon

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

The loss of prestress due to friction losses is calculated in accordance with Subarticle CC-3542 of the ASME Code. The wobble friction coefficient and curvature friction coefficient are determined experimentally and verified during stressing operations. In addition, NRC RG 1.35.1 is used to establish the upper bound and lower bound of prestress losses at the time of 60-year design life.

3.8.1.5.2.3 Reinforcing Steel

Tension

a. The design yield strength of reinforcing steel does not exceed 413.7 MPa (60 ksi).

b. The allowable stress for load resisting purpose does not exceed 0.9 $f_{y.}$

c. If more than one layer of reinforcement is provided to resist primary bending moment, the tensile strain in one or more of the layers may exceed 0.9 ε_y, provided a state of general yielding of the cross section is not reached.

d. The tensile strain in reinforcement around large openings may exceed 0.9 ε_y, provided the average strain for the total forces and moments over a distance of one-half the containment wall thickness from the opening or 25 percent of the opening diameter, whichever is smaller, does not exceed 0.9 $\varepsilon_{y.}$

e. Under combined primary and secondary forces, the tensile strain in reinforcement may exceed 0.9 ε_y. The maximum tensile strain does not exceed 2 ε_y in any reinforcement.

Compression

a. For load resisting purposes, the compressive stress in reinforcing steel does not exceed 0.9 f_y.

b. The compressive strains may exceed yield strength when acting in conjunction with concrete if the concrete requires larger strains than the reinforcing yield strain to develop its capacity.

Radial Shear

The radial shear reinforcement is provided in accordance with Subarticle CC-3521.2 of the ASME Code.

Tangential Shear

The orthogonal tangential shear reinforcement is provided in accordance with Subarticle CC-3521.1 of the ASME Code.

Peripheral Shear

The peripheral shear reinforcement is provided in accordance with Subarticle CC-3521.3 of the ASME Code.

Torsional Shear

The torsional shear reinforcement is provided in accordance with Subarticle CC-3521.4 of the ASME Code.

Radial Tension Reinforcement

Radial tie reinforcement is provided to resist radial tensile forces from curved tendons in portions of the containment with double curvature in accordance with Subarticle CC-3545 of the ASME Code.

End Anchor Reinforcement

Tendon end anchor reinforcement oriented perpendicular to the direction of applied force is provided to control cracking in the end anchor zone in accordance with Subarticle CC-3543 of the ASME Code.

3.8.1.5.3 Acceptance Criteria with Respect to Concrete Temperatures

The requirements pertaining to temperature limitations in concrete containments are in accordance with Subarticle CC-3440 of the ASME Code.

a. For normal operation or any other long-term period, the temperatures are not to exceed 66 °C (150 °F) except for local areas, such as around a penetration, which are allowed to have increased temperatures not to exceed 93 °C (200 °F).

b. For accident or any other short-term period, the temperatures are not to exceed 177 °C (350 °F) for the interior surface. However, local areas are allowed to reach 343 °C (650 °F) from steam or water jets in the event of a pipe rupture.

3.8.1.5.4 Acceptance Criteria for Impactive and Impulsive Loading

Yield strain and displacement values are permitted to exceed general stress and strain limits due to impactive and impulsive loading. In the case of impulse loads the usable ductility is 33 percent of the failure value and for impact effects the usable ductility is 67 percent of the failure value in accordance with ASME Section III, Subarticle CC-3920, for the design of the containment. Examples of impactive and impulsive loading include loading due to high-energy piping line breaks, localized yielding due to jet impingement and whip restraint loads, and external and internal missile loading. The design of containment internal structure is addressed in Subsection 3.8.3. General design for missiles is addressed in Section 3.5.

3.8.1.5.5 Acceptance Criteria for the Liner System

The acceptance criteria for the liner system are provided below.

Liner Plate

The acceptance criteria for the liner plate are the stress and strain limits specified in the ASME Section III, Table CC-3720-1, when considering the load combinations stated in Table CC-3230-1 with a load factor of 1.0.

Liner Anchors

The acceptance criteria for the liner anchors are the force and displacement allowable values given in *[ASME Section III, Table CC-3730-1.]**

Penetration Assemblies

The acceptance criteria are the design allowables given in *[ASME Section III, Subarticles CC-3740 and CC-3820.]** In accordance with Subarticle CC-3740 (b), the design allowables for penetration nozzles are the same as used for ASME Section III, Division 1, where a nozzle is defined as that part of the penetration assembly not backed by concrete.

In accordance with Subarticle CC-3740 (c), the design allowables for the liner in the vicinity of the penetration are the same as those given in the *[AISC N690]** for resisting mechanical loads in the service load category. For factored load categories, the allowables are increased by a factor of 1.5, except for impulse loads and impact effects.

In accordance with Subarticle CC-3740(d), the portion of the penetration sleeves backed by concrete is designed to meet the acceptance criteria described above for the liner plate and anchors. Additionally, consistent with requirements in Subarticle CC-3820, to verify acceptability, the structural capacities of penetration assemblies that are designed for pipe loads are compared against (a) the ultimate moment, axial, torque, and shear loadings that the piping is capable of producing or (b) penetration loads based on a dynamic analysis considering pipe rupture thrust as a function of time. In (b), penetration designs are later verified using results of piping analysis to provide reasonable assurance that the load used in the design is not exceeded.

Typically for the APR1400, in order to preclude pipe rupture effects, flued heads are used for high-energy piping if large pipe rupture design loads are anticipated. See Section 3.6 for further details on this topic.

Brackets and Attachments

The allowables given in the *[ASME Section III, Subarticles CC-3650 and CC-3750,]** are used as the acceptance criteria for brackets and attachments to the liner.

The APR1400 design avoids the use of brackets and similar items that transmit loads to the liner in the through-thickness direction. As much as practical in the design of attachments that have structural components carrying major loads, for example the upper plates of crane brackets, such a structural component of the attachment is made continuous through the liner. When through-thickness liner loads cannot be avoided and the liner is 25 mm (1 in) or more in thickness, then the special welding and material requirements of Subarticle CC-4543.6 are applied. In addition to the requirements given in Subarticle CC-4543.6 (a) through (d), ultrasonic examinations are required prior to fabrication to preclude the existence of laminations in the installed material.

3.8.1.6 Materials, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control program, and special construction techniques used in the fabrication and construction of the containment. Materials and quality control satisfy the following requirements:

a. *[ASME 2001 Edition with 2003 Addenda, Section III, Division 2, Code for Concrete Containments, Articles CC-2000, CC-4000, CC-5000, CC-6000, and CC-9000]**

b. NRC RG 1.136, Design Limits, Loading Combinations, Materials, Construction, and Testing of Concrete Containments, Revision 3, March 2007.

Concrete and reinforcement forming and placement tolerance not specifically addressed in these references are in accordance with *[ACI 349]** and ACI 117.

3.8.1.6.1 Concrete and Concrete Ingredients

The materials to be used for concrete and concrete ingredients are given below.

Cement

Cement used for the concrete containment conforms to the requirements of ASTM C150 (Reference 10).

Aggregates

Aggregates used for the concrete containment conforms to the requirements of ASTM C33, (Reference 11) with the requirements specified in *[Subarticle CC-2222 of the ASME Section III, Division 2.]**

Mixing Water

Mixing water used for the concrete containment conforms to the requirements of *[Subarticle CC-2223 of the ASME Section III, Division 2.]**

Admixtures

Air-entraining admixtures used for the concrete containment conform to the requirements of ASTM C260 (Reference 12). Chemical admixtures used for the concrete containment conform to the requirements of ASTM C494 (Reference 13). Mineral admixtures (fly ash and pozzolan) used for the concrete containment conform to the requirements of ASTM C618 (Reference 14).

Concrete Mix Design

The concrete mix design for the concrete containment conforms to the requirements of *[Subarticle CC-2230 of the ASME Section III, Division 2.]**

Concrete Compressive Strength

The specified minimum compressive strength of 41.37 MPa (6,000 psi) at 91 days is used for the containment wall and dome. For the containment common basemat, the specified minimum compressive strength of 34.47 MPa (5,000 psi) at 91 days is used.

3.8.1.6.2 Reinforcing Bars and Splices

The material to be used for reinforcing bars conforms to ASTM A615 (Reference 15) and the requirements described in *[Subarticle CC-2330 of ASME Section III, Division 2.]**

The mechanical splices conform to the permitted types described in *[Subarticle CC-4331.2 of ASME Section III, Division 2.]** The material to be used for bar-to-bar splice sleeves in reinforcing bars conforms to ASTM A513, A519, or A576 (References 16, 17, and 18, respectively). The material to be used for reinforcing bar splice sleeves attached to liner plates or structural steel shapes is a carbon steel conforming to ASTM A513, A519, or A576 Grades 1008 through 1030.

3.8.1.6.3 Prestressing System

The material to be used for prestressing system is given below.

Prestressing Steel

The material for prestressing elements conforms to ASTM A416 (Reference 19) and the requirements described in *[Subarticle CC-2420 of ASME Section III, Division 2.]**

Anchorage Components

Materials for anchorage components such as bearing plates, anchor head assemblies, and wedges conform to the tendon manufacturer's respective material specifications. In addition, the materials for anchorage components conform to the requirements described in *[Subarticle CC-2430 of ASME Section III, Division 2]** and NRC RG 1.136.

Nonload-carrying and Accessory Materials

Nonload-carrying materials such as tendon duct, channel, trumpet, and transition cones conform to the requirements in *[Subarticle CC-2441 of ASME Section III, Division 2.]** The temporary and permanent corrosion prevention materials conform to the requirements of *[Subarticle CC-2442 of ASME Section III, Division 2.]**

3.8.1.6.4 Liner Plate within Containment Backed by Concrete

The materials, fabrication procedures, and examination requirements conform to the technical provisions of *[Subarticles CC-2500, CC-4500, and CC-5500 of ASME Section III, Division 2.]**

The containment liner materials backed by concrete meet the requirements of *[Subarticles CC-2500 of ASME Section III, Division 2,]** and comply with the following specifications:

Application	Specification
Liner plate, embedment plate	SA-516 Grade 55, 60, or 70 SA-240
Liner anchor	SA-36

The material to be used for containment wall liner at El. 78 ft through El. 101 ft conforms to ASME SA-240 (Reference 20) and the requirements described in *[Subarticle CC-2500 of the ASME Section III, Division 2.]**

The fabrication of the containment steel boundaries backed by concrete is in accordance with *[Subarticle CC-4500 of ASME Section III, Division 2.]** The qualifications of welders and welding procedures are in accordance with *[Subarticle CC-4530 of ASME Section III, Division 2.]**

All nondestructive examination procedures are in accordance with Section V of the ASME Code.

3.8.1.7 Testing and Inservice Inspection Requirements

3.8.1.7.1 Structural Integrity Test

The structural integrity test (SIT) is performed in accordance with *[ASME Section III, Division 2, CC-6000]** to verify the structural integrity of the containment. The test is performed after the containment is complete, including the liner, concrete structures, all electrical and piping penetrations, equipment hatch, personnel airlocks, and post-tensioning.

The pressure will be brought up to 115 percent of the containment design pressure in approximately five or more equal increments. At each pressure level, the pressure will be held constant for 1 hour prior to measuring the deflections.

Under the test pressure level, the crack pattern for all cracks larger than 0.254 mm (0.01 in) and longer than 150 mm (6 in) will be mapped at the locations required by the ASME Code.

3.8.1.7.1.1 General Requirements

Prior to operating the plant, the SIT is performed to demonstrate the structural acceptability of the primary containment.

At each pressure level, the pressure will be held constant for 1 hour to allow for the pressure and containment response to stabilize and to survey the exterior surface of the primary containment. Internal and external temperature measurements will be taken.

Pre- and post-test inspections will be performed to confirm that the concrete, liner plate, and interior structures were not damaged during the structural integrity test.

3.8.1.7.1.2 Response Prediction Prior to the Structural Integrity Test

The expected readings of all devices used to monitor containment behavior are determined before the SIT.

The predictions of the containment responses under test pressure will be obtained using the same analytical models, computer programs, and analysis procedures that are used in the containment design so the adequacy of all analytical results is confirmed by the test.

The liner plate is not permitted to be used as a strength element in designing the containment to resist accident pressure or earthquake loads. However, during the SIT, the liner plate is in tension and is considered in the prediction of response.

Acceptance limits will be developed based on the analytical predictions for each pressurization increment to permit a judgment as to whether the test may proceed safely to the next increment of increased pressure.

3.8.1.7.1.3 Acceptance Criteria

a. Overall structure exhibits elastic behavior.

b. No visible signs of permanent damage to either the concrete structure or the steel liner are detected.

c. Residual displacements at the points of maximum predicted radial and vertical displacement at the completion of depressurization or up to 24 hours later do not exceed 20 percent of measured or predicted displacement at maximum test pressure, whichever is greater, plus 0.25 mm (0.01 in) plus measurement tolerance. The above criteria are applied to the average of radial displacements measured at the same elevation.

d. When the measured displacements at the points of maximum predicted radial and vertical displacement do not exceed the measurement tolerance plus 30 percent of the measured or predicted displacement at the maximum test pressure, the above criteria are applied to the average of radial displacements measured at the same elevation. This criterion may be waived if the residual displacements within 24 hours are not greater than 10 percent.

Test results and conclusions will be documented in a separate report.

3.8.1.7.2 Inservice Surveillance

3.8.1.7.2.1 General Requirements

During the plant life, the in-service inspection of the containment is performed in accordance with the requirements of the ASME Section XI, Subsection IWL.

The in-service inspection includes a visual examination of the concrete exterior surface for cracking, spalling, or grease leakage; a visual inspection of the tendon anchorage assembly of sampled tendons; a tendon lift-off test to discover damaged or broken tendon wires and to provide reasonable assurance of an acceptable prestress level during the plant life.

The containment is designed to allow access to the post-tensioning systems during in-service inspections.

3.8.1.7.2.2 Prediction of Minimum Lift-off Forces

The prediction of the minimum tendon lift-off forces is made prior to in-service inspection.

The prediction of tendon lift-off forces is determined based on the estimated prestress losses at the time of test. As a minimum, the following sources of prestress loss are considered:

a. Elastic shortening taking into consideration the sequence of stressing of the tendon

b. Creep and shrinkage of concrete

c. Stress relaxation in tendon

d. Reduction of wire cross section due to corrosion, if any

e. Ineffective wires (e.g., broken, unseated) documented during initial stressing

The procedures and formulations presented in NRC RG 1.35.1 are used to establish the upper bound and lower bound of prestress losses at the time of test.

3.8.1.7.2.3 Acceptance Criteria

The acceptance criteria for the in-service inspections are as specified in ASME Section XI, Subsection IWL-3000. The acceptance criteria also meet any additional requirements of NRC RG 1.35.

Items with examination results that do not meet the acceptance standards are evaluated to determine:

a. Causes of the condition

b. Acceptability of the containment without repair

c. Whether or not repair is required, and if required, the extent, method, and completion date for the repair

3.8.2 Steel Containment

The APR1400 does not use a steel containment.

This subsection pertains to ASME Class MC components that are part of the containment described in Subsection 3.8.1. ASME Class MC components include the equipment hatch, the personnel airlocks, and the piping and electrical penetration sleeves.

3.8.2.1 Description of Containment

3.8.2.1.1 Equipment Hatch

The equipment hatch consists of a dished head door, matching barrel frame with anchorage, and the lifting equipment that operate the hatch door as shown in Figure 3.8-10. The clear opening of the equipment hatch has an inside diameter of 7.92 m (26 ft). The hatch is located at centerline elevation of 167 ft 6 in.

The equipment hatch is provided for access to the interior of the reactor containment building during shutdown. The transfer of equipment through the containment wall is accomplished through this hatch. The equipment hatch will be a round barrel frame with a dished head access hatch. The dished head can be fully removed with a lifting bracket located near the center of gravity of the entire removable assembly.

3.8.2.1.2 Personnel Airlocks

A typical personnel airlock is shown in Figure 3.8-11. Two personnel airlocks are provided. Each personnel airlock has an inside diameter of 3.05 m (10 ft) to accommodate a door that is f 1.07 m (3 ft 6 in) wide and 2.03 m (6 ft 8 in) high.

Personnel airlocks consist of doors with two gaskets in series, which are mechanically interlocked so that one door cannot be opened unless the second door is closed and sealed. If needed, the mechanical interlock can be overridden by use of a special procedure provided. The doors operate manually. Either door is operated from inside the reactor containment building, inside the access hatch, or outside the reactor containment building. Each door is equipped with a valve for equalizing pressure on both sides of the door before the door can be operated.

Valves are operated at the same location where the associated door can be operated. The valves are interlocked so that only one valve can be operated at a time and only when the opposite door is closed and sealed. Indicators are located on the outside of the access hatch at each door to show whether the opposite door and its valves open or close. The pressure of access hatch can be tested any time without interference in the normal operation of the plant. Provisions are made for continuous leak testing of the door seals on both doors.

3.8.2.1.3 Penetrations

Penetrations are provided in the containment wall to:

a. Extend process piping and electrical conductors through the containment wall

b. Provide reasonable assurance of the integrity of the containment

c. Act as supports for the process pipelines

3.8.2.1.3.1 Penetration Types

Penetrations consist of two major types:

a. Process pipe penetrations

b. Electrical penetrations

3.8.2.1.3.1.1 Process Pipe Penetrations

Process pipe penetrations include instrumentation, HVAC, and mechanical piping penetrations. A typical penetration assembly consists of some or all of the following components:

a. Sleeve embedded in concrete wall

b. Sleeve anchors

c. Head fitting

d. Penetration seals (air, water, and radiation)

The process pipe penetrations used are the three types shown in Figure 3.8-6.

Determination of penetration types is made during design process based upon the magnitude of applicable loads and the in-service inspection requirements.

3.8.2.1.3.1.2 Electrical Penetrations

Electrical penetration assemblies are used to extend electrical conductors through the pressure boundary of the reactor containment building. Electrical penetrations are functionally grouped into medium-voltage power, low-voltage power, low-voltage control, and instrument cable penetration assemblies. Figure 3.8-7 shows a typical electric penetration assembly in place within the containment wall. An assembly is sized to be inserted into sleeves in the containment wall.

3.8.2.1.3.2 Component Classification

The penetration sleeve is designed as a class MC component in accordance with *[ASME Section III, Division 1, Subsection NE.]**

All penetration head fittings (penetration Type 1 of Figure 3.8-6) are classified as piping components and as such they have the same classification as the process pipe and are designed in accordance with ASME Section III, Division 1, Subsection NB, NC, or ND as applicable. The other head fittings are designed as ASME Class MC components.

3.8.2.1.4 Fuel Transfer Tube Sleeve and Bellows

The fuel transfer tube sleeve and bellows is designed as a class MC component in accordance with *[ASME Section III, Division 1, Subsection NE.]**

3.8.2.2 Applicable Codes, Standards, and Specifications

The following regulations, codes, standards, and specifications are used in the design of the class MC components.

3.8.2.2.1 Design Codes, Standards, Specifications, and Regulations

The design codes, standards, specifications, and regulations are listed in Table 3.8-1.

3.8.2.2.2 Regulatory Guides

Conformance to each regulatory guide is described in Section 1.9. The guide that is applicable to the design of the ASME class MC components is NRC RG 1.57 (Reference 21).

3.8.2.2.3 Industry Standards

Nationally recognized industry standards, such as those published by ASTM, are used whenever possible to describe material properties, testing procedures, and fabrication and construction methods.

3.8.2.3 Loads and Load Combinations

The loads and load combinations for class MC components except for the instrument and process piping penetrations are given in Table 3.8-3. These loads and their combinations conform to *[ASME Section III, Division 1, Subsection NE 3000.]**

The terms of design loads are defined in Subsection 3.8.1.3.

3.8.2.3.1 Loads for Instrument and Process Pipe Penetrations

The forces and moments imposed at the piping penetration assembly boundaries are due to the following:

a. Internal and external operating and design pressures and temperatures

b. Process pipe reactions due to (as applicable):

   1) Weight

   2) Safe shutdown earthquake (SSE)

   3) Thermal expansion

   4) Relative dynamic displacements

   5) Fluid dynamics (e.g., pressure, temperature, and hydraulic transients; main steam safety valves)

   6) Pipe rupture and jet impingement

c. Severe accident load due to (as applicable):

   1) Pressure load generated from 100 percent fuel clad metal-water reaction

   2) Pressure loads generated by hydrogen burning

3.8.2.3.2 Load Combinations for Instrument and Process Piping Penetrations

The load combinations for instrument and process piping penetrations are given in Table 3.8-4.

3.8.2.4 Design and Analysis Procedures

3.8.2.4.1 Equipment Hatch, Personnel Airlocks, and Electrical Penetrations

The equipment hatch, personnel airlocks, and electrical penetrations are designed as pressure-retaining components. The portions of the sleeves not backed by concrete are analyzed and designed according to the provisions of *[ASME Section III, Division 1, Subsection NE 3000.]**

3.8.2.4.2 Process Piping Penetrations

The entire penetration assembly including the sleeve, head fitting, and attached portion of pipe is designed for the loads described in Subsections 3.8.2.3.1 and 3.8.2.3.2 by the finite element computer program ANSYS. The boundary conditions for the model are considered fixed against all degrees of freedom at the containment building wall. The computer program is also used to evaluate thermal gradient. The final stress analysis of the piping penetration assemblies including metal fatigue evaluation is performed by this computer program.

3.8.2.5 Structural Acceptance Criteria

3.8.2.5.1 Equipment Hatch, Personnel Airlocks, and Electrical Penetrations

The equipment hatch, personnel airlocks, and electrical penetrations are designed as Class MC components according to *[ASME Section III, Division 1, Subsection NE.]**

Stress intensities are limited to the values defined by *[ASME Section III, Division 1, Subsection NE 3211.]** Buckling stresses are limited to the values defined by *[ASME Section III, Division 1, Subsection NE 3222,]** while primary, secondary, and peak stresses are defined by *[ASME Section III, Division 1, Subsection NE 3213.]** Load combinations and their corresponding service levels to determine the appropriate stress limits are given in Table 3.8-3.

3.8.2.5.2 Process Piping Penetration Assemblies

The process piping penetrations are designed in accordance with *[ASME Section III, Division 1, Subsection NE.]**

Stress intensities are limited to the values defined by *[ASME Section III, Division 1, Subsection NE 3220.]** Load combinations and their corresponding service levels to determine the appropriate stress limits are given in Tables 3.8-4 and 3.8-5.

3.8.2.6 Materials, Quality Control, and Special Construction Techniques

The materials comply with the requirements of *[ASME Section III, Division 1, Subsection NE 2000]** and physical properties for the materials are shown in the Table 3.8-6.

The testing of the containment building leak-tight boundaries not backed by concrete is in accordance with *[ASME Section III, Division 1, Subsection NE.]**

All welds between the penetration and head fitting and between the penetration reinforcing plate and frames for airlocks and access openings are examined radiographically.

All welds in bellows-type expansion joints in penetration assemblies or appurtenances to the containment vessel are examined either by magnetic particle examination for ferrite material or by liquid penetrant examination for austenitic material.

The qualifications of welders and welding procedures are in accordance with *[ASME Section III, Division 1, Subsection NE 4300.]**

The physical properties of these materials are listed in Table 3.8-6. The penetration components mentioned in Subsection 3.8.1.6 fully comply with the materials specified in *[ASME Section III, Division 1, Subsection NE 2000.]**

The fabrication and installation requirements of *[ASME Section III, Division 1, Subsection NE 4000, and the provisions of ASME Section III, Division 1, Subsection NE 5000 and NE 6000,]** dealing with examination and testing of components are to be met. Standard construction techniques are used in the fabrication and erection of ASME Class MC components.

3.8.2.7 Testing and Inservice Inspection Requirements

3.8.2.7.1 Structural Acceptance and Initial Leak Rate Tests

All MC components are tested for their structural acceptance and leak rate at the same time of the containment tests described in Subsection 3.8.1.7.

Leak rate tests are performed on all hatches by pressurizing the plenum between the double gaskets. In addition, the personnel airlock will be shop tested according to the following procedure:

a. Pressure tests are performed for hatches in accordance with criteria specified in *[ASME Section III, Division 1, Subsection NE 6000.]**

b. Initial leak rate test: hatches are tested at a peak pressure. Leakage does not exceed the design limit of the volume of the airlock in 24 hours.

3.8.2.7.2 Inservice Inspection

MC components iare tested in accordance with *[ASME Section III, Division 1, Subsection NE 6000.]**

Inservice inspections of the MC components follow the requirements of *[ASME Section XI, Subsection IWE,]** with the additional requirements of 10 CFR 50.55a. Subsection 6.2.6 describes leak-rate testing of the containment system and associated acceptance criteria.

3.8.3 Concrete and Steel Internal Structures of Steel or Concrete Containment

3.8.3.1 Description of the Internal Structures

The internal structure is a group of reinforced concrete structures that enclose the reactor vessel and primary system. The internal structure provides biological shielding for the containment interior. A description of various structures that constitute the internal structure is given in the following paragraphs. The details of the internal structure are shown in Figures 1.2-2 through 1.2-8.

The internal structures are seismic Category I structures with the exception of platforms that do not support seismic Category I equipment and miscellaneous steel.

Platforms that do not support seismic Category I equipment and miscellaneous steel are seismic Category II structures. Seismic Category II structures are designed for the SSE using seismic Category I criteria to prevent adverse interaction with other seismic Category I structures, systems, and components.

The internal structures located in the reactor containment building consist of the following major components:

a. Reactor support system

b. Steam generator support system

c. Reactor coolant pump support system

d. Pressurizer support system

e. Primary shield wall (PSW) and reactor cavity

f. Secondary shield wall (SSW)

g. Refueling pool

h. In-containment refueling water storage tank (IRWST)

i. Holdup volume tank

j. Operating and intermediate floors

k. Interior concrete fill slab

l. Polar crane supports

3.8.3.1.1 Reactor Support System

The reactor vessel is supported by four columns under the cold leg nozzles (elevation 35.76 m [117 ft 4 in]), as described in Subsection 5.4.15.2, which interface with anchor bolts embedded in the primary shield wall. Lateral supports are provided for the reactor vessel to resist horizontal loads. The lateral supports transmit the loads to the reactor cavity wall, which houses the reactor. In addition, shear keys at the lower part of the reactor vessel fit into the keyways located in the base plate (elevation 28.74 m [94 ft 3.5 in]) of the column supports. The keyways, which are described in Subsection 5.4.15.2, transmit the horizontal loads to the cavity wall through shear bars attached to the bottom of the base plate. Both the lateral supports and shear keys are designed to allow movement that is the result of thermal growth of the reactor vessel in the radial and vertical directions. Reactor vessel supports are shown in Figure 3.8-12. Subsection 5.4.15 provides further information on the design of the reactor vessel support structure.

3.8.3.1.2 Steam Generator Supports

The steam generator is supported at the bottom by a sliding base bolted to an integrally attached conical skirt at elevation 34.53 m (113 ft 3.34 in). The sliding base rests on low friction spherical head bearings at elevation 34.21 m (112 ft 2.68 in), which allows unrestrained thermal expansion of the reactor coolant system. Two keyways in the sliding base mate with keys in a forged plate installed on the concrete pedestal by anchor bolts to guide the movement of the steam generator during expansion and contraction of the reactor coolant system and to limit movement of the bottom of the steam generator during seismic, IRWST discharge, and BLPB events. Keys and snubbers on the steam drum guide the top of the steam generator at centerline elevations 51.672 m (169 ft 6.35 in) and 48.399 m (158 ft 9.48 in), respectively, during expansion and contraction of the reactor coolant system and provide support during seismic, IRWST discharge, and BLPB events. Typical steam generator supports are shown in Figure 3.8-13. Subsection 5.4.15 provides further information on the design of the steam generator support structures.

3.8.3.1.3 Reactor Coolant Pump Support System

Reactor coolant pump supports consist of four vertical columns at elevation 31.33 m (102 ft 9.5 in), two horizontal snubbers, two upper horizontal columns at elevation 40.05 m (131 ft 4.75 in), and two lower horizontal columns at elevation 34.82 m (114 ft 2.75 in). These rigid structural columns provide support for the pumps during normal operation, earthquake conditions, IRWST discharge, and BLPB. Each column, horizontal and vertical, and the snubber end in a drilled clevis to accept anchor bolts. Support loads are transmitted to the concrete structures by anchor bolts. Typical reactor coolant pump supports are shown in Figure 3.8-14. Subsection 5.4.15 provides further information on the design of the reactor coolant pump support structures.

3.8.3.1.4 Pressurizer Support System

The pressurizer is supported by a cylindrical skirt as shown in Figure 3.8-15. This skirt is welded to the pressurizer and is anchored to the concrete slab at elevation 41.71 m (136 ft 10.25 in). The skirt is designed to withstand dead weight and normal operating loads as well as the loads due to earthquakes, pressurizer POSRV actuation, IRWST discharge, and BLPB events. Support loads are transmitted to the concrete slab through the skirt flange and anchor bolts. Four keys welded to the upper shell of the pressurizer at elevation 54.52 m (178 ft 10.38 in) provide an additional restraint for earthquake, pressurizer POSRV actuation, and BLPB conditions. Four keys in the pressurizer mate with keyways that are installed in the secondary shield wall by anchor bolts as shown in Figure 3.8-15. Subsection 5.4.15 provides further information on the design of the pressurizer support structures.

3.8.3.1.5 Primary Shield Wall and Reactor Cavity

The primary shield wall is a heavily reinforced concrete structure that houses the reactor vessel, provides the primary radiation shielding, and provides protection for the reactor vessel from internal missiles. It is anchored to the containment basemat through the use of mechanical splices welded to both sides of the thickened liner plate. The massive primary shield walls provide a support for the refueling canal walls above the reactor cavity. In plan, the primary shield walls form a monolithic ring, housing the reactor vessel. Penetrations in the primary shield wall are provided for the primary loop. The primary shield wall is designed to withstand the temperatures and pressures following a LOCA. The primary shield wall is a minimum of 2.01 m (6 ft 7 in) thick.

3.8.3.1.6 Secondary Shield Wall

The secondary shield wall is a reinforced concrete structure surrounding steam generators, reactor coolant pumps, and pressurizer. The secondary shield wall protects the reactor containment building from internal missiles. In addition to providing a biological shield for the coolant loop and equipment, the secondary shield wall also provides structural support for pipe supports/restraints and platforms at various levels. The secondary shield wall is a right cylinder with an inside diameter of 29.87 m (98 ft) and a height of 34.44 m (113 ft) from its base. The secondary shield wall is a minimum of 1.22 m (4 ft) thick.

The secondary shield wall is anchored into the basemat by mechanical splices welded to both sides of the thickened liner plate.

3.8.3.1.7 Refueling Pool

The refueling pool filled with borated water facilitates the fuel handling operation without exceeding the acceptable level of radiation inside the reactor containment building. The inside of refueling pool is lined with a stainless steel liner plate. The refueling pool has the following subcompartments:

a. Upper guide structure laydown area

b. Core support barrel laydown area

c. Refueling area

The refueling pool filled with borated water forms a pool above the reactor vessel. The reactor vessel flange is sealed to the bottom of the refueling pool to prevent leakage of refueling water into the reactor cavity as described in Subsection 9.1.4.2.1.11. The fuel transfer tube connects the refueling cavity to the refueling canal. The refueling pool is filled with borated water to a depth that limits the radiation at the surface of the water to acceptable levels during the period when a fuel assembly is being transferred to the spent fuel pool. The shield walls that form the refueling pool are a minimum of 1.22 m (4 ft) thick.

The bottom of the refueling pool varies in elevation from 106 ft 6.375 in to 130 ft. The top of the refueling pool wall elevation is 156 ft. The bottom and wall inside of refueling pool are lined with 5 mm (3/8 in) thick stainless steel plate.

3.8.3.1.8 In-containment Refueling Water Storage Tank

The in-containment refueling water storage tank (IRWST) provides storage of refueling water, a single source of water for the safety injection and containment spray pumps and a heat sink for the safety depressurization system. The IRWST is annular and uses the lower section of the internal structure as its outer boundary. The IRWST is lined with a stainless steel liner plate to prevent leakage. The IRWST consists of the top and bottom slab and the exterior wall. The bottom slab of IRWST rests on the reactor containment building basemat, and the top and bottom slabs are rigidly connected to the secondary shield wall. The design of the IRWST considers pressurization as a result of the reactor containment building systems design basis accident. Refer to Section 6.8 for a description of the IRWST.

3.8.3.1.9 Holdup Volume Tank

The holdup volume tank (HVT) is a rectangular structural tank located between the primary shield wall and the IRWST inner wall. A screen is provided at the top of the HVT to prevent debris from getting into the tank. The HVT has a sump with pumps to measure the leakage rate and route the liquid to the liquid waste management system. During an accident, the water from breaks and the reactor containment building spray is collected in the HVT and overflows into the IRWST. Refer to Section 6.8 for a description of the HVT.

3.8.3.1.10 Operating and Intermediate Floors

The operating floor provides access for operating personnel functions and biological shielding. Intermediate floors provide access to equipment and components. The operating floor is located at elevation 156 ft 0 in, and intermediate floors are located at elevations 114 ft 0 in and 136 ft 6 in. These floors consist of reinforced concrete or steel grating supported by structural steel framing that spans between the containment wall and the secondary shield wall. The steel framing has a horizontally sliding connection at the containment wall side to allow axial displacement of framing due to seismic displacement and thermal expansion. Openings are provided in the floor for equipment removal.

3.8.3.1.11 Interior Concrete Fill Slab

The interior concrete fill slab is located on the surface of liner plate of the reactor containment building basemat for protection of pressure boundary structures.

3.8.3.1.12 Polar Crane Supports

A large capacity of polar crane is supported by brackets installed in the containment shell, and the bracket is a steel structure consisting of cantilever beam.

3.8.3.2 Applicable Codes, Standards, and Specifications

The following codes, standards, and specifications are applied to the design of internal concrete and steel structures.

3.8.3.2.1 Design Codes and Standards

The design codes, standards, and regulations are listed in Table 3.8-1.

3.8.3.2.2 NRC Regulatory Guides

Conformance to each NRC RG is described in Section 1.9. The NRC RGs applicable to the design of the concrete and steel structures are 1.60, 1.61, 1.92, 1.122, 1.142, and 1.199 (References 22, 23, 24, 25, 26, and 27).

3.8.3.2.3 Industry Standards

Nationally recognized industry standards, such as those published by ASTM, will be used whenever possible to describe material properties, testing procedures, and fabrications and construction methods.

3.8.3.3 Loads and Load Combinations

The typical loads and load combinations used for the internal structures are detailed in Subsection 3.8.4.3.

The internal structures are designed for the following loads:

a. Dead load

b. Equipment operating loads and other live loads

c. Pipe reactions

d. Seismic load

e. Internal missiles (the internal structure is designed to withstand internal missiles, as described in Section 3.5)

f. Pipe rupture jet impingement

g. Compartment accident pressure

h. The greatest pipe rupture loads from (1) pipe breaks not eliminated by leak-before-break, (2) the largest through wall leakage crack in a high energy line (minimum 37.9 L/min [10 gpm]) whether or not consideration of dynamic effects is eliminated by leak-before-break for the line, or (3) the largest leak from another leak source, such as a valve or pump seal.

i. Operating and accident temperatures

Seismic Category I concrete structures are designed for impulsive and impactive loads in accordance with the *[ACI 349]** Code, and special provisions of Appendix C of the same code, with exceptions given in NRC RG 1.142. Impactive and impulsive loads are considered concurrent with seismic and other loads (i.e., dead and live loads) in determining the load resistance of structural elements.

Subcompartment pressure loads are the result of postulated high-energy pipe ruptures. In determining an appropriate equivalent static load for Y_r, Y_j, and Y_m, elasto-plastic behavior is acceptable with appropriate ductility ratios, provided excessive deflections do not result in loss of function of any safety-related system.

3.8.3.4 Design and Analysis Procedures

3.8.3.4.1 Analysis Procedure

The internal structure is designed for the loads and loading combinations specified in Subsection 3.8.3.3. The internal reinforced concrete structure including the reactor coolant system (RCS) is modeled with eight-node solid elements, three-node or four-node shell elements, and two-node beam elements using the ANSYS computer program. The design loads for analysis of internal structures are classified dead load, live load, hydrostatic and dynamic loads, temperature load, accident pressure load, pipe break load, and seismic load.

Dead loads include the self-weight of the PSW, SSW, IRWST, and fill concrete; equipment; and intermediate steel floor framing. Large equipment loads (e.g., reactor drain tank, letdown/regenerative heat exchanger, safety injection tank, recirculation fan) are treated as dead loads. In addition, potential loads during construction or operating periods are treated as live loads.

The vertical and lateral pressures of liquids inside containment are treated as dead loads. Structures supporting fluid loads during normal operation and accident conditions are designed for the hydrostatic as well as hydrodynamic loads.

The thermal stress analysis is carried out by inputting the normal operating thermal load into the corresponding FE model of internal structure. During the thermal analysis, the equivalent uniform temperature gradient is input directly in the ANSYS model at the appropriate nodes.

The compartment pressures on internal structures are the result of a pipe break inside containment. In addition, branch line pipe break (BLPB) loads are dynamic reactions caused by the combined effects of branch line nozzle reactions or thrust due to pipe break, jet impingement on RCS equipment, or subcompartment pressure effects on RCS equipment. These loads are applied to the ANSYS model with pressure and concentrated loads.

Response spectrum analysis is performed for the two horizontal and one vertical seismic load directions using the methodology described in Subsection 3.7.2.

3.8.3.4.2 Structural Design

The forces and moments resulting from the applied static and dynamic loads are used to design the walls, slabs, beams, and columns, which make up the internal structure. The design is performed using *[ACI 349 or ANSI/AISC N690]** as amended by Subsection 3.8.4.5.

3.8.3.4.3 Design Summary Report

A design summary report is prepared in Appendix 3.8A where the design of the representative critical sections of the structures is described.

The evaluation considering the deviations of as-procured or as-built construction to the design will be performed with the acceptance criteria described in Subsection 3.8.3.5.

3.8.3.5 Structural Acceptance Criteria

The structural acceptance criteria for the internal structures are outlined in Subsection 3.8.4.5.

3.8.3.6 Materials, Quality Control, and Special Construction Techniques

3.8.3.6.1 Concrete Internal Structures

Materials, quality control, and special construction techniques for the concrete internal structures are outlined in Subsection 3.8.4.6. The compressive strength of concrete is 6,000 psi at 91 days.

3.8.3.6.2 Structural Steel

The following materials are used:

a. Structural steel – ASTM A36, A572, A588, and A53

b. Bolts – ASTM A325, A490, and A307

c. Anchor bolts – ASTM 193 Grade B-7 and A36

Furnishing and fabrication of structural steel conform to all applicable requirements of *[AISC N690]**. Certified mill test reports for structural steel are submitted for review.

3.8.3.6.3 Stainless Steel Pool Liners

Stainless steel pool liners are fabricated from ASTM A240 Type 304 material, hot rolled, annealed and pickled and further processed by cold rolling.

Welding procedures are in accordance with ASME Section, Division 2, Subarticle CC-4540 and ASME Section IX. All seam welds are full penetration butt welds. The liner plate seam welds are examined and tested as follows:

a. Liquid penetrant examination is performed on austenitic materials. The weld surfaces and at least 12.7 mm (1/2 in) of the adjacent base material on each side of the weld are examined. The examination coverage is 100 percent of all shop and field seam welds.

b. Vacuum leak test is performed for leak-tightness on all liner plate seam welds.

3.8.3.6.4 Stainless Steel Other Than Pool Liners

Stainless steel embedded plates and stainless steel checkered floor plates are fabricated from A240 Type 304 material, hot rolled, annealed, and pickled. Stainless steel bars and rounds are fabricated from A276 or A479 Type 304 material, hot rolled, annealed, and pickled.

Stainless steel pipes are fabricated from A312 Type 304 or A358 Type 304 or A376 Type 304 materials, hot rolled, annealed, and pickled.

Stainless steel gratings are fabricated from A240 Type 302 or Type 304 materials, hot rolled, annealed, and pickled prior to fabrication and then electro-polished after fabrication.

Stainless steel sump liners are fabricated from A240 Type 304 or Type 316 materials.

Stainless steel bolts are fabricated from A193 Type 304 class 1 material.

Stainless steel nuts are fabricated from A194 Type 304 material.

Stainless shapes are fabricated from A276 or A479 Type 304 materials.

3.8.3.7 Testing and Inservice Inspection Requirements

Testing and inservice inspection requirements are outlined in Subsection 3.8.4.7.

3.8.4 Other Seismic Category I Structures

The other seismic Category I structures of the APR1400 plant are the auxiliary building and emergency diesel generator building.

The COL applicant is to provide the design of site-specific seismic Category I structures in addition to the above structures, such as the essential service water supply structure, component cooling water heat exchanger building, essential service water conduits, and class 1E electrical duct runs (COL 3.8(1)).

3.8.4.1 Description of the Structures

3.8.4.1.1 Auxiliary Building

The auxiliary building houses the mechanical and electrical equipment used for normal plant operation and safe shutdown of the reactor. The auxiliary building is composed of the electrical and control area, main steam valve house, chemical and volume control system (CVCS) areas, emergency diesel generator area, and fuel handling area.

The electrical and control area consists of the Class 1E electrical equipment rooms at elevation 78 ft 0 inch and those areas located above them. The electrical and control area provides two physically separate divisions for electrical distribution, control, and instrumentation systems leading to the main control room (MCR). The upper floor of the electrical and control area contains the MCR, which is designed to provide security, fire, and environmental protection to the control equipment and the MCR operators.

The main steam valve house is a compartment located above the auxiliary feedwater (AFW) tank areas on the north and south sides of the auxiliary building. The compartment is from elevation 137 ft 6 in to 175 ft 0 in. The main steam valve house is designed to provide environmental protection, primarily missile protection, for the main steam and feedwater line safety-related valves and piping.

The CVCS area consists of a number of small rooms that are used to isolate components for water treatment required by operating systems. Individual rooms are used for radiation shielding.

The emergency diesel generator areas provide protection to two diesel generators installed in separate compartments located on opposite sides of the auxiliary building.

The fuel handling area includes the spent fuel pool, refueling canal, cask loading pit, cask decontamination pit, truck/rail shipping bay, and new fuel storage area. The spent fuel pool is an open stainless steel lined reinforced concrete vessel used for submerged storage of radioactive spent fuel assemblies. The pool is approximately 10.8 m × 12.8 m (35 ft 6 in × 42 ft) with a depth of 12.8 m (42 ft). The walls and floor of the spent fuel pool are a minimum of 1.7 m (5 ft 6 in) thick.

Fuel assemblies are transferred from the fuel handling area to the refueling pool via the refueling canal in the auxiliary building and then the fuel transfer tube in the reactor containment building. The refueling canal measures 1.8 m (6 ft) wide by 20.5 m (67 ft 3 in) long. The minimum wall thickness on the fuel pool side is 1.8 m (6 ft). An opening in the fuel pool wall allows for passage of fuel between the fuel pool and the refueling canal. A steel divider is provided for the opening. Seals are incorporated to allow draining of the refueling canal while maintaining the water level in the spent fuel pool. An overhead bridge crane with a capacity of 150 tons is provided over the shipping bay and extending over the fuel pool and refueling canal. Interlocks are provided to prevent the crane from moving over the spent fuel storage area during cask handling operations. A new fuel-handling crane, running on rails mounted over the operating floor, is provided to handle the new fuel assemblies.

The two AFW tanks consist of three stainless steel lined reinforced concrete rooms. Each room has a single tank. The tanks extend from elevation 100 ft 0 in to the underside of the floor slab at elevation 137 ft 6 in.

The auxiliary building is rectangular with maximum dimensions of 106.0 m × 107.6 m (348 ft × 353 ft). It wraps around the reactor containment building with a seismic gap of 50 mm (2 in). The auxiliary building shares common basemat structure with the reactor containment building. The auxiliary building is separated from other buildings by the isolation gap of 900 mm (3 ft).

The outlines of the auxiliary building are shown in Figures 1.2-9 through 1.2-19.

3.8.4.1.2 Emergency Diesel Generator Building

The emergency diesel generator (EDG) building block comprises two buildings, one that houses two additional generators and the other for the diesel fuel oil tank (DFOT). The two buildings are independent structures built on separate basemats – one at elevation 100 ft 0 in for the EDG building, and the other at 63 ft 0 in for the DFOT building. The two basemats are horizontally separated by an isolation gap of 900 mm (3 ft).

The EDG building block is a seismic Category I reinforced concrete rectangular structure. The EDG building is approximately 19.2 m (63 ft) wide, 40.8 m (134 ft) long, and 10.7 m (35 ft) high and the DFOT building is 20.3 m (66 ft 8 in) wide, 21.6 m (71 ft) long, and 10.5 m (34 ft 6 in) high. The EDG building block is separated from the other buildings by an isolation gap of 900 mm (3 ft).

The EDG and DFOT buildings are both single-story structures with a basemat and roof slab. The buildings are founded on a 1.2 m (4 ft) thick continuous mat foundation. The roof slab for the EDG building is at elevation 135 ft 0 in, and the roof slab for the DFOT building is at elevation 97 ft 6 in.

The lateral load resisting system of the two buildings is composed of a diaphragm slab at roof level and shear walls monolithically interconnected at the roof. The lateral loads such as wind load and horizontal earthquake load are transferred to the soil foundation through the shear walls and the basemat. The vertical load-resisting system in each of the buildings consists of columns and shear walls. The vertical loads due to gravity and earthquake are carried by slabs, floor beams, columns, and shear walls down to the basemat and soil foundation.

The outlines of the emergency diesel generator building are shown in Figures 1.2-20 and 1.2-22.

3.8.4.1.3 Spent Fuel Storage Rack

The spent fuel storage rack is designed as a free standing type, i.e., neither anchored to the pool floor nor attached to the side walls, and designed as a seismic Category I structure. The spent fuel storage rack is designed to meet the following criteria even under the plant abnormal condition, such as seismic or fuel handling accident:

a. Protect the stored fuel against a physical damage

b. Maintain the stored fuel in a subcritical configuration

c. Maintain the capability to load and unload fuel assemblies

d. Maintain the store fuel in a coolable geometry

3.8.4.2 Applicable Codes, Standards, and Specifications

The following design codes, standards, specifications, regulations, Regulatory Guides, and other industry standards are used in the design, fabrication, construction, testing, and inspection of all seismic Category I structures other than the reactor containment building.

3.8.4.2.1 Design Codes and Standards

The design codes, standards, and regulations are listed in Table 3.8-1.

3.8.4.2.2 Regulatory Guides

The conformance of other seismic Category I structures to the applicable NRC RGs is addressed in Section 1.9. The NRC RGs that are applicable to the design of all seismic Category I structures other than the reactor containment building are NRC RGs 1.29 (Reference 28), 1.60, 1.61, 1.69 (Reference 29), 1.91 (Reference 30), 1.92, 1.115 (Reference 31), 1.122, 1.142, 1.143 (Reference 32), and 1.199.

3.8.4.2.3 Industry Standards

Nationally recognized industry standards, such as those published by ASTM, are used where practicable to define material properties, testing procedures, and fabrication and construction methods.

3.8.4.3 Loads and Load Combinations

This section presents the structural design load information for the APR1400 seismic Category I structures other than the reactor containment building. This load information consists of a summary list of major loads and load combinations. These load combinations are categorized on the basis of their nature, the probability of occurrence of each of the individual loads, and the probability of simultaneous occurrence of these loads to form a loading combination.

Evaluation of the capability of a structure for a given load combination is based on providing a factor of safety appropriate to the probability of occurrence. The appropriate factor of safety is reflected in the load factors and allowable stresses for the various load combinations.

The COL applicant is to identify any applicable site-specific loads such as site proximity explosions and missiles, potential aircraft crashes, and the effects of seiches, surges, waves, and tsunamis (COL 3.8(2)).

3.8.4.3.1 Normal Loads

a. Dead loads – (D)

Dead load refers to loads that are constant in magnitude and point of application. The types and definitions of dead loads and their combination requirements are given in Table 3.8-8.

b. Live loads – (L)

Live load refers to any normal loads that may vary with intensity and location of occurrence. The types and definitions of live loads and their combination requirements are given in Table 3.8-8. The specified design values for live loads are summarized in Table 3.8-7.

1) Soil and surcharge load (L_g)

Soil and surcharge load refers to load due to weight and pressure of soil, water in soil, or other material such as soil surcharge. Maximum flood level is specified to be 0.30 m (1 ft) below plant grade for safety-related structures. For the construction loading condition, the minimum surcharge load is 48.0 kN/m^2 (1,000 psf) over any unoccupied area plus the actual construction loading surcharge from any known structures or load sources. For the normal loading condition, the minimum surcharge load is 24.0 kN/m^2 (500 psf). For the design of underground utilities, the minimum surcharge load for the construction loading condition is 24.0 kN/m^2 (500 psf) and for the normal loading condition is 12.0 kN/m^2 (250 psf). Any loading conditions that result in soil surcharge loads greater than these minimum values are checked on an individual basis.

2) Hydrostatic load (L_h)

Hydrostatic loads are due to weight and pressures of fluids with well-defined densities and controllable maximum heights or related internal moment and forces.

3) Snow load (L_s)

Based on the assumed site-related parameters, the 100-year snowpack roof load is considered to be 2.873 kN/m^2 (60 psf).

c. Thermal operating load – (T_o)

Thermal operating load is thermal load effect from the most critical transient or steady-state thermal condition at normal operation or shutdown conditions. This also includes thermal effects such as frictional loads due to expansion.

d. Pipe, cable tray, duct supports, and ties – (R_o)

This includes their dead load, live load, thermal load, seismic load, thrust load, and unbalanced internal pressure under normal and severe environmental conditions.

R_{os} – Self weights, including contents

R_{ot} – Transient or steady state thermal loading conditions during normal operation and shutdown conditions

For test loading condition, this includes piping reactions due to test cleanup and blowdown conditions.

R_{op} – Effects of unbalanced pressure and thrust

e. Crane and trolley loads – (C)

C is crane and trolley lifted load, including impact load, longitudinal load and lateral load. All of these loads are considered as acting simultaneously.

1) Bridge crane

A bridge crane is a crane that has a bridge girder that moves longitudinally on two parallel beams, and a trolley hoist that moves laterally along the bridge girder. It can either ride on a rail on top of the two parallel beams or hang from their bottom flanges.

The lifted load is the rated capacity of the main hook. The manufacturer usually provides the maximum wheel load to be applied to the support steel.

The vertical impact load is considered to be 25 percent of the maximum wheel loads.

The longitudinal load is considered as 10 percent of the maximum wheel loads of the crane applied at the supporting beam flange.

The lateral load on crane runways for bridge cranes (to provide for the effect of the moving crane trolleys) is considered as 20 percent of the sum of the lifted load and the crane trolley. The load is applied to each side at the supporting beam flange (top or bottom depending on the support arrangement) acting in either direction normal to the support beams, and is distributed based on lateral stiffness of the structure supporting the bridge crane.

2) Trolley

A trolley is a hoist that can move longitudinally but not laterally and is hung from the bottom flange of the support beam (trolley beam). It can rotate laterally. Trolleys may be motorized or hand-operated.

The lifted load is the rated capacity of the trolley hoist.

The vertical impact load is considered as 25 percent of the maximum wheel loads (lifted load plus the hoist self-weight).

The longitudinal load is considered as 10 percent of the maximum wheel loads of the trolley (lifted load plus the hoist self-weight), without impact, applied at the bottom flange of the support beam.

The lateral load for trolleys is calculated for the maximum wheel loads without impact, rotated a minimum angle of 5 degree about a vertical plane at the bottom flange. When an angle is specified on the equipment removal drawings and is greater than 5 degree, it is used. The load is applied at the bottom flange of the support beam.

For severe environmental and extreme environmental loading combinations on seismic Category I structures, 100 percent of the lifted load is used.

f. Operating pressure – (P_o)

Operating pressure load is the external or internal air or gas pressure loads during normal operating conditions. Examples of this are pressures within air and gas ducts, and differential air pressures on building walls.

g. Miscellaneous normal loads – (M_o)

M_o is other miscellaneous normal loads, such as the column contingency load, transformer high-voltage line pull-off loads, vehicle loads, miscellaneous material handling loads (e.g., belt pulls, barge berthing impact). Column contingency loads are considered in the column design to account additional loads.

h. Construction loads

Construction loads are related to all events and loads during construction. These loads include dead loads, live loads, temperature loads, precipitation loads, wind loads, and construction loads such as surcharge loads due to construction equipment, hoisting loads due to construction activities, and laydown loads during construction. SEI/ASCE 37-02 (Reference 18) is considered to be supplemental guidance.

3.8.4.3.2 Abnormal Loads

a. Accident pressure – (P_a)

Accident pressure is applied external or internal air, gas, or liquid pressure loads during abnormal operating conditions. Examples of this are excursion pressures within gas ducts due to fan or damper type failures and differential air pressure on a building wall due to a postulated pipe break including annulus pressurization effects and flooding loads. An appropriate dynamic factor to account for the dynamic response of the structure and the time dependency of the load is included.

1) Main steam valve house

The compartmental accident pressures due to main steam and feedwater line breaks are considered.

2) Other areas

Accident pressures in other areas of seismic Category I structures are defined during plant layout and design.

b. Accident temperature – (T_a)

Accident temperature is thermal load effects during abnormal operating conditions. Accident temperatures in other areas of seismic Category I structures are defined during plant layout and design.

c. Accident reactions of pipe, cable tray and duct supports and ties – (R_a)

R_a is reactions of pipe, cable tray, and duct supports and ties. This includes their dead load, live load, thermal load, seismic load, thrust load, and transient unbalanced internal pressure loads under abnormal and/or extreme environmental conditions.

d. Pipe break reactions – (Y_r)

Y_r is equivalent static load on the structure generated by the reaction of the broken high-energy pipe during the postulated break, including an appropriate dynamic factor to account for the dynamic response of the structure, and the time dependency of the load.

1) Pipe whip restraint reactions

Pipe whip restraint reactions are the loads transferred from the restraint to the supporting structure.

2) Pipe hanger loads

This is the portion of the pipe hanger reaction that is due to a pipe break (excluding thermal effects).

e. Jet impingement load – (Y_j)

Y_j is the jet impingement equivalent static load on a structure generated by a postulated pipe break, including an appropriate dynamic factor to account for the dynamic response of the structure, and the time dependency of the load.

f. Missile impact load – (Y_m)

Y_m is the missile impact load on a structure generated by or during a postulated pipe break, like pipe whipping, including an appropriate dynamic load factor to account for the dynamic response of the structure, and the time dependency of the load.

g. Flooding load – (Y_f)

Y_f is the load within or across a compartment and/or building due to flooding generated by a postulated pipe break. These loads are calculated considering the design basis flood heights.

h. Miscellaneous abnormal loads – (M_a)

M_a includes other miscellaneous site-related accidents such as blast, aircraft impact, or internally generated equipment missiles.

i. Internal flooding – (H_a)

H_a includes loads on the containment resulting from internal flooding other than from pipe breaks.

3.8.4.3.3 Severe Environmental Loads

a. Wind loads – (W)

W is the equivalent static load generated by the design wind velocity, is calculated in accordance with ASCE 7 (Reference 33) and is described in Subsection 3.3.1. Seismic Category I structures are designed for a 100-year recurrence interval wind and for tornado and hurricane winds and missiles as described in Subsections 3.3.2 and 3.5.1.4.

For seismic Category I structures, an importance factor I of 1.15 is used with 50-year, 3-second gust speed at exposure Category C, as defined in ASCE 7.

b. Design flood/precipitation – (H)

Flood loads on seismic Category I structures are determined based on the maximum site flood levels specified in Chapter 2.

c. Operating basis earthquake

The operating basis earthquake (OBE) is defined as one-third of the SSE. Therefore, an analysis or design of APR1400 seismic Category I SSCs based on OBE is not required in accordance with Appendix S of 10 CFR 50.

3.8.4.3.4 Extreme Environmental Loads

a. Safe-shutdown earthquake – (E_s)

SSE loads are considered as follows:

1) Seismic Category I structures

For seismic Category I structures, E_s are the loads generated by the SSE. Hydrodynamic load and dynamic soil pressure are included in E_s.

Seismic response for SSE is determined using a dynamic analysis. Enveloped floor response spectra in both the horizontal (N-S and E-W) and vertical directions are prepared for all major building floor elevations. An equivalent static method is used to determine SSE loads on structural components (e.g., floor slabs, beams).

2) Combination of SSE loads

For each load, the responses from all three directional earthquakes are combined simultaneously. The independent directional responses are combined using the square root of the sum of the squares (SRSS) method or the 100-40-40 percent rule described in ASCE 4. The 100-40-40 percent rule is based on the observation that the maximum increase in the resultant for two orthogonal forces occurs when these forces are equal. The maximum value is 1.4 times one component. All possible combinations of the three orthogonal responses are considered. The 100-40-40 percent rule may also be applied for combining responses in the same direction due to different components of motion.

Stresses due to seismic loads from different directions are combined by the SRSS method using the following expression:

3) Additional seismic loads due to accidental torsion

Additional seismic loads due to accidental torsion are accounted for as required by SRP Subsection 3.7.2.II.11. An additional eccentricity of the mass at each floor equivalent to 5 percent of the maximum building dimension is included. The accidental torsion load is represented by an additional shear force at each floor elevation determined from the analysis for the product of resultant story shear and accidental eccentricity at each elevation.

b. Tornado or hurricane load – (W_t)

The tornado or hurricane loads are described in Subsection 3.3.2.

c. Probable maximum flood/precipitation – (H_s)

H_s is the forces, due to the probable maximum precipitation as well as the maximum flood level, which includes the effects of seiches, surges, waves, and tsunamis.

3.8.4.3.5 Other Loads

Other loads are loads resulting from aircraft hazard and explosion pressure wave that are not included in the design basis. These loads are evaluated to prevent damage to safety-related structures, systems, and components beyond the design basis condition.

3.8.4.3.6 Load Combinations

The load combinations to be used in the design of the structure are in accordance with Tables 3.8-9A and 3.8-9B, and in conjunction with the definitions of load conditions and design loads as provided in Subsections 3.8.4.3.1 through 3.8.4.3.5.

3.8.4.4 Design and Analysis Procedures

The auxiliary building and the emergency diesel generator building are composed of basemat foundation, rectangular walls, floor slabs, columns, and beams. The slabs and shearwalls in the building represent the primary lateral and vertical load-resisting system and are designed for both gravity- and seismic-related loads. Concrete slabs at various elevations in the building distribute lateral forces (via diaphragm action) to the shearwalls as in-plane loads and resist vertical forces (self-weight and seismic forces) as out-of-plane loads. Lateral loads are transferred down to the basemat foundation through shearwalls as in-plane shear forces and moments. Vertical loads on slabs are supported by concrete beams or walls. The loads are transferred to the basemat foundation by the walls and the frames composed of concrete beams and concrete columns. In addition to the structural components, components are designed to provide biological shielding and protection against tornado, hurricane, and turbine missiles.

Structural analyses of the concrete structures are performed by the ANSYS or GTSTRUDL (Reference 34) program to determine the design forces of structure due to various loads and load combinations.

Other seismic Category I concrete structures are analyzed and designed in accordance with the requirements of *[ACI 349]** with exceptions of the requirements in NRC RG 1.142. Those requirements are incorporated into the design and accommodated in the load combinations described in Subsection 3.8.4.3 for concrete structures.

Other seismic Category I steel structures are designed in accordance with *[ANSI/AISC N690]** using the allowable stress design method.

The spent fuel storage rack in the spent fuel pool is designed to withstand the seismic load that is seismic excitation along three (3) orthogonal directions is applied simultaneously for the design of the rack.

3.8.4.4.1 Analysis of Structure

A detailed three-dimensional finite element model of the other seismic Category I structures is developed to distribute the global loads to all structural components. The structural analysis model of the auxiliary building is shown in Figure 3.8-9. The model includes all walls, floor slabs, and major structural beams and columns. The walls and slabs are modeled with three- or four-node shell elements, and the beams and columns are modeled with two-node beam elements using the ANSYS computer program.

Global static analysis for each loading condition is performed using the models, and results are combined using the load combinations identified in Subsection 3.8.4.3.4. Seismic analyses of seismic Category I structures conform to the procedures described in Subsection 3.7.2. The accelerations from the seismic analysis are applied to the finite element models as equivalent static loads at the corresponding elevations.

3.8.4.4.2 Structure Design

3.8.4.4.2.1 Concrete Structure

The requirements for the design of seismic Category I concrete structures conform to all requirements of *[ACI 349]** and NRC RG 1.142.

Design provisions for impulsive and impactive effects in the seismic Category I structures are in accordance with *[ACI 349]**, Appendix C.

*[ACI 349]**Appendix A, ACI Report ACI 349.1R or computer analysis programs are used to evaluate thermally induced forces and moments in seismic Category I structural members.

Required reinforcing for the seismic Category I concrete members are determined in accordance with *[ACI 349.]**

When feasible, uniform reinforcement patterns are used for sections with similar requirements, thickness, and loading.

The design of the support anchorage to the concrete structure meets the requirements of *[ACI 349-01 Appendix B]** and NRC RG 1.199.

3.8.4.4.2.2 Steel Structure

The design of seismic Category I steel structures and components uses the allowable stress design methods in accordance with *[ANSI/AISC N690]** including Supplement 2.

Bolted connections are used for field erection of structural steel beams and columns. The design of bolted connections is in accordance with [*Section Q1.16 of AISC N690]** and the “Specification for Structural Joints Using ASTM A325 or A490 Bolts” (Reference 35).

Welding activities associated with seismic Category I structural steel and their connections are accomplished in accordance with the requirements of AWS D1.1 (Reference 36).

3.8.4.4.2.3 Missile Protection

Exterior walls and roof slabs of seismic Category I structures function as missile barriers. Design of missile barriers provides reasonable assurance that the structure will not collapse under the missile load and the barrier will not be penetrated. Safety-related SSCs are protected from secondary missiles as a result of backface scabbing. Interior walls and floors are designed to function as missile barriers when it is evaluated to be necessary.

The design of seismic Category I structures for internally generated and externally generated missiles conforms to the procedures described in Section 3.5.

3.8.4.4.2.4 Flooding

Flooding is addressed in Section 3.4.

3.8.4.4.2.5 Wall/Floor Penetrations

Openings are acceptable without analysis if they meet the criteria in *[ACI 349]**, Section 13.5.2.

Penetration sleeves usually consist of a pipe embedded in a concrete wall or concrete floor with a short projection at one of both faces. As a minimum, penetration sleeves have sufficient thickness to maintain roundness during concrete pouring of other construction. Penetration sleeves are designed in accordance with *[ACI 349 and AISC N690.]**

Each corner of rectangular openings in walls or slabs is provided with diagonal reinforcing to reduce cracking due to stress concentration at these locations in accordance with *[ACI 349,]** Section 14.3.7.

3.8.4.4.2.6 Embedment Plates

Embedment plates are located throughout the plant to provide sufficient and efficient support for the various structures and components. The plate is designed in accordance with *[AISC N690.]** The anchorage to concrete is designed in accordance with *[ACI 349-97, including Appendix B (2001),]** and NRC RG 1.199.

3.8.4.4.3 Design Summary Report

A design summary report is prepared for the other seismic Category I structures in Appendix 3.8A where the design summaries for the representative critical sections of the structures are described.

Deviations from the standard design of as-procured or as-built construction are acceptable based on an evaluation following the methods and procedures described in Sections 3.7 and 3.8. The structural design is evaluated in accordance with the acceptance criteria described in Subsection 3.8.4.

3.8.4.5 Structural Acceptance Criteria

Structural acceptance criteria for design strengths and allowable stresses are listed in Table 3.8-9A for concrete structures and in Table 3.8-9B for steel structures, and are in accordance with ACI 349 and *[AISC N690,]** except as provided in the table notes.

Limits for crack controls, deflections, and other design criteria are in accordance with *[ACI 349]** and NRC RG 1.142 for concrete structures and *[AISC N690]** for steel structures.

The structural acceptance criteria for the foundation design are described in Subsection 3.8.5.5.

The seismic Category I concrete structures that are subjected to thermal effects conform to the minimum provisions of *[ACI 349 Appendix A.]**

The structural acceptance criterion on the spent fuel storage rack is to meet the maximum allowable stress limits with given load combinations described in Table 3.8-9C in accordance with the NRC SRP 3.8.4, Appendix D. When the effects of seismic loads are considered, factors of safety against gross sliding and overturning of racks and rack modules under all probable service conditions is in accordance with the NRC SRP 3.8.5, subsection II.5.

3.8.4.6 Material, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control programs, and special construction techniques used in the fabrication and construction of the seismic Category I concrete and steel structures other than the reactor containment building.

3.8.4.6.1 Material

The seismic Category I structures are poured-in-place reinforced concrete structures. The major materials that are used in the construction are concrete, reinforcing bars, and structural steel.

3.8.4.6.1.1 Concrete

The minimum concrete compressive strength used in other seismic Category I structures is 34.5 MPa (5,000 psi) at 91 days. The basic ingredients of concrete are cement, fine aggregates, coarse aggregates, and mixing water. Admixtures may be used if needed. The concrete conforms to *[ACI 349]** and ASTM C94.

The COL applicant is to determine the environmental condition associated with the durability of concrete structures and provide the concrete mix design to prevent concrete degradation caused by factors such as the reactions of sulfate and other chemicals, the corrosion of reinforcing bars, and the effect of reactive aggregates (COL 3.8(3)).

Cement is Type I and conforms to ASTM C150. In special circumstances, other approved cements may be used.

Aggregates conform to ASTM C33.

The water and ice used in mixing concrete are clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances that may be deleterious to concrete or steel. The water and ice do not contain more than 500 ppm of chlorides as Cl^-, as determined in accordance with ASTM D 512 and not more than 2,000 ppm of total solids as determined in accordance with ASTM D 1888. A comparison of the proposed mixing water properties is made with distilled water by performing the following tests:

a. Time of setting, in accordance with ASTM C191 (Reference 37). The results obtained for the proposed mixing water conform to ASTM C 94.

b. Compressive strength, in accordance with ASTM C109 (Reference 38). The results obtained for the proposed mixing water are not lower by more than 10 percent of those obtained for distilled water.

The water used to make ice for concrete pours in hot weather conforms to the requirements for mixing water described above.

Admixtures, if used and as determined by detailed mix design, conform to the applicable ASTM standards, as follows:

a. Air-entraining admixtures, ASTM C260, “Standard Specification for Air-Entraining Admixtures for Concrete”

b. Water reducing, retarding, and accelerating admixtures, ASTM C494, “Standard Specification for Chemical Admixtures for Concrete”

c. Ground granulated blast-furnace slag, ASTM C989. “Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars”

d. Silica fume, ASTM C1240, “Standard Specification for Silica Fume Used in Cementitious Mixtures”

e. Slag cement, ASTM C595, “Standard Specification for Blended Hydraulic Cements”

f. Plasticizing admixtures, ASTM C1017, “Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete”

The ingredient materials are stored in accordance with the recommendations in ACI 304R.

Concrete mixes are designed in accordance with ACI 301. The batching, mixing and transporting of concrete conform to ACI 301. The placement of concrete, consisting of preparation before placing, conveying, depositing, protection, and bonding is in accordance with ACI 301.

3.8.4.6.1.2 Reinforcing Steel

Reinforcing steel consists of deformed reinforcing bars conforming to ASTM A615, Grade 60, or ASTM A706, Grade 60. The fabrication of reinforcing bars, including fabrication tolerances, is in accordance with CRSI, MSP-1. The placing of reinforcing bars, including spacing of bars, concrete protection of reinforcement, splicing of bars and field tolerances is in accordance with *[ACI 349.]** Epoxy-coated reinforcing steel may be used for areas where a corrosive environment is encountered.

3.8.4.6.1.3 Structural Steel

Structural steels are used as follows:

Other structural steels listed in AISC N690 may also be used.

a. ASTM A36 (Reference 39), “Standard Specification for Carbon Structural Steel”

b. ASTM A572, “Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural”

c. ASTM A588, “Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4 in. [100 mm] Thick”

d. ASTM A53, “Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless”

Fabrication and erection of structural steel in seismic Category I structures are in accordance with the requirements of *[AISC N690.]**

Welding materials conform to the requirements of the Structural Welding Code (AWS-D1.1). AWS D1.1 Table 3.1 shows the compatibility of filler metal with base metal. *[ANSI/AISC N690]** provides supplemental information on weld materials for stainless steel.

Bolted connections conform to one of the following specifications:

a. ASTM A325, “Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength”

b. ASTM A490, “Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength”

c. ASTM A307, “Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength”

Bolts listed in *[AISC N690]** may also be used.

3.8.4.6.1.4 Stainless Steel

Stainless steel pool liners are fabricated from ASTM A240 Type 304 material, hot rolled, annealed and pickled and further processed by cold rolling. Further requirements for stainless steel pool liners and other stainless steel are described in Subsections 3.8.3.6.3 and 3.8.3.6.4.

3.8.4.6.2 Quality Control

The quality of materials is controlled by requiring the suppliers to furnish appropriate mill test reports as required under relevant ASTM specifications as described in Subsection 3.8.4.6.1. The mill test reports are reviewed and approved in accordance with the general provisions of the overall quality assurance program outlined in Chapter 17 and supplemented by the special provisions of the appropriate codes and specifications for design listed in Subsection 3.8.4.2.

Erection tolerances, in general, are in accordance with the referenced design code. Where special tolerances that influence the erection of equipment are required, they are indicated on the design drawings.

3.8.4.6.3 Special Construction Techniques

No special construction techniques are used in the construction of other seismic Category I structures.

The corrosion protection of the auxiliary building reinforcing steel is provided by an adequate cover of high-quality concrete over the reinforcing bar. Unless the concrete is penetrated by chloride or sulfide ions, the reinforcing bar remains passive and will not corrode.

Slabs in the auxiliary building are constructed using metal deck and steel beams that support metal deck and concrete slab during construction. Steel beams are connected to shear walls or concrete beams. This method allows concrete slabs to be constructed without shorings and forms.

The COL applicant is to determine construction techniques to minimize the effects of thermal expansion and contraction due to hydration heat, which could result in cracking (COL 3.8(4)).

3.8.4.7 Testing and Inservice Inspection Requirements

There is no testing or in-service surveillance beyond the quality control tests performed during construction, which is in accordance with *[ACI 349, AISC N690]**, or ANSI N45.2.5, in accordance with NRC RG 1.127 and NUMARC 93-01.

However, the COL applicant is to monitor the safety and serviceability of seismic Category I structures during the operation of the plant, and appropriate maintenance will be provided as necessary (COL 3.8(5)).

3.8.5 Foundations

3.8.5.1 Description of the Foundations

The foundation basemat is a reinforced concrete common basemat structure for the nuclear island that consists of the reactor containment building and auxiliary building.

3.8.5.1.1 Reactor Containment Building Foundation

The reactor containment building basemat is reinforced at the top and bottom with layers of reinforcing steel bars. The reinforcing bars are arranged in radial and hoop directions for top layers and orthogonal directions for bottom layers. In addition, the reinforcing bars at the floor of the reactor pit below the liner are arranged in orthogonal directions for the top and bottom layers.

The steel liner plate for the containment basemat is 6.0 mm (0.25 in) thick except for embedments in local areas where it is thickened. The liner is anchored by welding on the top of the structural steel rolled sections embedded in the concrete.

Interior structural concrete is poured over the basemat liner to provide support for the reactor coolant loop (RCL) equipment, RCL piping, and the interior concrete walls. Tensile loads generated from analyses are carried by anchorage through the liner plate and into the basemat, if required. Tensile loads from internal concrete walls are transferred from the wall reinforcement to a thickened liner plate using mechanical splices and are then transferred to the base slab through steel reinforcement dowels welded to the underside of the thickened liner plate.

3.8.5.1.2 Auxiliary Building Foundation

The foundation of the auxiliary building is a reinforced concrete mat and rests on competent material with a thickness of 3.05 m (10 ft). The bottom of the basemat is located at elevation 40 ft 0 in and 45 ft 0 in, below the finished grade elevation.

The auxiliary building basemat is reinforced at the top and bottom with layers of reinforcing steel bars. The reinforcing bars are arranged in orthogonal directions for the top and bottom layers.

3.8.5.1.3 Emergency Diesel Generator Foundations

The emergency diesel generator (EDG) building block comprises two buildings, one of which houses the EDGs and the other the diesel fuel oil tank (DFOT). The two buildings are independent structures built on a separate concrete reinforced mat foundation with a thickness of 1.2 m (4 ft). The bottom of the basemat is located at 92 ft 0 in for the EDG building and 59 ft 0 in for the DFOT building.

3.8.5.2 Applicable Codes, Standards, and Specifications

The reinforced concrete foundations of the reactor containment building are designed using the codes and standards described in Subsection 3.8.1.2. The reinforced concrete foundations and supports of other seismic Category I structures are designed using the codes and standards described in Subsection 3.8.4.2.

3.8.5.3 Loads and Load Combinations

The design loads and load combinations of the reactor containment building foundation are described in Table 3.8-2. The design loads and load combinations of the auxiliary building foundation and EDG foundation are described in Subsection 3.8.4.3.

3.8.5.4 Design and Analysis Procedures

The NI common basemat is analyzed using the ANSYS computer program. Stiffening effects of the reactor containment building wall, internal concrete structures, and auxiliary building are included in the model.

The NI common basemat is modeled with eight-node solid element in the ANSYS computer program. In addition, in order to consider the soil effect, the link element in ANSYS is used with the NI common basemat model.

The reinforced concrete basemat of the reactor containment building is designed in accordance with ASME Section III, Division 2, Subsection CC. Other seismic Category I basemats of reinforced concrete are designed in accordance with *[ACI-349]** and the provisions of NRC RG 1.142 where applicable.

The maximum differential settlement of foundation is 12.7 mm per 15.24 m (0.5 in per 50 ft) within NI common basemat. The maximum differential settlement between buildings is 12.7 mm (0.5 in) based on enveloping properties of subsurface materials. In addition, the common basemat is analyzed for construction sequences to minimize any potential differential settlement during construction.

3.8.5.4.1 Analyses for Loads during Operation

The reinforced concrete foundations of seismic Category I structures are analyzed and designed for the reactions due to static, seismic and all other significant loads at the base of the superstructures supported by the foundation. The effect of the temperature load in the basemat is negligible and is not considered in the basemat analysis based on *[ACI-349]**. According to *[ACI-349]**, thermal gradients less than approximately 38 °C (100 °F) need not be analyzed because such gradients do not cause significant stress in the reinforcement or strength deterioration. In the NI common basemat, the temperature gradient is approximately 50 °F and a uniform temperature change is less than 10 °C (50 °F). The analysis of the foundation mat is performed by a three-dimensional finite element structure model, and the forces and moments determined in the analysis are input to the structural design.

The analysis and design of the foundations consider the effects of potential mat uplift, with particular emphasis on differential settlements of the basemat.

The foundation of the seismic Category I structure analysis is performed considering a soil/rock properties beneath the foundation as a nonlinear spring elements. The model is capable of determining the possibility of uplift of the basemat from the subgrade during postulated SSE events. The vertical spring at each node in the analytical model acts in compression only. The horizontal springs are active when the vertical spring is in compression and inactive when the vertical spring lifts off.

3.8.5.4.2 Analyses of Settlement during Construction

The basemat is analyzed and designed to consider settlements in various phases of construction.

The basemat is sufficiently reinforced to control stresses until the concrete placement of basemat walls and containment internal structure is completed.

3.8.5.4.3 Design Summary Report

A design summary report for the basemats is presented in Appendix 3.8A, where the design of representative critical sections of the structures is described.

The evaluation considering the deviations of as-procured or as-built construction to the design will be performed with the acceptance criteria, as described in Subsection 3.8.5.5 (Reference 40).

3.8.5.5 Structural Acceptance Criteria

The structural acceptance criteria for the containment and other seismic Category I structures excluding the reactor containment building are described in Subsections 3.8.1.5 and 3.8.4.5, respectively. In particular, the acceptance criteria for the stability of seismic Category I structures are checked together with the structural acceptance criteria against the design loadings. The overturning, sliding, and flotation are checked as a minimum for stability of the basemat.

The design soil conditions are as provided in Section 2.5. The COL applicant is to provide reasonable assurance that the design criteria listed in Table 2.0-1 are met or exceeded (COL 3.8(6)).

The acceptance criteria for overturning, sliding, and flotation are described in Table 3.8-10. The factor of safety to design load combinations is calculated as stated below and compared to the minimum factors to provide reasonable assurance of the stability of the basemats.

3.8.5.5.1 Overturning Acceptance Criteria

The factor of safety against overturning is identified as the ratio of the resisting moment on overturning (M_r) to the overturning moment (M_o). Therefore,

$FS_o = [\ M_r\ /\ M_o\ ]$, not less than the factor of safety determined from Table 3.8-10.

Where:

FS_o = structure factor of safety against overturning caused by the design basis wind, tornado, hurricane, or earthquake load

M_r = resisting moment determined as the dead load of the structure minus buoyant force from normal design ground water table, multiplied by the distance from the structure edge to the structure center of gravity provided there is no overstress at the edge of the structure

M_o = overturning moment caused by earthquake

Resistance moment due to passive soil pressure is not included in M_r. Therefore, active and overburden soil pressures are also not considered.

3.8.5.5.2 Sliding Acceptance Criteria

The factor of safety against sliding caused by earthquake is identified by the following ratio:

$FS_s = [\ F_s\ ]\ /\ [\ F_d\ ]$, not less than the factor of safety determined from Table 3.8-10

Where:

FS_s = structure factor of safety against sliding caused by earthquake

F_s = sliding resistance along bottom of the basemat determined as the dead load of the structure minus the buoyant force from the normal design ground water table

F_d = earthquake load

The sliding resistance is based on the friction force developed between the basemat and the foundation with a coefficient of friction of 0.7 calculated with an internal friction angle of 35 degrees in the soil below the basemat. Resistance force due to passive soil pressure is not included in F_s. Therefore, active and overburden soil pressures are also not considered.

3.8.5.5.3 Flotation Acceptance Criteria

The factor of safety against flotation is identified as the ratio of the total dead load of the structure including basemat (D_r) to the buoyant force (F_b). Therefore, $FS_f = D_r / F_b$, not less than the factor of safety determined from Table 3.8-10.

Where:

FS_f = structure factor of safety against flotation caused by the maximum design basis flood or ground water table

D_r = total dead load of the structure including basemat

F_b = buoyant force caused by the design basis flood or high ground water table, whichever is greater

3.8.5.6 Material, Quality Control, and Special Construction Techniques

The materials, quality control, and special construction techniques for foundations conform to those set forth for the superstructures as discussed in Subsections 3.8.1.6 and 3.8.4.6 and Appendix 3.8A.

The COL applicant is to confirm that uneven settlement due to construction sequence of theb NI basemat falls in the values specified in Table 2.0-1 (COL 3.8(7)).

3.8.5.7 Testing and Inservice Inspection Requirements

Testing and inservice surveillance of the basemat are performed in accordance with the requirements described in Subsections 3.8.1.7 and 3.8.4.7.

The COL applicant is to provide the necessary measures for foundation settlement monitoring considering site-specific conditions (COL 3.8(8)).

The COL applicant is to provide testing and inservice inspection programs to examine inaccessible areas of concrete structures for degradation and monitoring of groundwater chemistry (COL 3.8(9)).

3.8.6 Combined License Information

COL 3.8(1) The COL applicant is to provide the design of site-specific seismic Category I structures such as the essential service water supply structure and the component cooling water heat exchanger building.

COL 3.8(2) The COL applicant is to identify any applicable site-specific loads such as site proximity explosions and missiles, potential aircraft crashes, and the effects of seiches, surges, waves, and tsunamis.

COL 3.8(3) The COL applicant is to determine the environmental condition associated with the durability of concrete structures and provide the concrete mix design that prevents concrete degradation including the reactions of sulfate and other chemicals, corrosion of reinforcing bars, and influence of reactive aggregates.

COL 3.8(4) The COL applicant is to determine construction techniques to minimize the effects of thermal expansion and contraction due to hydration heat, which could result in cracking.

COL 3.8(5) The COL applicant is to monitor the safety and serviceability of seismic Category I structures during the operation of the plant and provide the appropriate maintenance.

COL 3.8(6) The COL applicant is to provide reasonable assurance that the design criteria listed in Table 2.0-1 are met or exceeded.

COL 3.8(7) The COL applicant is to confirm that uneven settlement due to construction sequence of the NI basemat falls within the values specified in Table 2.0-1.

COL 3.8(8) The COL applicant is to provide the necessary measures for foundation settlement monitoring considering site-specific conditions.

COL 3.8(9) The COL applicant is to provide testing and inservice inspection program to examine inaccessible areas of the concrete structure for degradation and to monitor groundwater chemistry.

3.8.7 References

1. 10 CFR 50, “Domestic Licensing of Production and Utilization Facilities.”

2. ASME Section III, Division 1, “Rules for Construction of Nuclear Facility Components,” Subsection NE, “Class MC Components,” American Society of Mechanical Engineers, 2001 Edition with 2003 Addenda.

3. ASME Section III, Division 2, “Code for Concrete Containments,” Subsection CC, American Society of Mechanical Engineers, 2001 Edition with 2003 Addenda.

4. NRC RG 1.35, “Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containment,” Rev. 3, Nuclear Regulatory Commission, July 1990.

5. NRC RG 1.35.1, “Determining Prestressing Forces for Inspection of Prestressed Concrete Containments,” Nuclear Regulatory Commission, July 1990.

6. NRC RG 1.136, “Design Limits, Loading Combinations, Materials, Construction, and Testing of Concrete Containments,” Rev. 3, Nuclear Regulatory Commission, March 2007.

7. NRC RG 1.7, “Control of Combustible Gas Concentrations in Containment,” Rev. 3, Nuclear Regulatory Commission, March 2007.

8. SEI/ASCE 37-02, “Design Loads on Structures during Construction Standard.”

9. ANSYS, Advanced Analysis Techniques Guide, Release 14.0, ANSYS Inc., November 2011.

10. ASTM C150, “Standard Specification for Portland Cement.”

11. ASTM C33, “Standard Specification for Concrete Aggregates.”

12. ASTM C260, “Standard Specification for Air-Entraining Admixtures for Concrete.”

13. ASTM C494, “Standard Specification for Chemical Admixtures for Concrete.”

14. ASTM C618, “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.”

15. ASTM A615, “Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.”

16. ASTM A513, “Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing.”

17. ASTM A519, “Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing.”

18. ASTM A576, “Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality.”

19. ASTM A416, “Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete.”

20. ASME SA240, “Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications.”

21. NRC RG 1.57, “Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components,” Rev. 2, Nuclear Regulatory Commission, May 2013.

22. NRC RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” Rev. 1, Nuclear Regulatory Commission, December 1973.

23. NRC RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” Rev. 1, Nuclear Regulatory Commission, March 2007.

24. NRC RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Rev. 3, Nuclear Regulatory Commission, October 2012.

25. NRC RG 1.122, “Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components,” Rev. 1, Nuclear Regulatory Commission, Feburary 1978.

26. NRC RG 1.142, “Safety-Related Concrete Structures for Nuclear Power Plants,” Rev. 2, Nuclear Regulatory Commission, November 2001.

27. NRC RG 1.199, “Anchoring Components and Structural Supports in Concrete,” Nuclear Regulatory Commission, November 2003.

28. NRC RG 1.29, “Seismic Design Classification,” Rev. 4, Nuclear Regulatory Commission, March 2007.

29. NRC RG 1.69, “Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants,” Rev. 1, Nuclear Regulatory Commission, May 2009.

30. NRC RG 1.91, “Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants,” Rev. 2, Nuclear Regulatory Commission, Aprl 2013.

31. NRC RG 1.115, “Protection Against Low-Trajectory Turbine Missiles,” Rev. 2, Nuclear Regulatory Commission, January 2012.

32. NRC RG 1.143, “Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants,” Rev. 2, Nuclear Regulatory Commission, November 2001.

33. ASCE 7-05, “Minimum Design Loads for Buildings and Other Structures,” American Society of Civil Engineering/Structural Engineering Institute, 2006.

34. GTSTRUDL User Guide, GTSTRUDL Version 31, Georgia Institute of Technology, August 2010.

35. Research Council on Structural Connections, “Specification for Structural Joints Using ASTM A325 or A490 Bolts,” 2004.

36. AWS D1.1, Structural Welding Code, 2010.

37. ASTM C191, “Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle.”

38. ASTM C109, “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.”

39. ASTM A36, “Standard Specification for Carbon Structural Steel.”

40. APR1400 Technical Report, “APR1400-E-S-NR-13006-P,” Rev. 0, September 2013.

Table 3.8-1 (1 of 2)

Codes, Standards, Specifications, and Regulations

Document Reference No.	Document Designation	Document Tit1e
Codes		
1	*[ASME CC]**	Code for Concrete Containment
2	*[ACI-349]**	Code requirements for nuclear safety related concrete structure
3	*[AISC N690 and Supplement No. 2]**	Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities
4	AISC ASD	General structure – steel structure (allowable stress design)
5	AISC LRFD	General structure – steel structure (load and resistance factor design)
6	*[ASME NE]**	Nuclear mechanic – metal containment vessel
7	ASME NQA	Quality assurance – nuclear quality assurance
8	ASME	Boiler and pressure vessel code
9	ACI 318	Building code requirements for reinforced concrete
Specifications		
10	ACI 301	Specifications for structural concrete for building
11	AWS D1.1	Structural welding code – steel structure
12	AWS D1.3	Structural welding code – sh. steel structure
13	AISI SG 673	Specification for the design of cold-formed steel structural members
14	ACI 211.1	Standard practice for selecting proportions for normal, heavy weight, and mass concrete
15	ACI 214	Recommended practice for evaluation of strength test results of concrete
16	ACI 304 R	Guide for measuring, mixing, transporting, and placing concrete
17	ACI 305 R	Hot weather concreting
18	ACI 306 R	Cold weather concreting
19	ACI 308	Standard practice for curing concrete
20	ACI 309 R	Guide for consolidation of concrete

Table 3.8-1 (2 of 2)

Document Reference No.	Document Designation	Document Tit1e
21	ACI 311.1 R	ACI manual of concrete inspection
22	ACI 315	Details and detailing of concrete reinforcement
23	ACI 347	Guide to formwork for concrete
24	ANSI/ANS 8.1	Nuclear criticality safety in operations with fissionable materials outside reactors
25	ANSI/ANS 8.17	Criticality safety criteria for handling, storage, and transportation of LWR fuel outside reactors
26	ANSI/ANS 57.2	Design requirements for light water reactor spent fuel storage facilities at nuclear power plants
27	ASTM C570	Standard specification for nuclear grade boron carbide power
28	ASTM E3	Preparation of metallographic specimens
29	ASTM E190	Guided bend test for ductility of weld
U.S. Regulations		
30	10 CFR 50	Domestic licensing of production and utilization facilities
31	10 CFR 52	Licenses, Certifications, and Approvals for Nuclear Power Plants
32	10 CFR 100	Reactor site criteria

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
AWS	American Welding Society

Table 3.8-2

Seismic Category I Structure Load Combination for the Reactor Containment Building

Category / Loading Condition		No	D(1)	L(2)	F	P_t	G	Pa	T_t	T_o	T_a	E_s	W	Wt	R_o	R_a	Y_r	Y_j	Y_m	Y_f	H	H_s	P_v	H_a	P_s
Service	Test	1	1.0	1.0	1.0	1.0	—	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Construction	2	1.0	1.0	1.0	—	—	—	—	1.0	—	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—
	Normal	3	1.0	1.0	1.0	—	1.0	—	—	1.0	—	—	—	—	1.0	—	—	—	—	—	—	—	1.0	—	—
Factored	Severe environmental	4	1.0	1.3	1.0	—	1.0	—	—	1.0	—	—	1.5	—	1.0	—	—	—	—	—	—	—	1.0	—	—
		5	1.0	1.3	1.0	—	1.0	—	—	1.0	—	—	—	—	1.0	—	—	—	—	—	1.5	—	1.0	—	—
	Extreme environmental	6	1.0	1.0	1.0	—	1.0	—	—	1.0	—	1.0	—	—	1.0	—	—	—	—	—	—	—	1.0	—	—
		7	1.0	1.0	1.0	—	1.0	—	—	1.0	—	—	—	1.0	1.0	—	—	—	—	—	—	—	1.0	—	—
		8	1.0	1.0	1.0	—	1.0	—	—	1.0	—	—	—	—	1.0	—	—	—	—	—	—	1.0	1.0	—	—
	Abnormal	9	1.0	1.0	1.0	—	1.0	1.5	—	—	1.0	—	—	—	—	1.0	—	—	—	—	—	—	—	—	—
		10	1.0	1.0	1.0	—	1.0	1.0	—	—	1.0	—	—	—	—	1.25	—	—	—	—	—	—	—	—	—
		11	1.0	1.0	1.0	—	1.25	1.25	—	—	1.0	—	—	—	—	1.0	—	—	—	—	—	—	—	—	—
	Abnormal/severe environmental	12	1.0	1.0	1.0	—	1.0	1.25	—	—	1.0	—	1.25	—	—	1.0	—	—	—	—	—	—	—	—	—
		13	1.0	1.0	1.0	—	1.0	—	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0	—
		14	1.0	1.0	1.0	—	1.0	—		1.0	—	—	1.0	—	—	—	—	—	—	—	—	—	—	1.0	—
	Abnormal/extreme environmental	15	1.0	1.0	1.0	—	1.0	1.0	—	—	1.0	1.0	—	—	—	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—
	Severe Accident(3)	16	1.0	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0

(1) D_d is included in D.

(2) Includes all temporary construction loads during and after construction of the containment, also includes Lh and C.

(3) The strain does not exceed the values given in *[ASME Section III, Division 2, Table CC-3720-1.]**

Table 3.8-3

Load Definitions and Load Combinations for ASME Class MC Containment Components (1)

See Appendix 3.8A for definitions of the terms in this table

No.	Loads Factors														Service Load Category	Limitation of Stress Intensity
	Normal						Severe Environmental	Extreme Abnormal						Extreme Environmental		
	D	L	R_o	T_o	P_v	P_t	R_r(2)	T_a	P_a	R_a	Y_f	P_{g1}	P_{g2}	E_s		
1	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	A	Table NE 3221-1
2	1.0	1.0	—	—	—	—	—	1.0	1.0	1.0	—	—	—	—	A	Table NE 3221-1
3	1.0	1.0	—	—	—	—	—	1.0	1.0	1.0	—	—	—	—	B	Table NE 3221-1
4	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	1.0	C	Table NE 3221-1
5	1.0	1.0	—	—	—	—	—	1.0	1.0	1.0	—	—	—	1.0	C	Table NE 3221-1
6	1.0	1.0	—	—	—	—	1.0	1.0	1.0	1.0	—	—	—	—	D	Table NE 3221-1
7	1.0	1.0	—	1.0(3)	—	1.0	—	—	—	—	—	—	—	—	Test Condition	NE 3226
8	1.0	1.0	—	—	—	—	—	—	—	—	1.0	—	—	—	Post-LOCA Flood	Table NE 3221-1
9	1.0	—	—	—	—	—	—	—	—	—	—	1.0	1.0	—	C	Table NE 3221-1

(1) Not applicable to process piping penetrations

(2) $R_r=Y_r+Y_j+Y_m$

(3) Temperature at time of test

Table 3.8-4

Load Combinations for Penetration Sleeves and Head Fittings

Loading Components	Loading Combination	Design	Expansion	Primary + Secondary	Service Level C	Service Level D	Fatigue	Testing
Internal and External Pressures	Maximum Operating			×	×	×		
	Design	×						
	Transient			×			×	
	Test							×
	Severe Accident				×			
Temperatures	Normal Operating		×	×	×	×		×
	Design	×						
	Transient			×			×	
Weight	—	×		×	×	×	×	
Thermal Expansion	—		×	×			×	
Seismic	SSE				×	×		
	Relative Displacement		×	×			×	
Fluid Dynamic	Hydraulic Transients			×	×	×	×	
	Main Steam SRV			×	×	×	×	
Pipe Rupture and Jet Impingement	—				×	×		

Table 3.8-5

Allowable Stresses for Penetration Sleeves and Head Fittings

Stress Category	Service Level A, B	Design(1)	Service Level C(1)	Service Level D(1)(2)
General Membrane (P_m)	(3)	S_m	Larger of $1.2S_m$ or S_y	Lesser of $2.4S_m$ or $0.7S_u$
Local Membrane (P_L)	(3)	$1.5S_m$	Larger of $1.8S_m$ or $1.5S_y$	$1.5P_m$
Membrane + Bending (P_L+P_B)	(3)	$1.5S_m$	Larger of $1.8S_m$ or $1.5S_y$	$1.5P_m$
Expansion Stresses (P_E)	$3.0S_m$	—	—	—
Primary + Secondary (P_L+P_B+P_E+Q)	$3.0S_m$	—	—	—
Peak (F)	(4)	—	—	—

Notes:

Values for S_m, S_y and S_u are temperature-dependent and taken from ASME Section II, Part D tables, as follows: S_y from Tables Y-1; S_u from Tables U; S_m from Tables 2A.

(1) Design, service level C, and service level D conditions do not require secondary and peak stress evaluation.

(2) The specified stress limits for service level D conditions are applicable for inelastic-system and elastic-component evaluation. ASME Section III, Appendix F 1341.

(3) There are no established limits on the primary stresses that result from operating conditions ASME NB 3222-1.

(4) Used in combination with all primary and secondary stresses for calculating alternating stresses (for fatigue evaluation).

Table 3.8-6

Physical Properties for Materials to be Used for Pressure Parts or Attachment to Pressure Part ASME Code Class MC Components

Material Specification	S_u Minimum Ultimate Tensile MPa (ksi)	S_y Minimum Yield at Ambience MPa (ksi)	S_y Minimum Yield at 171°C (340°F) MPa (ksi)	S_m ASME Code Allowable Stress Intensity at 171°C (340°F) MPa (ksi)	Note
Plate					
SA-516 Gr 70	483 (70)	262 (38)	229 (33.26)	153 (22.18)	
SA-516 Gr 60	414 (60)	221 (32)	193 (27.94)	129 (18.66)	
SA-240 Type 304	517 (75)	207 (30)	150 (21.78)	134 (19.48)	
Pipe					
SA-106 Gr B	414 (60)	241 (35)	211 (30.6)	138 (20.0)	
SA-333 Gr 6	414 (60)	241 (35)	211 (30.6)	138 (20.0)	
SA-312 Type 304	517 (75)	207 (30)	150 (21.78)	134 (19.48)	
Forgings and fittings					
SA-350 LF-2	483 (70)	248 (36)	217 (31.5)	144 (20.94)	
SA-182 F22 Class 3	517 (75)	310 (45)	268 (38.84)	168 (24.34)	
Bolting					
SA-193 B7	793 (115)	655 (95)	579 (83.98)	193 (28.0)	Between 6.35 and 10.16 cm (2.5 and 4 in) diameter
SA-320 Gr L43	862 (125)	724 (105)	642 (93.06)	214 (31.04)	Under 6.35 cm (2.5 in) diameter

Table 3.8-7

Design Loads for Nuclear Island Category I Structures

Structures	Loadings kN/m^2 (psf)							Remarks
	Dead Load (D)	Live Load (L)	Rain and Wind (L and W)	Soil (L_g)	Fluid Pressure (L_h)	Tornado (W_t)	Temp.°F Min/Max (T_o)	
	*	*	*	*	*	*	*	Notes: 1, 2, 4, 6
Interior walls	1.0 (20)	16.8 (350)	N/A	N/A	—	N/A	—	Note 8
Exterior walls	0.5 (10)	16.8 (350)	—	—	—	—	—	Notes: 3, 7, 8
Roof slabs	—	2.4 (50) ~ 10.0 (200)	—	N/A	N/A	—	—	Notes: 3, 5, 9
Main floor at elevation 78 ft 0 in to 174 ft 0 in	—	10.0 (200) ~ 24.0 (500)	—	N/A	—	—	—	—
Basemat at elevation 55 ft 0 in	—	24.0 (500)	N/A		—	N/A	—	—
CASK loading and decontamination pit	—	52.7 (1,000)	N/A	N/A	—	N/A	—	—

(1) The mass of all structures are included in all load combinations as dead loads.

(2) All structures are designed for seismic loads.

(3) See Subsection 3.8.4.3 for design soil loads, including groundwater, thermal loads, wind loads, tornado loads, and added live load due to precipitation.

(4) Abnormal loads due to main steam and feedwater line breaks are considered.

(5) Loads for SG removal are considered at elevation 156 ft 0 in CVCS area.

(6) Extreme external temperatures are evaluated to determine temperatures to be combined with extreme internal temperatures.

(7) Soil surcharge load on exterior walls due to construction loads.

(8) Live load on shear wall in horizontal (out-of-plane) direction to account for attachment loads.

(9) Snow drifts are considered for live load on lower roofs.

Table 3.8-8

Types and Applicable Loading Conditions for Dead Loads and Live Loads

Applicable Loading Conditions									
Construction	Test	Normal	Severe Environmental	Abnormal	Extreme Environmental	Abnormal/ Severe Environmental	Abnormal/ Extreme Environmental	Load	Definition of Loads
×	×	×	×	×				DEAD LOADS	D_h – Vertical Pressure of liquids (with due regard to variations in the liquid depth)
×	×	×	×	×					D_d – Self weight of structure including waterproofing, siding, and insulation
	×	×	×	×					D_e – Weight of equipment and its contents (gravity load under operating conditions). This includes crane self-weights and trolley hoists self-weights.
×									D_{cn} – Shoring and other loads provided by contractor
×	×	×	×	×				LIVE LOADS	L_h – Hydrostatic loads due to weight and pressures of fluids with well-defined densities and controllable maximum height
×	×	×	×	×					L_g – Loads due to the weight and pressure of soil, water in soil, or other materials
×	×	×	×	×					L_s – Snow loads
	×	×	×						L_f – Floor and roof live loads
	×	×	×	×					L_o – Operating reaction of equipment excluding De
				×					L_e – 2.4 kN/m^2 (50 psf) occupancy load for concrete and steel galleries during SSE loadings

Table 3.8-9A

Seismic Category I Structures Excluding Containment Structure Reinforced Concrete – Ultimate Strength Design Load Combination Table

Loading Condition	No	Loads																							Design Strength
		Normal									Severe Environmental		Abnormal									Extreme Environmental			
		$D^{(1)}$	D_d	L	L_h	T_o	R_o	C	P_o	M_o	W	H	P_a	T_a	R_a	Y_r	Y_j	Y_m	Y_f	$M_{=}$	E_s	W_t	H_s	
Construction	1	1.1	—	1.3	1.1	—	1.3	1.3	—	1.3	1.6	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
	2	—	0.9	—	1.1	—	—	1.3	—	1.3	1.6	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
Test	3	1.1	—	1.3	1.1	1.2	1.3	1.3	1.3	1.3	—	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
Normal	4	1.4	—	1.7	1.4	—	—	1.7	1.7	1.7	—	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
	5	1.1	—	1.3	1.1	1.2	1.3	1.3	1.3	1.3	—	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
Severe Environmental	6	1.4	—	1.7	1.4	—	1.7	1.7	1.7	1.7	1.7	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
	7	1.1	—	1.3	1.1	1.2	1.31.7	1.3	1.3	1.3	1.3	—	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
	8	1.4	—	1.7	1.4	—	1.3	1.7	1.7	1.7	—	1.7	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
	9	1.1	—	1.3	1.1	1.2	—	1.3	1.3	1.3	—	1.3	—	—	—	—	—	—	—	—	—	—	—	[ACI 349]*
Abnormal	10	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	1.0	—	—	—	[ACI 349]*
	11	1.0	—	1.0	1.0	—	—	1.0	—	1.0	—	—	1.4	1.0	1.0	—	—	—	—	—	—	—	—	[ACI 349]*
Extreme Environmental	12	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	1.0	—	—	[ACI 349]*
	13	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	1.0	—	[ACI 349]*
	14	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	1.0	[ACI 349]*
Abnormal/ Extreme Environmental	15	1.0	—	1.0	1.0	—	—	1.0	—	1.0	—	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	1.0	—	—	[ACI 349]*

(1) Where a load occurs simultaneously with and reduces effects of other loads, the load factor is taken as 0.9; otherwise, the load factor is taken as zero.

(2) Hydrodynamic loads associated with seismic loads are included in E_s.

Table 3.8-9B (1 of 2)

Seismic Category I Structures Structural Steel – Elastic Design Load Combination Table

Loading Condition	No	Loads (1)																						Design Strength(6), (7)
		Normal									Severe Environmental		Abnormal									Extreme Environmental			
		D	D_d	L	T_o	S	R_o	C	P_o	M_o	W	H	P_a	T_a	R_a	Y_r	Y_j	Y_m	Y_f	M_a	E_s	W_t	H_s	
Construction	1	1.0	—	1.0	—	1.0	1.0	1.0	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	[1.33 AISC N690]*
	2	1.0	—	1.0	—	—	1.0	1.0	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	[1.33 AISC N690]*
	3	—	0.75	—	—	—	—	1.0	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	[1.33 AISC N690]*
Test	4	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	[1.33 AISC N690]*
Normal	5	1.0	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	[1.00 AISC N690]*
	6	1.0	—	1.0	—	1.0	—	1.0	—	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	[1.00 AISC N690]*
Severe Environmental	7	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	[1.00 AISC N690]*
	8	1.0	—	1.0	—	—	—	1.0	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	[1.00 AISC N690]*
	9	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	—	1.0	—	—	—	—	—	—	—	—	—	—	—	[1.00 AISC N690]*
Abnormal (4), (7)	10	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	1.0	—	—	—	[1.60 AISC N690(3), (5)]*
	11	1.0	—	1.0	—	—	—	1.0	—	1.0	—	—	1.0	1.0	1.0	—	—	—	—	—	—	—	—	[1.60 AISC N690(3), (5)]*
	12	1.0	—	1.0	—	—	—	1.0	—	1.0	—	—	1.0	1.0	—	—	—	—	—	—	—	—	—	[1.60 AISC N690(3), (5)]*
Extreme Environmental	13	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	1.0	—	—	[1.60 AISC N690(3), (5)]*
	14	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	1.0	—	[1.60 AISC N690(3), (5)]*
	15	1.0	—	1.0	1.0	—	1.0	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	1.0	[1.60 AISC N690(3), (5)]*
Abnormal/ Extreme Environmental(7),(8)	16	1.0	—	1.0	—	—	—	1.0	—	1.0	—	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	1.0	—	—	[1.70 AISC N690(3), (5)]*

Table 3.8-9B (2 of 2)

(1) All load combinations are checked for a no-live-load condition.

(2) For primary plus secondary stress, the allowable stresses are increased by a factor of 1.5.

(3) In load combinations 10 through 16, the design stress in shear is not to exceed 1.4 × *[AISC N690]** in members and bolts.

(4) The load combination 12 is to be used when the global (non-transient) sustained effects of T_a are considered.

(5) The design stress where axial compression exceeds 20 percent of normal allowable is 1.5 × *[AISC N690]** for load combinations 10, 11, 12, 13, 14, and 15 and 1.6 for load combination 16.

(6) In no instance is the allowable stress exceed 0.7 F_u in axial tension or 0.7 F_u times the ratio Z/S for tension plus bending.

(7) The maximum values of P_a, T_a, R_a, Y_j, Y_r and Y_m, including an appropriate dynamic load factor, is used in load combination 11, 12, and 16, unless an appropriate time history analysis is performed to justify otherwise.

(8) In combining loads from a postulated high-energy pipe break accident and a seismic event the SRSS (square root of the sum of the squares) may be used, provided the responses are calculated on a linear basis.

(9) Secondary stresses that are used to limit primary stresses are treated as primary stresses.

Table 3.8-9C

Spent Fuel Storage Rack – Design Loading Combination Table

Load Combination	Service Limit
$D + L$ $D + L + T_o$ $D + L + T_o + E$	Level A
$D + L + T_a + E$ $D + L + T_o + P$	Level B
$D + L + T_a + E'$	Level D
$D + L + F_d$	The functional capability of the fuel racks should be demonstrated.

Where,

D : Dead weight including fuel assembly weight

L : Live load

E : Operating Basis Earthquake (OBE)

E' : Safe Shutdown Earthquake (SSE)

T_o = Differential temperature induced loads, based on the most critical transient or steady state condition under normal operation or shutdown conditions.

T_a = Differential temperature induced loads, based on the postulated abnormal design conditions

F_d = Force caused by the accidental drop of the heaviest load from maximum possible height.

P_f = Force on the racks caused by postulated stuck fuel assembly.

Table 3.8-10

Acceptance Criteria for Overturning, Sliding, and Flotation

Load Combination	Minimum Factor of Safety		
	Overturning	Sliding	Flotation
D+He+W	1.5	1.5	—
D+He+E_s	1.1	1.1	—
D+He+W_t	1.1	1.1	—
D+H_s	—	—	1.1

D	Dead load
H_e	Static and dynamic lateral and vertical earth pressure including buoyant effect of normal design ground water table level
H_s	Buoyant force of the design basis flood
W	Wind load
W_t	Tornado load
E_s	Seismic load

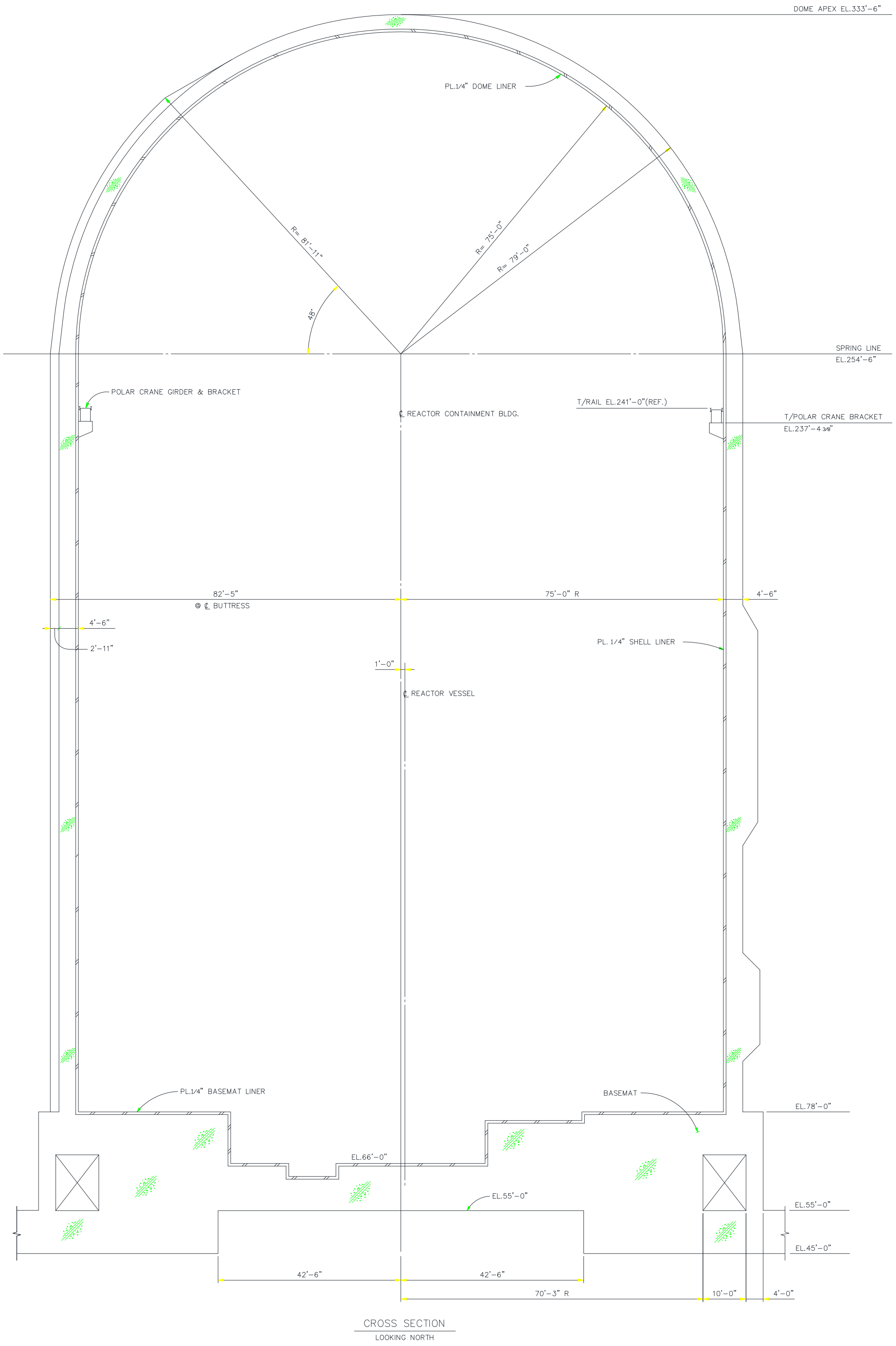

Figure 3.8-1 Typical Section of Containment Structures (Looking North)

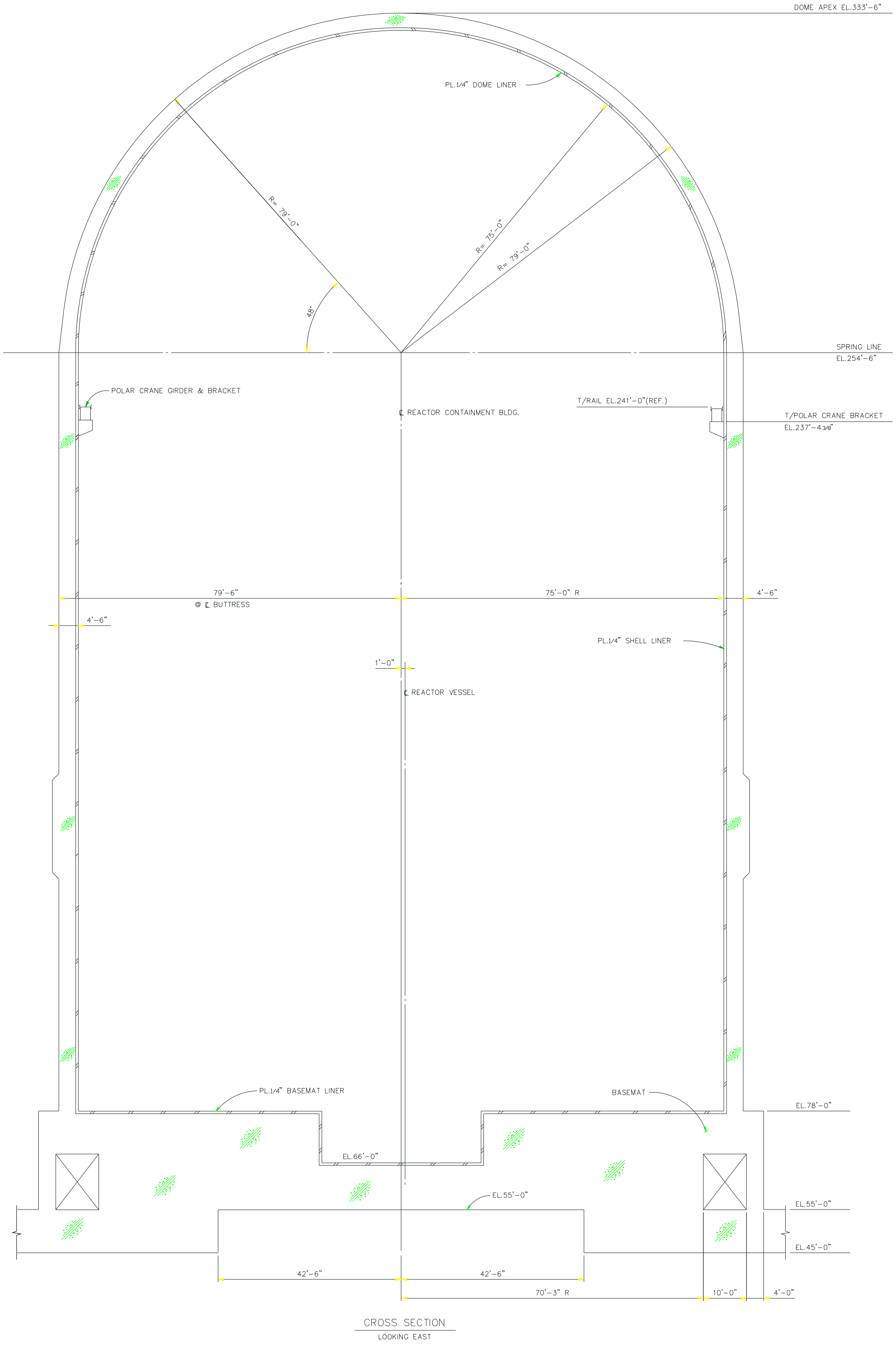

Figure 3.8-2 Typical Section of Containment Structures (Looking East)

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Figure 3.8-3 Local Area around Large Penetrations

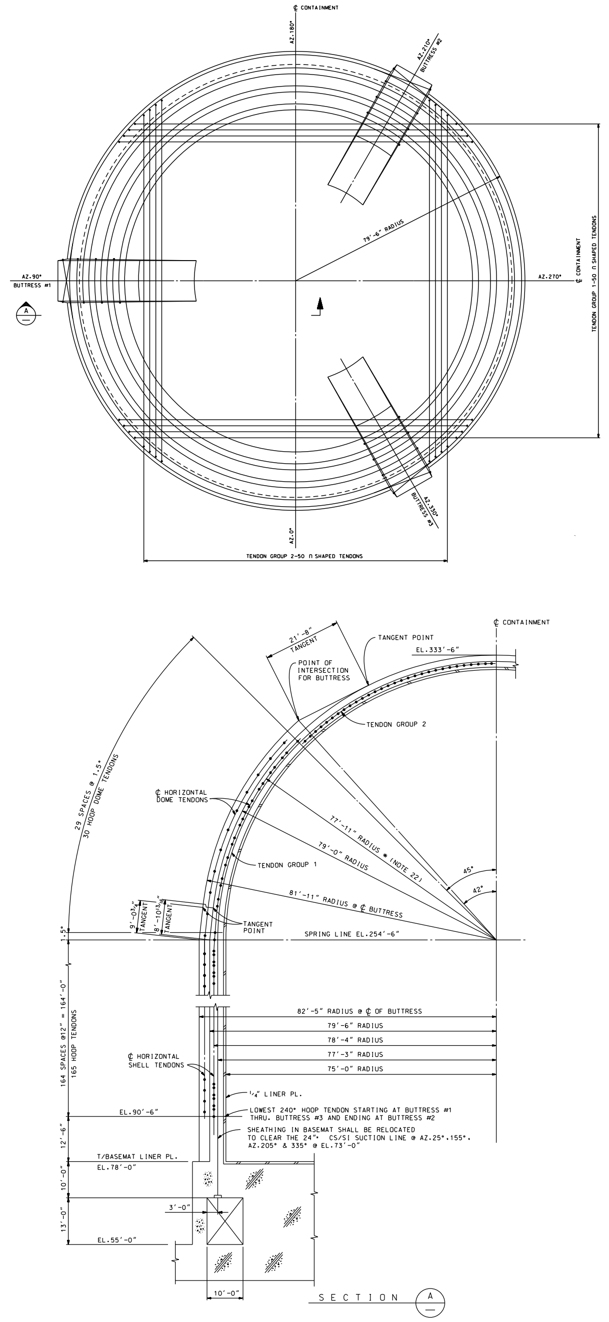


Figure 3.8-4 Arrangement of Containment Post-Tensioning System

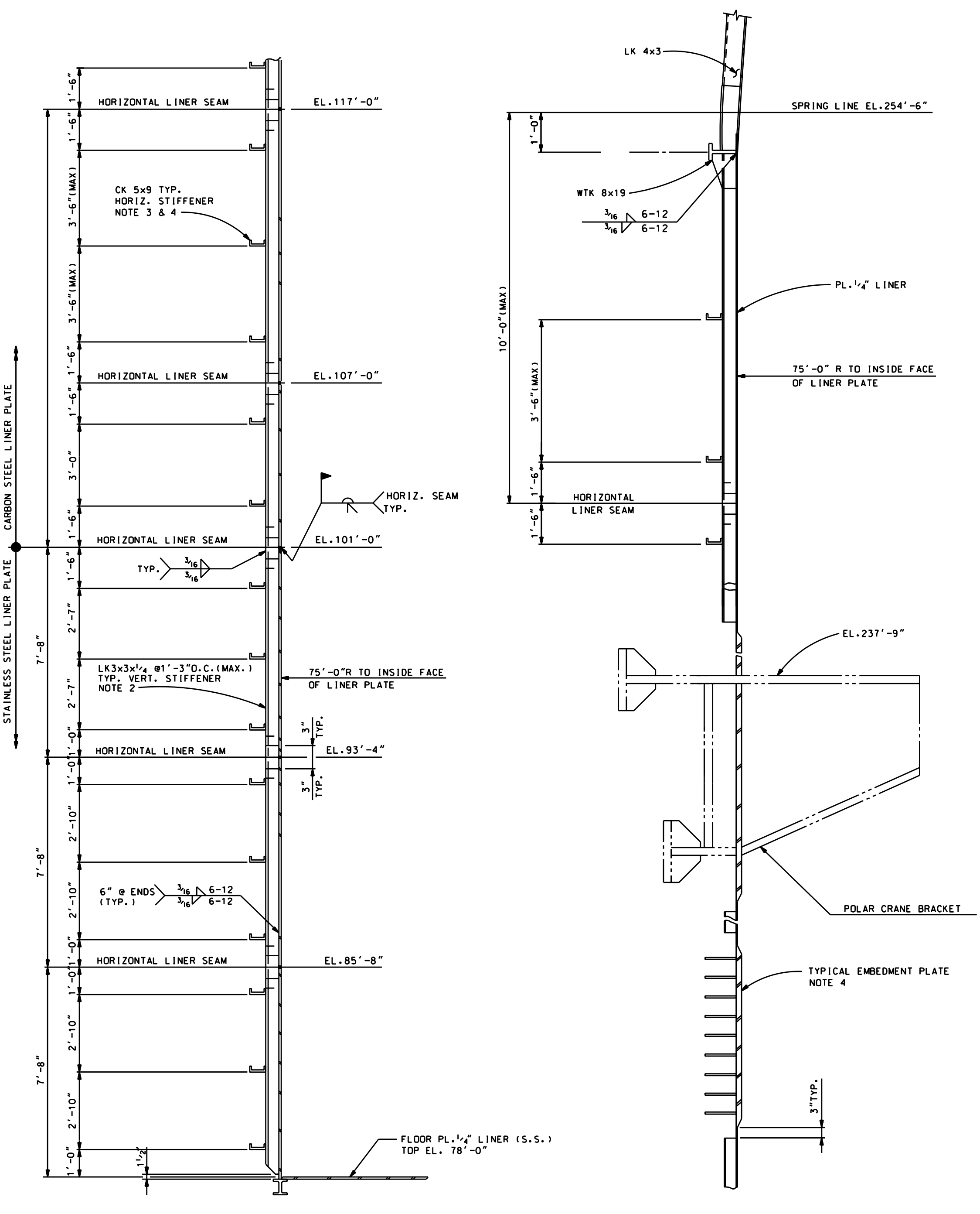
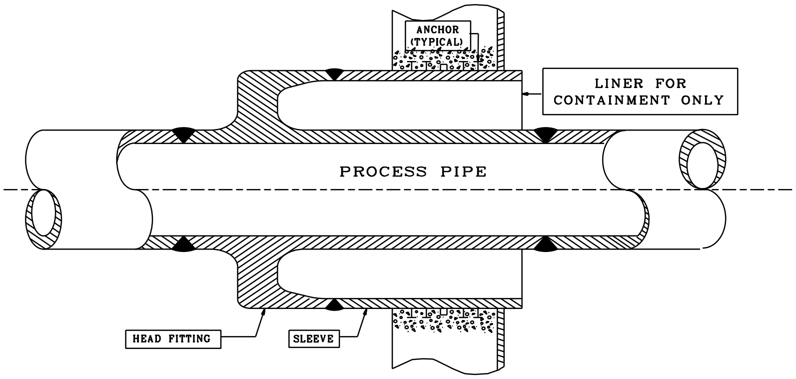
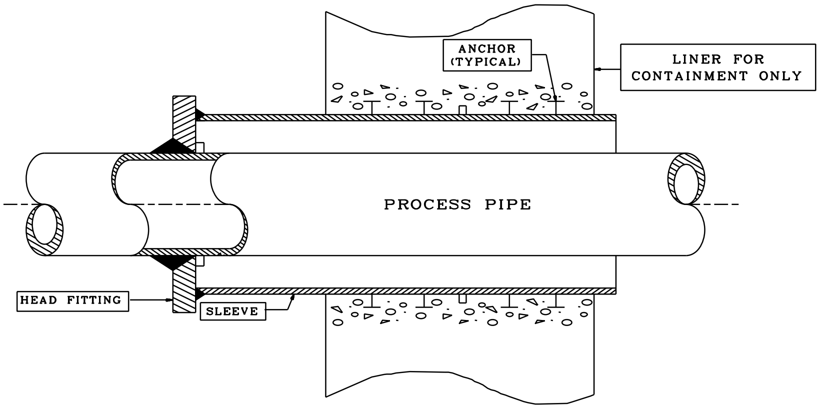


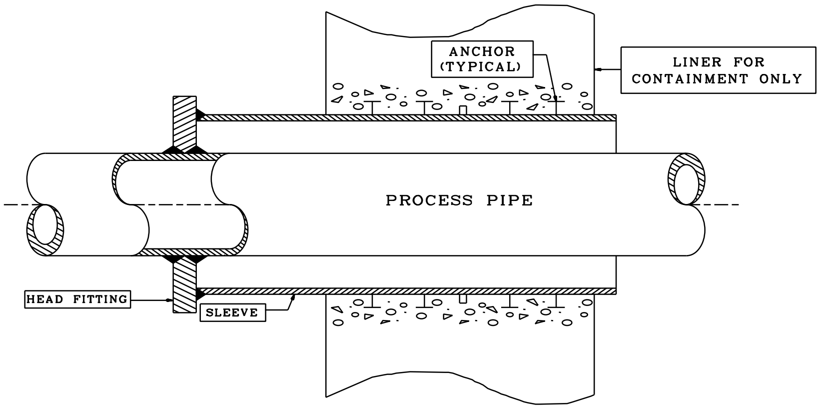
Figure 3.8-5 Liner Plate and Anchorage System



PENETRATION ASSEMBLY TYPE-1



PENETRATION ASSEMBLY TYPE-2



PENETRATION ASSEMBLY TYPE-3

Figure 3.8-6 Typical Penetration Assembly System

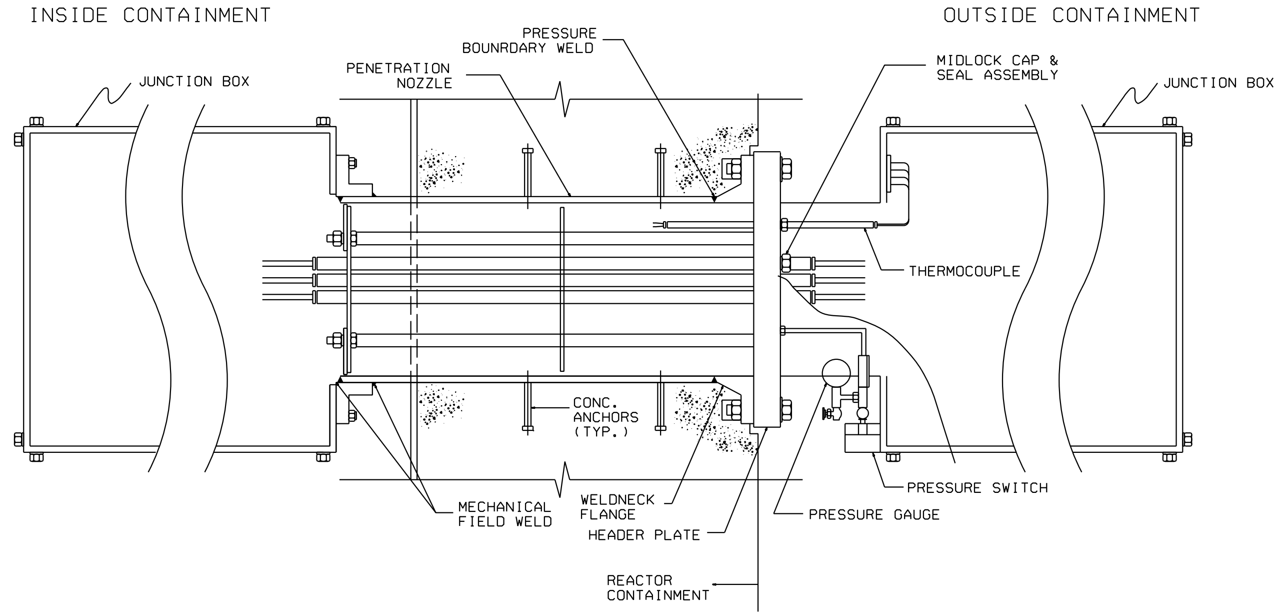


Figure 3.8-7 Typical Electrical Penetration Assembly

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Figure 3.8-8   Containment Shell and Dome Analysis Model

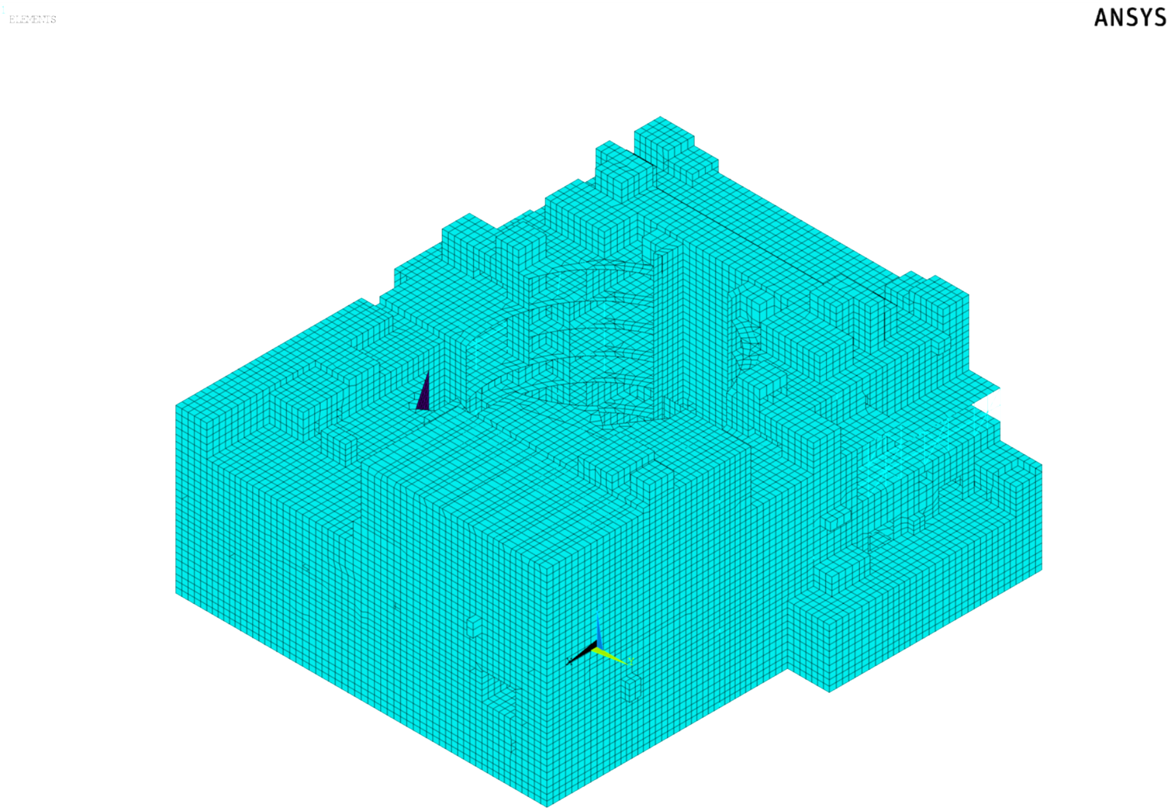

Figure 3.8-9 Finite Element Model for Auxiliary Building Global Structural Analysis

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Figure 3.8-10   Equipment Hatch

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Figure 3.8-11 Personnel Airlock

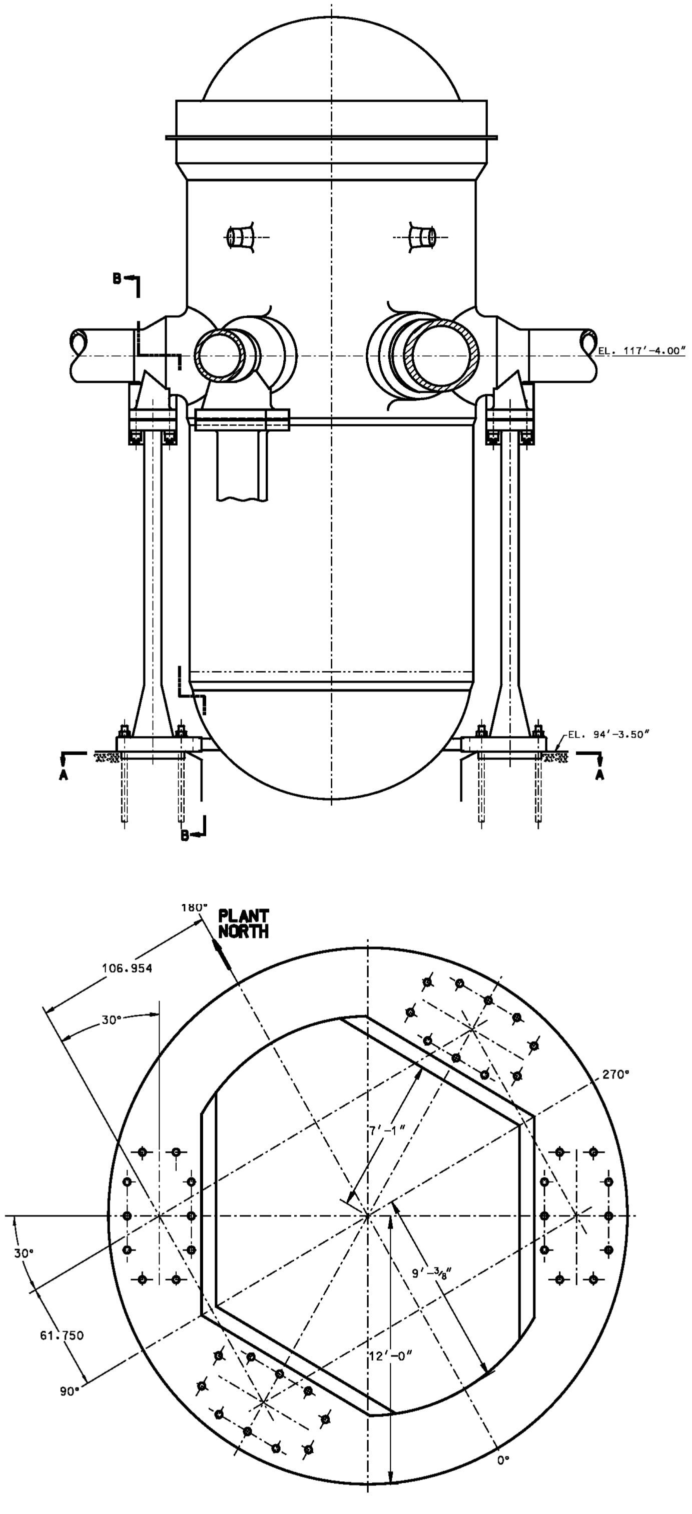
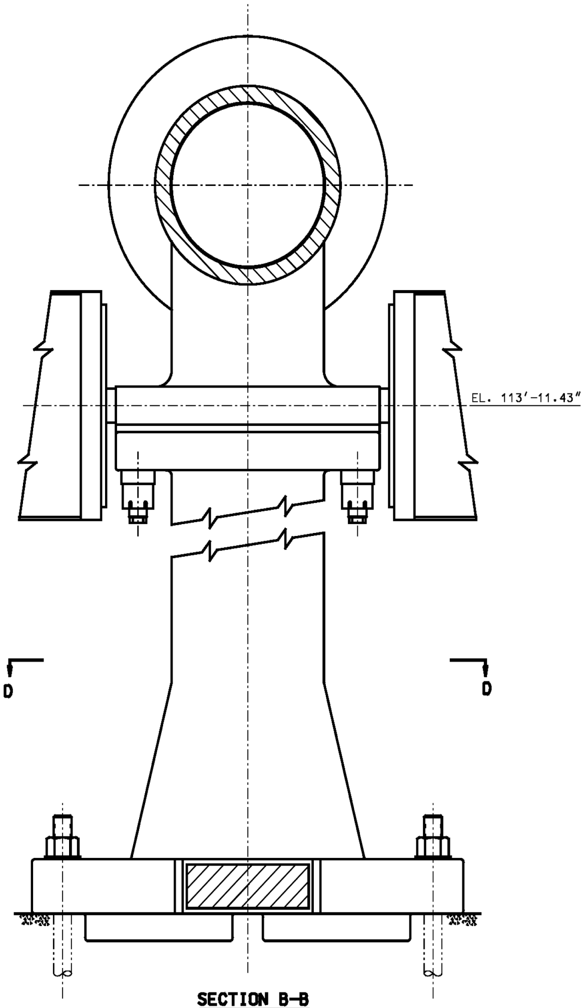
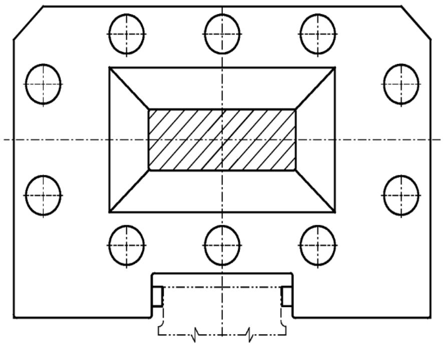


Figure 3.8-12 Reactor Vessel Supports (1 of 2)



SECTION B-B



SECTION D-D

Figure 3.8-12 Reactor Vessel Supports (2 of 2)

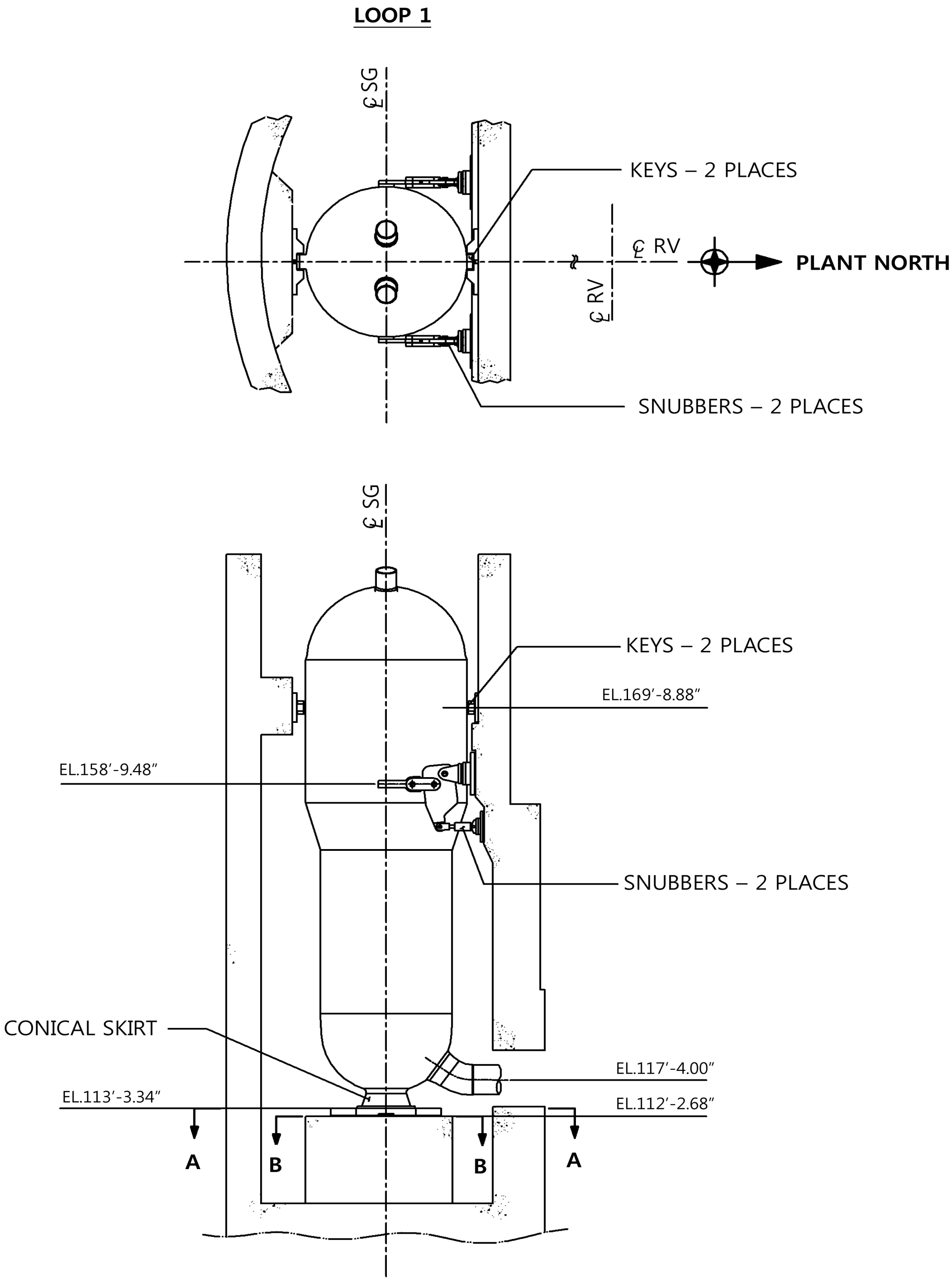
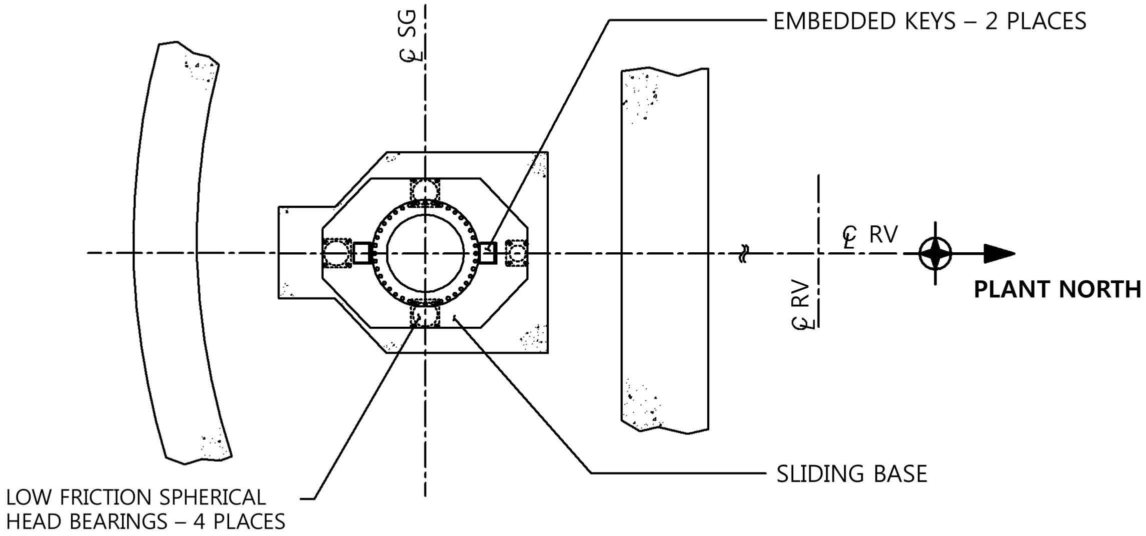
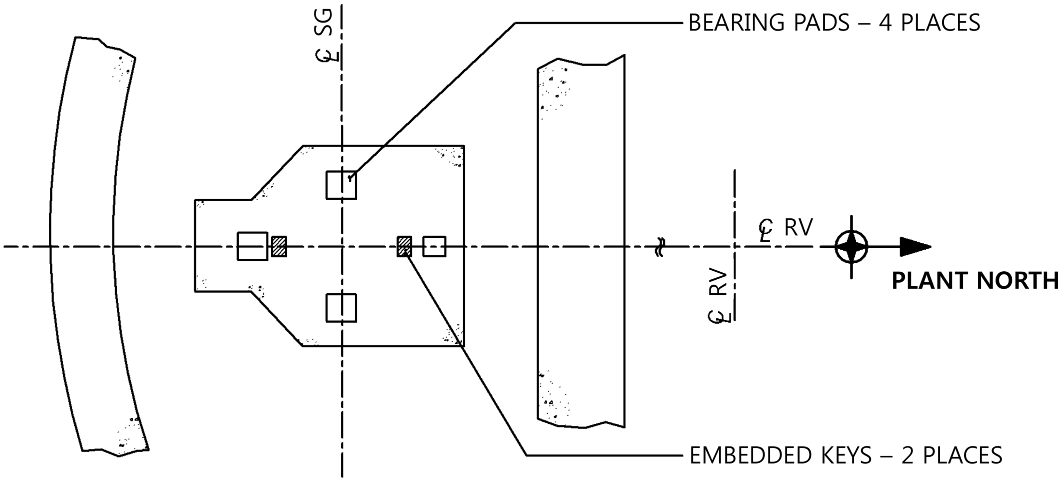


Figure 3.8-13 Steam Generator Supports (1 of 2)

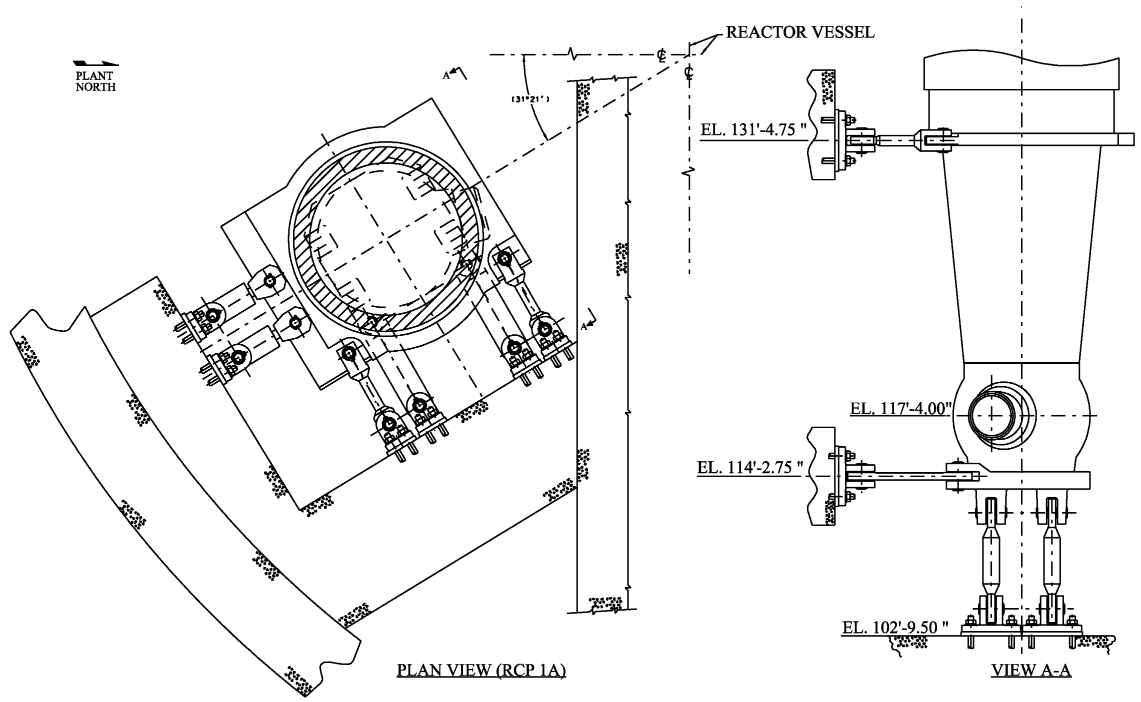


SECTION A-A



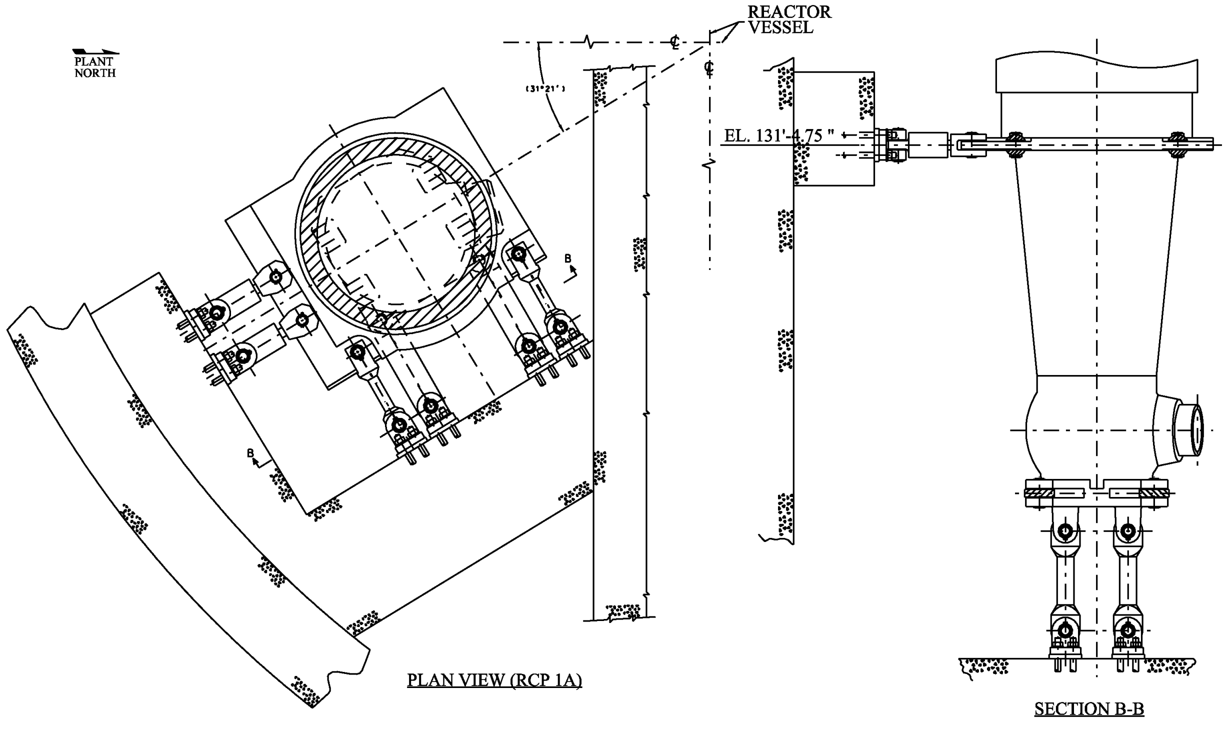
SECTION B-B

Figure 3.8-13 Steam Generator Supports (2 of 2)



PLAN VIEW (RCP 1A)

VIEW A-A



PLAN VIEW (RCP 1A)

SECTION B-B

Figure 3.8-14 Reactor Coolant Pump Supports

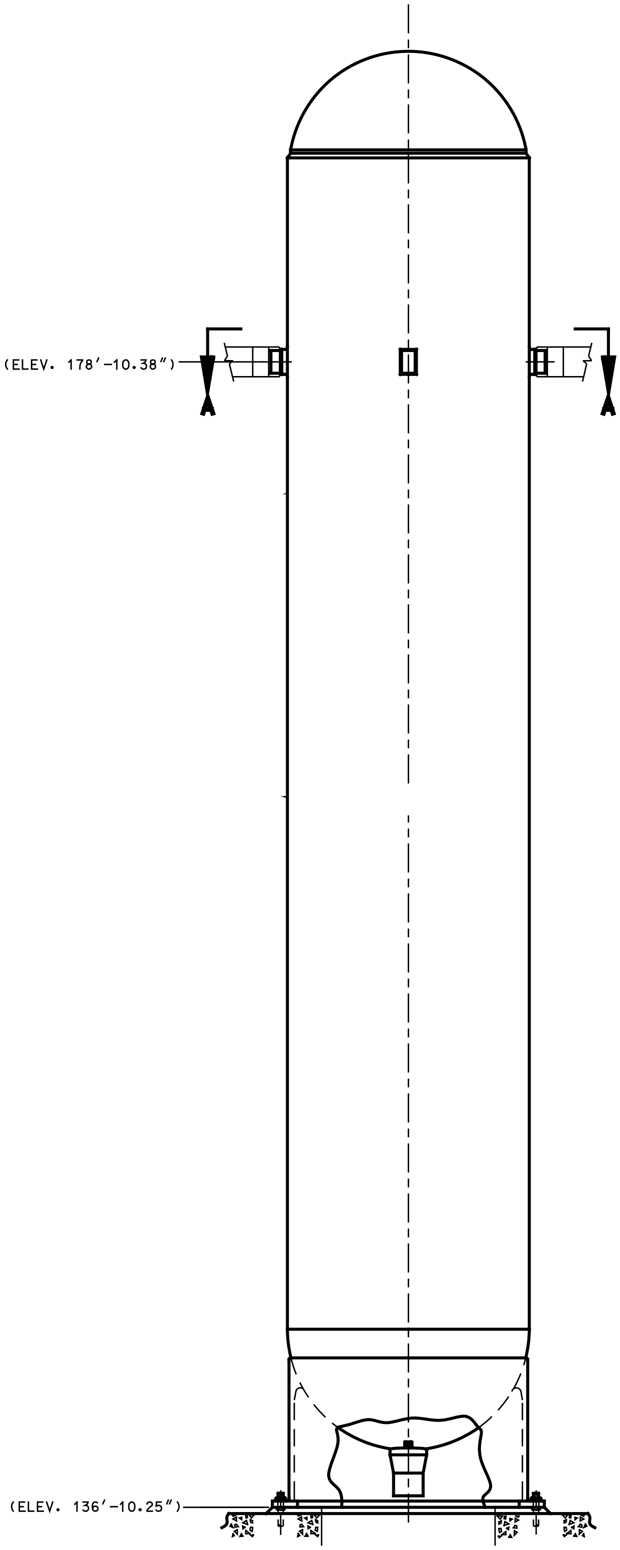


Figure 3.8-15   Pressurizer Supports

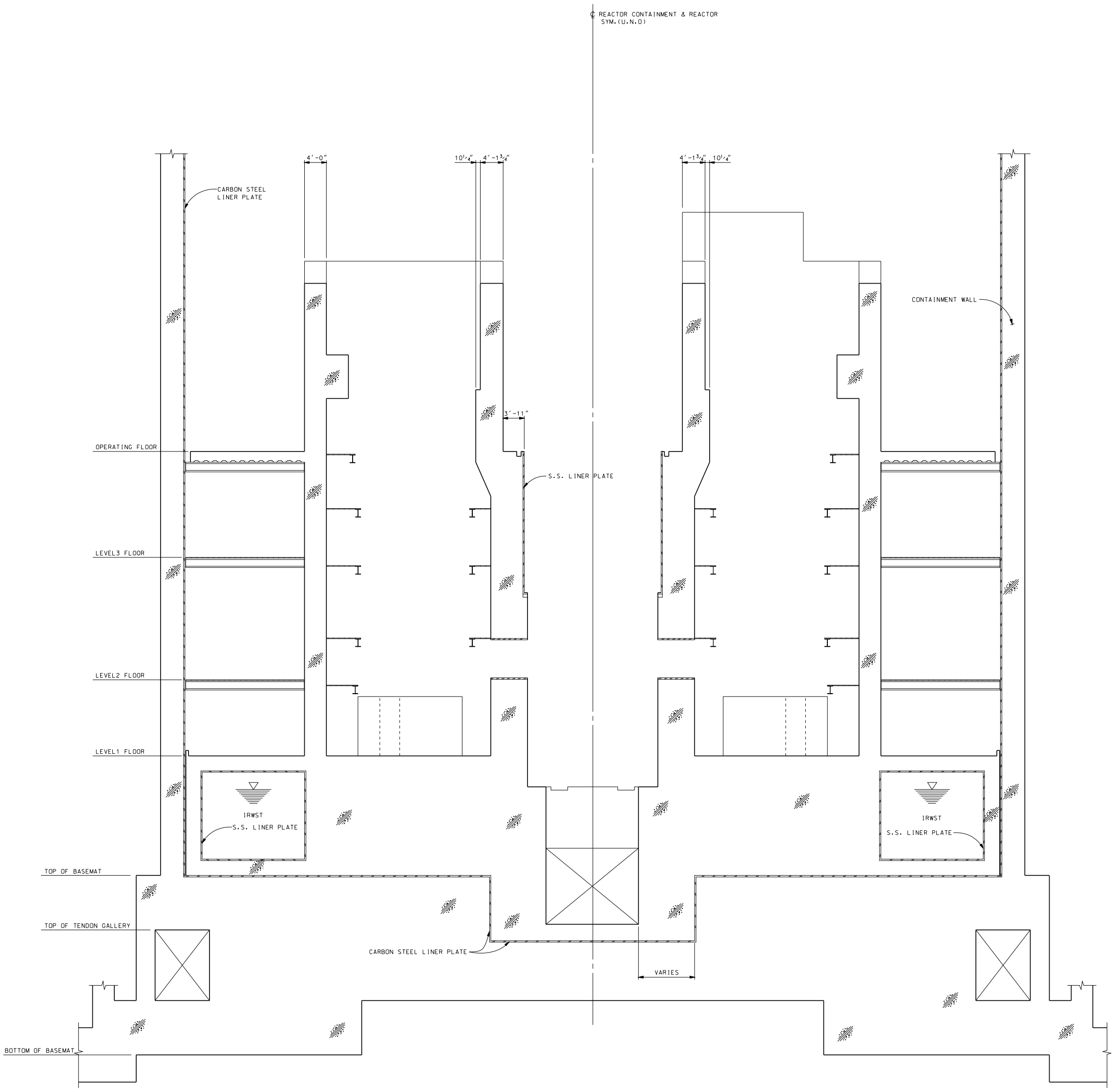


Figure 3.8-16 Reactor Containment Building Section in N-S Direction

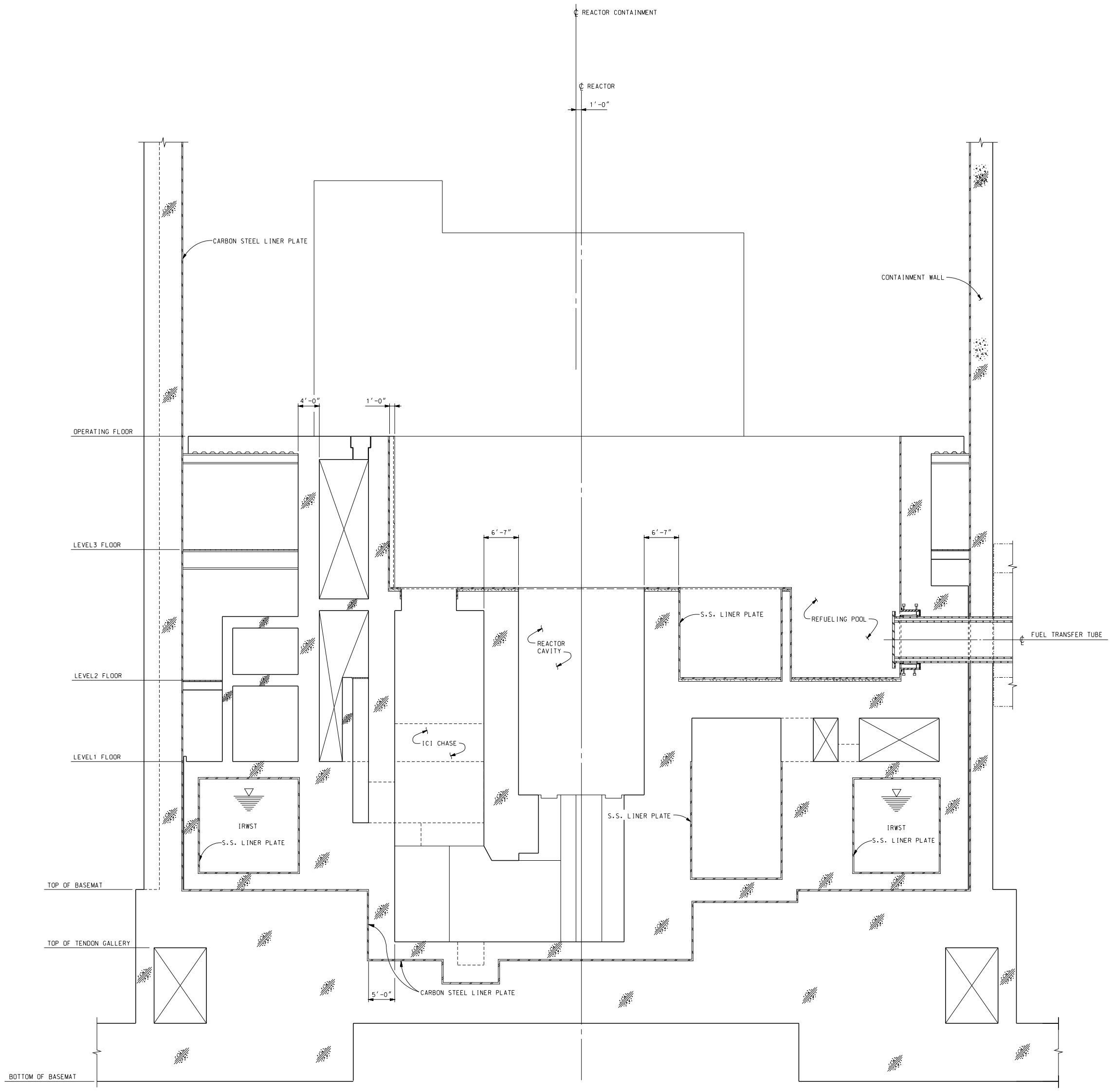


Figure 3.8-17 Reactor Containment Building Section in E-W Direction