3.4.4 Normal Operating Conditions Analysis

The Universal Storage System is evaluated using individual finite element models for the fuel basket, canister, and vertical concrete cask. Because the individual components are free to expand without interference, the structural finite element models need not be connected.

3.4.4.1 Canister and Basket Analyses

The evaluations presented in this Section are based on consideration of the bounding conditions for each aspect of the analysis. Generally, the bounding condition is represented by the component, or combination of components, of each configuration that is the heaviest. The bounding thermal condition is established by the configuration having the largest thermal gradient in normal use. Some cases require the evaluation of both a PWR and a BWR configuration because of differences in the design of these systems. For reference, the bounding case used in each of the structural evaluations is:

Section	Aspect Evaluated	Bounding Condition	Configuration
3.4.4.1.1	Canister Thermal Stress	Largest temperature gradient	Temperature[a] distribution
3.4.4.1.2	Canister Dead Weight	Heaviest loaded canister	BWR Class 5
3.4.4.1.3	Canister Pressure	Bounding pressure 15 psig, smallest canister	PWR Class 1 BWR Class 4
3.4.4.1.4	Canister Handling	Shortest canister dimensions w/ heaviest canister load [b]	PWR Class 1 BWR Class 5
3.4.4.1.5	Canister Load Combinations	Bounding pressure 15 psig + shortest canister dimensions w/ heaviest loaded canister[b] (handling) + shortest canister dimensions w/ heaviest loaded canister [b] (dead load) largest temperature gradient (thermal)	PWR Class 3 PWR Class 1 BWR Class 5 PWR Class 1 BWR Class 5 Temperature[a] distribution
3.4.4.1.6	Canister Fatigue	Bounding thermal excursions (58°F)	Not Applicable
3.4.4.1.7	Canister Pressure Test	Loaded canister (smallest canister)	PWR Class 1
3.4.4.1.8	PWR Basket Support Disk	Loaded PWR Canister	PWR fuel basket
	BWR Basket Support Disk	Loaded BWR Canister	BWR fuel basket [c]
3.4.4.1.9	PWR Basket Weldment	Loaded PWR Canister	PWR Class 2
	BWR Basket Weldment	Loaded BWR Canister	BWR Class 5
3.4.4.1.10	PWR Fuel Tube	Loaded PWR Canister (Longest)	PWR Class 3
	BWR Fuel Tube	Loaded BWR Canister (Longest)	BWR Class 5
3.4.4.1.11	Canister Closure Weld	Same as 3.4.4.1.5	Same as 3.4.4.1.5

[a] See Section 3.4.4.1.1 for an explanation of the composite temperature distribution used in the analyses. The shortest canister, PWR Class 1, has the fewest number of fuel basket support disks.

[b] When combined with the heaviest fuel assembly/fuel basket weight (BWR Class 5), the load per support disk or weldment disk is maximized. Accelerations are applied in the axial and transverse directions to account for horizontal and vertical handling.

[c] The evaluation of the BWR basket uses the analysis presented in the UMS Transport SAR [2].

3.4.4.1.1 Canister Thermal Stress Analysis

A three-dimensional finite element model of the canister was constructed using ANSYS SOLID45 elements. By taking advantage of the symmetry of the canister, the model represents one-half (180° section) of the canister including the canister shell, bottom plate, structural lid, and shield lid. Contact between the structural and shield lids is modeled using COMBIN40 combination elements in the axial (UY) degree of freedom. Simulation of the spacer ring is accomplished using a ring of COMBIN40 gap/spring elements connecting the shield lid and the canister in the axial direction at the lid lower outside radius. In addition, CONTAC52 elements are used to model the interaction between the structural lid and the canister shell and between the shield lid and canister shell, just below the respective lid weld joints as shown in Figure 3.4.4.1-2. The size of the CONTAC52 gaps is determined from nominal dimensions of contacting components. The gap size is defined by the "Real Constant" of the CONTAC52 element. Due to the relatively large gaps resulting from the nominal geometry, these gaps remain open during all loadings considered. The COMBIN40 elements used between the structural and shield lids and for the spacer ring are assigned small gap sizes of 1×10^{-8} in. All gap/spring elements are assigned a stiffness of 1×10^{8} lb/in. The three-dimensional finite element model of the canister used in the thermal stress evaluation is shown in Figure 3.4.4.1-1 through Figure 3.4.4.1-3.

The model is constrained in the Z-direction for all nodes in the plane of symmetry. For the stability of the solution, one node at the center of the bottom plate is constrained in the Y-direction, and all nodes at the centerline of the canister are constrained in the X-direction. The directions of the coordinate system are shown in Figure 3.4.4.1-1.

This model represents a "bounding" combination of geometry and loading that envelopes the Universal Storage System PWR and BWR canisters. Specifically, the shortest canister (PWR Class 1) is modeled in conjunction with the heaviest fuel and fuel basket combination (BWR Class 5). By using the shortest canister (PWR Class 1), which has the fewest number of support disks, in combination with the weight of the heaviest loaded fuel basket, the load per support disk and weldment disk is maximized. Thus, the analysis yields very conservative results relative to the expected performance of the actual canister configurations.

The finite element thermal stress analysis is performed with canister temperatures that envelope the canister temperature gradients for off-normal storage (106°F and -40°F ambient temperatures) and transfer conditions for all canister configurations. Prior to performing the thermal stress analysis, the steady-state temperature distribution is determined using temperature data from the storage and transfer thermal analyses (Chapter 4.0). This is accomplished by converting the SOLID45 structural elements of the canister model to SOLID70 thermal elements and using the material properties from the thermal analyses. Nodal temperatures are applied at six key locations for the steady state heat transfer analysis — top-center of the structural lid, top-outer diameter of the structural lid, bottom-center of the shield lid, bottom-center of the bottom plate, bottom-outer diameter of the bottom plate, and mid-elevation of the canister shell.

Two temperature distributions are used in the structural analyses to envelope the worst-case allowable temperatures and temperature gradients experienced by all PWR and BWR canister configurations under storage and transfer conditions. The temperatures at the key locations are:

Top center of the structural lid	= 160
Top outer diameter of the structural lid	= 150
Bottom center of the shield lid	= 200
Bottom center of the bottom plate	= 300
Bottom outer diameter of the bottom plate	= 200
Mid-elevation of the canister shell	= 600

Temperatures used for determining allowable stress values were selected to envelope the maximum temperatures experienced by the canister components during storage and transfer conditions. Allowable stress values for the structural/shield lid region were taken at 220°F, those for the center of the bottom plate were taken at 300°F, those for the outer radius of the bottom plate at 220°F, and those for the canister shell at 550°F.

The temperatures for all nodes in the canister model are obtained by the solution of the steady state thermal conduction problem. The key temperature differences, ΔT, of the worst-case

PWR and BWR canisters in the radial and axial directions and those used in the canister thermal stress analysis are:

	Maximum ΔT (°F)							
	Top of Structural Lid (Radial)		Bottom Plate (Radial)		Shield and Structural Lid (Axial)		Canister Shell (Axial)	
Condition	PWR	BWR	PWR	BWR	PWR	BWR	PWR	BWR
Storage, Normal 76°F ambient	3	3	3	7	6	8	267	299
Storage, Off-Normal 106°F ambient	4	3	3	7	6	8	266	298
Storage, Off-Normal, -40°F ambient	3	3	4	7	5	7	264	296
Storage, Off-Normal Half Inlets Blocked 76°F	4	3	3	7	6	8	265	296
Transfer, 76°F ambient	10	4	69	64	16	7	396	388
Parameters used for Canister Thermal Stress Analysis	10		100		40		450	

The resulting maximum (secondary) thermal stresses in the canister are summarized in Table 3.4.4.1-1. The sectional stresses at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4. After solving for the canister temperature distribution, the thermal stress analysis was performed by converting the SOLID70 elements back to SOLID45 structural elements.

3.4.4.1.2 Canister Dead Weight Load Analysis

The canister is structurally analyzed for dead weight load using the finite element model described in Section 3.4.4.1.1. The canister temperature distribution discussed in Section 3.4.4.1.1 is used in the dead load structural analysis to evaluate the material properties at temperature. The fuel and fuel basket assembly contained within the canister are not explicitly modeled but are included in the analysis by applying a uniform pressure load representing their combined weight to the top surface of the canister bottom plate. The nodes on the bottom surface of the bottom plate are restrained in the axial direction in conjunction with the constraints described in Section 3.4.4.1.1. The evaluation is based on the weight of the BWR Class 5 canister, which has the highest weight, and the length of the PWR Class 1 canister, which is the shortest configuration. An acceleration of 1g is applied to the model in the axial direction (Y) and transverse (X) direction to bound the dead load for both configurations for the canister being in horizontal and vertical conditions.

The resulting maximum canister dead load stresses are summarized in Table 3.4.4.1-2 and Table 3.4.4.1-3 for primary membrane and primary membrane plus bending stresses, respectively. The sectional stresses at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4.

The lid support ring is evaluated for the dead load condition using classical methods. The ring, which is made of ASTM A-479, Type 304 stainless steel, is welded to the inner surface of the canister shell to support the shield lid. For conservatism, a temperature of 400°F, which is higher than the anticipated temperature at this location, is used to determine the material allowable stress. The total weight, W, imposed on the lid support ring is conservatively considered to be the weight of the auxiliary shielding and the shield lid. A 10% load factor is also applied to ensure that the analysis bounds all normal operating loads. The stresses on the support ring are the bearing stresses and shear stresses at its weld to the canister shell.

The bearing stress $\sigma_{bearing}$ is:

$$\sigma_{bearing} = \frac{W}{area} = \frac{14{,}200 \text{ lb}}{102.6 \text{ in}^2} = 138 \text{ psi}$$

where:

W = (7,000 lb + 5,890 lb) × 1.1 = 14,179 lb, use 14,200 lb
where the weight of the auxiliary shielding (W_s) can be comprised of three 2-inch-thick stainless steel plates resting on the shield lid, or

W_s = .291 x (π/4) x 65.5^2 x 6 = 5,883 lb, use 5,890 lb

A = $\frac{\pi}{4}(D^2-(D-2t)^2)\,in^2 = 102.6\ in^2$

D = lid support ring diameter = 65.81 in.

t = radial thickness of support ring = 0.5 in.

The yield strength, S_y, for A-479, Type 304 stainless steel = 20,700 psi, and the ultimate allowable tensile stress, S_u = 64,400 psi at 400°F. The allowable bearing stress is 1.0 S_y per ASME Code, Section III, Subsection NB. The acceptability of the support ring design is evaluated by comparing the allowable stresses to the maximum calculated stress:

$$MS = \frac{20{,}700\ \text{psi}}{138\ \text{psi}} - 1 = +\text{Large}$$

Therefore, the support ring is structurally adequate.

The attachment weld for the lid support ring is a 1/8-in. partial penetration groove weld. The total shear force on the weld is considered to be the weight of the shield lid, the structural lid, and the lid support ring. The total effective area of each weld is A_{eff} = .125 × π × 65.81 in. = 25.8 in^2. The average shear stress in the weld is:

$$\sigma_w = \frac{W}{A_{eff}} = \frac{14{,}200\ \text{lb}}{25.8\ \text{in}^2} = 550\ \text{psi}$$

The allowable stress on the weld is 0.30 × the nominal tensile strength of the weld material [Ref.23, Table J2.5]. The nominal tensile strength of E308-XX filler material is 80,000 psi [Ref.28, SFA-5.4, Table 5]. However, for conservatism, S_y and S_u for the base metal, are used. The acceptability of the support ring weld is evaluated by comparing the allowable stress to the maximum calculated stress:

$$MS = \frac{0.3 \times 20{,}700\ \text{psi}}{550\ \text{psi}} - 1 = +\text{Large}$$

3.4.4.1.3 Canister Maximum Internal Pressure Analysis

The canister is structurally analyzed for a maximum internal pressure load using the finite element model and temperature distribution and restraints described in Section 3.4.4.1.1. A maximum internal pressure of 15 psig is applied as a surface load to the elements along the internal surface of the canister shell, bottom plate, and shield lid. This pressure bounds the calculated pressure of 7.1 psig that occurs in the smallest canister, PWR Class 1, under normal conditions. The PWR Class 1 canister internal pressure bounds the internal pressures of the other four canister configurations because it has the highest quantity of fission-gas-to-volume ratio.

The resulting maximum canister stresses for maximum internal pressure load are summarized in Table 3.4.4.1-9 and Table 3.4.4.1-10 for primary membrane and primary membrane plus primary bending stresses, respectively. The sectional stresses at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4.

3.4.4.1.4 Canister Handling Analysis

The canister is structurally analyzed for handling loads using the finite element model and conditions described in Section 3.4.4.1.1. Normal handling is simulated by restraining the model at nodes on the structural lid simulating three lift points and applying a 1.1g acceleration, which includes a 10% dynamic load factor, to the model in the axial and transverse directions, since the canister may be handled in a vertical or horizontal position. The canister is lifted at six points; however, a three-point lifting configuration is conservatively used in the handling analysis. Since the model represents a one-half section of the canister, the three-point lift is simulated by restraining two nodes 120° apart (one node at the symmetry plane and a second node 120° from the first) along the bolt diameter at the top of the structural lid in the axial direction. Additionally, the nodes along the centerline of the lids and bottom plate are restrained in the radial direction, and the nodes along the symmetry face are restrained in the direction normal to the symmetry plane.

The maximum stresses occur for the BWR class 5 canister handling, which is the heaviest configuration. Thus, the BWR class 5 canister analysis is the bounding condition for handling loads.

The resulting maximum stresses in the canister are summarized in Table 3.4.4.1-4 and Table 3.4.4.1-5 for primary membrane and primary membrane plus primary bending stresses, respectively. The sectional stresses at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4.

3.4.4.1.5 Canister Load Combinations

The canister is structurally analyzed for combined thermal, dead, maximum internal pressure, and handling loads using the finite element model and the conditions described in Section 3.4.4.1.1. Loads are applied to the model as discussed in Sections 3.4.4.1.1 through 3.4.4.1.4. A maximum internal pressure of 15.0 psi is used in conjunction with a positive axial acceleration of 1.1g. Two nodes 120° apart (one node at the symmetry plane and a second node 120° from the first) are restrained along the bolt diameter at the top of the structural lid in the axial direction. Additionally, the nodes along the centerline of the lids and bottom plate are restrained in the radial direction, and the nodes along the symmetry face are restrained in the direction normal to the symmetry plane.

The resulting maximum stresses in the canister for combined loads are summarized in Table 3.4.4.1-6, Table 3.4.4.1-7, and Table 3.4.4.1-8, for primary membrane, primary membrane plus primary bending, and primary plus secondary stresses, respectively. The sectional stresses at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4.

As shown in Table 3.4.4.1-6 through Table 3.4.4.1-8, the canister maintains positive margins of safety for the combined load conditions.

3.4.4.1.6 Canister and Basket Fatigue Evaluation

The purpose of this section is to evaluate whether an analysis for cyclic service is required for the Universal Storage System components. The requirements for analysis for cyclic operation of components designed to ASME Code criteria are presented in ASME Section III, Subsection NB-3222.4 [5] for the canister and Subsection NG-3222.4 [6] for the fuel basket. Guidance for components designed to AISC standards is in the Manual of Steel Construction, Table A-K4.1 [23].

During storage conditions, the canister is housed in the vertical concrete cask. The concrete cask is a shielded, reinforced concrete overpack designed to hold a canister during long-term storage conditions. The cask is constructed of a thick inner steel shell surrounded by 28 in. of reinforced concrete. The cask inner shell is not subjected to cyclic mechanical loading. Thermal cycles are limited to changes in ambient air temperature. Because of the large thermal mass of the concrete cask and the relatively minor changes in ambient air temperature (when compared to the steady state heat load of the cask contents), fatigue as a result of cycles in ambient air is not significant, and no further fatigue evaluation of the inner shell is required.

ASME criteria for determining whether cyclic loading analysis is required are comprised of six conditions, which, if met, preclude the requirement for further analysis:

1. Atmospheric to Service Pressure Cycle
2. Normal Service Pressure Fluctuation
3. Temperature Difference — Startup and Shutdown
4. Temperature Difference — Normal Service
5. Temperature Difference — Dissimilar Materials
6. Mechanical Loads

Evaluation of these conditions follows.

Condition 1 — Atmospheric to Service Pressure Cycle

This condition is not applicable. The ASME Code defines a cycle as an excursion from atmospheric pressure to service pressure and back to atmospheric pressure. Once sealed, the canister remains closed throughout its operational life, and no atmospheric to service pressure cycles occur.

Condition 2 — Normal Service Pressure Fluctuation

This condition is not applicable. The condition establishes a maximum pressure fluctuation as a function of the number of significant pressure fluctuation cycles specified for the component, the design pressure, and the allowable stress intensity of the component material. Operation of the canister is not cyclic, and no significant cyclic pressure fluctuation is anticipated.

Condition 3 — Temperature Difference — Startup and Shutdown

This condition is not applicable. The Universal Storage System is a passive, long-term storage system that does not experience cyclic startups and shutdowns.

Condition 4 — Temperature Difference — Normal and Off-Normal Service

The ASME Code specifies that temperature excursions are not significant if the change in ΔT between two adjacent points does not experience a cyclic change of more than the quantity:

$$\Delta T = \frac{S_a}{2E\alpha} = 58\,^\circ F,$$

where, for Type 304L stainless steel,

S_a = 28,200 psi, the value obtained from the fatigue curve for service cycles < 10^6,
E = 26.5×10^6 psi, modulus of elasticity at 400 °F,
α = 9.19×10^{-6} in./in.-°F.

Because of the large thermal mass of the canister and the concrete cask and the relatively constant heat load produced by the canister's contents, cyclic changes in ΔT greater than 58 °F will not occur.

Condition 5 — Temperature Difference Between Dissimilar Materials

The canister and its internal components contain several materials. However, the design of all components considers thermal expansion, thus precluding the development of unanalyzed thermal stress concentrations.

Condition 6 — Mechanical Loads

This condition does not apply. Cyclic mechanical loads are not applied to the vertical concrete cask and canister during storage conditions. Therefore, no further cyclic loading evaluation is required.

The criteria ASME Code Subsections NB-3222.4 and NG-3222.4 are met, and no fatigue analysis is required.

3.4.4.1.7 Canister Pressure Test

The canister is designed and fabricated to the requirements of ASME Code, Subsection NB, to the extent possible. A 35 psia (35 – 14.7 = 20.3 psig) hydrostatic pressure test is performed in accordance with the requirements of ASME Code Subsection NB-6220 [5]. The pressure test is performed after the shield lid to canister shell weld is completed. The test pressure slightly exceeds 1.25 × design pressure (1.25 × 15 psig = 18.75 psig). Considering head pressure for the tallest canister (191.75 x 0.036 = 6.9 psig), the maximum canister pressure developed during the pneumatic pressure test is bounded by using 27.2 psig in the structural evaluation for the canister test pressure.

The ASME Code requires that the pressure test loading comply with the following criteria from Subsection NB-3226:

(a) P_m shall not exceed $0.9S_y$ at test temperature. For convenience, the stress intensities developed in the analysis of the canister due to a normal internal pressure of 15 psig (Tables 3.4.4.1-9 and 3.4.4.1-10) are ratioed to demonstrate compliance with this requirement. From Table 3.4.4.1-9, the maximum primary stress intensity, P_m, is 2.24 ksi. The canister material is ASME SA-240, Type 304L stainless steel, and the test temperature will be less than 200°F for the design basis heat load of 23 kW (Figures 4.4.3-5 and 4.4.3-6). Since yield strength decreases with increasing temperature, for purposes of this calculation, the minimum material yield strength at the bounding canister temperature of 200°F is used for the structural critical limit.

$(P_m)_{test}$ = (27.2/15)(2.24 ksi) = 4.1 ksi, which is < 0.9 S_y = 0.9 (21.4 ksi) = 19.3 ksi

Thus, criterion (a) is met.

(b) For $P_m < 0.67S_y$ (see criterion a), the primary membrane plus bending stress intensity, $P_m + P_b$, shall be $\leq 1.35S_y$. From Table 3.4.4.1-10, $P_m + P_b$ = 7.36 ksi.

$(P_m + P_b)_{test}$ = (27.2/15)×(7.36 ksi) = 13.3 ksi, which is $\leq 1.35S_y$ = 28.9 ksi (1.35×21.4 ksi).

Thus, criterion (b) is met.

(c) The external pressure shall not exceed 135% of the value determined by the rules of NB-3133. The exterior of the canister is at atmospheric pressure at the time the pressure test is conducted. Therefore, this criterion is met.

(d) For the 1.25 Design Pressure pneumatic test of NB-6221, the stresses shall be calculated and compared to the limits of criteria (a), (b), and (c). This calculation and the fatigue evaluation of (e) need not be revised unless the actual hydrostatic test pressure exceeds 1.25 Design Pressure by more than 6%.

The test pressure (20.3 psig) slightly exceeds 1.25 × Design Pressure (18.75). However, the stresses used in this evaluation are ratioed to the test pressure. Thus, the stresses at the test pressure are calculated.

(e) Tests, with the exception of the first 10 hydrostatic tests in accordance with NB-6220, shall be considered in the fatigue evaluation of the component.

The canisters are not reused, and the hydrostatic test will be conducted only once. Thus, the pressure test is not required to be considered in the fatigue analysis.

The canister hydrostatic pressure tests comply with all NB-3226 criteria. These results bound the performance of a pneumatic pressure test performed in accordance with NB-6220, since the pneumatic pressure test pressure is lower (1.2 × the design pressure or 1.2 × 15 psig = 18 psig).

3.4.4.1.8 Fuel Basket Support Disk Evaluation

The PWR and BWR fuel baskets are described in detail in Sections 1.2.1.2.1 and 1.2.1.2.2, respectively. The design of the basket is similar for the PWR and BWR configurations. The major components of the BWR basket are shown in Figure 3.4.4.1-5. The structural evaluation for the PWR and BWR support disks for the normal conditions of storage is presented in the following sections. Note that the canister may be handled in a vertical or horizontal position. The evaluation is performed for the governing configuration in which the canister is handled in a vertical position. During normal conditions, the support disk is subjected to its self-weight only (in canister axial direction) and is supported by the tie rods/spacers at 8 locations for PWR configuration and 6 locations for the BWR configuration. To account for the condition when the canister is handled, a handling load, defined as 10 percent of the dead load, is considered. Finite element analyses using the ANSYS program are performed for the support disk for PWR and BWR configurations, respectively. In addition to the dead load and handling load (10% of dead load), thermal stresses are also considered based on conservative temperatures that envelop those experienced by the support disk during normal, off-normal (106°F and –40°F ambient temperatures) and transfer conditions. The stress criteria is defined according to ASME Code, Section III, Subsection NG. For the normal condition of storage, the Level A allowable stresses from Subsection NG as shown below are used.

Stress Category	Normal (Level A) Allowable Stresses
P_m	S_m
P_m+P_b	1.5 S_m
P+Q	3.0 S_m

3.4.4.1.8.1 PWR Support Disk

As shown in Figure 3.4.4.1-6, a finite element model is generated to analyze the PWR fuel basket support disks. The model is constructed using the ANSYS three-dimensional SHELL63 elements and corresponds to a single support disk with a thickness of 0.5 inch. The only loading on the model is the inertial load (1.1g) that includes the dead load and handling load in the out-of-plane direction (Global Z) for normal conditions of storage. The model is constrained in eight locations in the out-of-plane direction to simulate the supports of the tie rods/spacers.

Note that a full model is generated because this model is also used for the evaluation of the support disk for the off-normal handling condition (Section 11.1.3) in which non-symmetric loading (side load) is present. In addition, this model is used for the evaluation of a support disk for the 24-inch end drop accident condition of the vertical concrete cask (Section 11.2.4).

The model accommodates thermal expansion effects by using the temperature data from the thermal analysis and the coefficient of thermal expansion. Prior to performing the structural analyses, the temperature distribution in the support disk is determined by executing a steady-state thermal conduction analysis. This is accomplished by converting the SHELL63 structural elements to SHELL57 thermal elements. A maximum temperature of 700°F is applied to the nodes at the center slot of the disk model, and a minimum temperature 275°F is applied to the nodes around the outer circumferential edge of the disk, thus providing a bounding temperature delta of 425°F for the support disk. All other nodal temperatures are then obtained by the steady state conduction solution. Note that the applied temperatures are conservatively selected to envelope the maximum temperature, as well as the maximum radial temperature gradient (ΔT) of the disk for all normal, off-normal and accident conditions of storage and for transfer conditions. For normal conditions of storage, the support disk is evaluated using stress allowables at 800°F.

To evaluate the most critical regions of the support disk, a series of cross sections are considered. The locations of these sections on a PWR support disk are shown in Figures 3.4.4.1-7 and

3.4.4.1-8. Table 3.4.4.1-11 lists the cross sections versus Point 1 and Point 2, which spans the cross section of the ligament in the plane of the support disk.

The stress evaluation for the support disk is performed according to ASME Code, Section III, Subsection NG. According to this subsection, linearized stresses of cross sections of the structure are to be compared against the allowable stresses. The stress evaluation results for the support disks for normal condition are presented in Tables 3.4.4.1-12 and 3.4.4.1-13. The tables list the 40 highest P_m+P_b and P+Q stress intensities with large margins of safety. The Level A allowable stresses, 1.5S_m and 3S_m of the 17-4PH stainless steel at corresponding nodal temperatures, are used for the P_m+P_b and P+Q stresses respectively. Note that the P_m stresses for the support disk for normal conditions are essentially zero since there is no loads in the plane of the support disk. Stress allowables for the section cuts are taken at 800°F.

3.4.4.1.8.2 BWR Support Disk

Similar to the evaluation for the PWR fuel basket support disk, a finite element model is generated to analyze the BWR fuel basket support disks, as shown in Figure 3.4.4.1-12. The model is constructed using the ANSYS three-dimensional SHELL63 elements and corresponds to a single support disk with a thickness of 5/8 inch. The only loading on the model is the inertial load (1.1g) that includes the dead load and handling load in the out-of-plane direction (Global Z) for normal conditions of storage. The model is constrained in six locations in the out-of-plane direction to simulate the supports of the tie rods/spacers.

The model accommodates thermal expansion effects by using the temperature data from the thermal analysis and the coefficient of thermal expansion. The temperature distribution in the BWR support disk is determined using the same method used in Section 3.4.4.1.8.1 for the PWR support disk. A maximum temperature of 700°F is applied to the nodes at the center of the disk model, and a minimum temperature of 300°F is applied to the nodes around the outer circumferential edge of the disk, thus providing a bounding temperature delta of 400°F for the support disk. All other nodal temperatures are then obtained by the steady state conduction solution. Note that the applied temperatures are conservatively selected to envelope the maximum temperature, as well as the maximum radial temperature gradient (ΔT) of the disk for all normal, off-normal, and accident conditions of storage and transfer conditions. For normal conditions of storage, the support disk is evaluated using stress allowables at 800°F.

To evaluate the most critical regions of the support disk, a series of cross sections are considered. The locations of these sections on a BWR support disk are shown in Figures 3.4.4.1-13 through 3.4.4.1-16. Table 3.4.4.1-14 lists the cross sections versus Point 1 and Point 2, which spans the cross section of the ligament in the plane of the support disk.

The stress evaluation results for the BWR support disks for normal condition are presented in Tables 3.4.4.1-15 and 3.4.4.1-16. The tables list the 40 highest P_m+P_b and P+Q stress intensities with large margins of safety. The Level A allowable stresses from ASME Code, Section III, Subsection NG, 1.5S_m and 3.0S_m of the SA533 carbon steel at corresponding nodal temperatures, are used for the P_m+P_b and P+Q stresses, respectively. Note that the P_m stresses for the support disk for normal conditions are essentially zero, since there is no loads in the plane of the support disk.

3.4.4.1.9 Fuel Basket Weldments Evaluation

The PWR and BWR fuel basket weldments are evaluated for normal storage conditions using the finite element method. In addition to the dead load of the weldment, a 10% dynamic load factor is considered to account for handling loads. Therefore, a total acceleration of 1.1g is applied to the weldment model in the out of plane direction. Thermal stresses for the basket weldments are determined using the method presented in Sections 3.4.4.1.8.1 and 3.4.4.1.8.2 for the PWR and BWR support disks, respectively. The temperatures used in the model to establish the weldment temperature gradient are:

Basket Weldment	Temperature at Center of Weldment (°F)	Temperature at Edge of Weldment (°F)
PWR Top	600	275
PWR Bottom	325	175
BWR Top	525	225
BWR Bottom	475	200

These temperatures are conservatively selected to envelop the maximum temperature and the maximum radial temperature gradient of the weldments for all normal and off-normal conditions of storage. The results of the structural analyses for dead load, handling load, and thermal load are summarized in Table 3.4.4.1-17.

3.4.4.1.9.1 PWR Fuel Basket Weldments

The PWR top and bottom weldment plates are 1.25 and 1.0-in. thick Type 304 stainless steel plate, respectively. The weldments support their own weight plus the weight of up to 24 PWR fuel assembly tubes. An ANSYS finite element analysis was prepared for both plates because the support location for each weldment is different. Both models use the SHELL63 elements, which permits out-of-plane loading. The finite element models for the top and bottom weldments are shown in Figures 3.4.4.1-8 and 3.4.4.1-9, respectively. Note that the corner baffles are conservatively omitted in the top weldment model. The load from the fuel tube on the bottom weldment is represented as point forces applied to the nodes at the periphery of the fuel assembly slots. An average point force is applied. The application of the nodal loads at the slot periphery is accurate because the tube weight is transmitted to the edge of the slot, which provides support to the fuel tubes while in the vertical position.

The maximum stress intensity and the margin of safety for the weldments are shown in Table 3.4.4.1-17. Note that the nodal stress intensity is conservatively used for the evaluation. The Pm stresses for the weldments for normal conditions are essentially zero since there are no loads in the plane of the weldments. The weldments satisfy the stress criteria in the ASME Code Section III, Subsection NG [6].

3.4.4.1.9.2 BWR Fuel Basket Weldments

In the BWR fuel basket transport analysis, the responses of the top and bottom weldment plates to normal storage conditions are evaluated in conjunction with the thermal expansion stress. The weldment plates are 1.0-in. thick Type 304 stainless steel. The weldments support their own weight and the weight of up to 56 BWR fuel assembly tubes. A finite element analysis was performed for the top and bottom plates because the support for each weldment differs depending upon the location of the welded ribs for each. Both models use SHELL63 elements, which permit out-of-plane loading. The finite element models for the top and bottom weldments are shown in Figure 3.4.4.1-18 and Figure 3.4.4.1-19, respectively. The load from the fuel tube on the bottom weldment is represented as average point forces applied to the nodes at the periphery of the fuel assembly slots because the tube weight is transmitted to the edge of the slot in the end-impact condition.

The maximum stress intensity and the margin of safety for the weldments are shown in Table 3.4.4.1-17. Note that the nodal stress intensity is conservatively used for the evaluation. The P_m stresses for the weldments for normal conditions are essentially zero since there are no loads in the plane of the weldments. The weldments satisfy the stress criteria in the ASME Code Section III, Subsection NG [6].

3.4.4.1.10 Fuel Tube Analysis

Under normal storage conditions, the fuel tubes, Figure 3.4.4.1-9 (PWR) and Figure 3.4.4.1-17 (BWR), support only their own weight. The fuel assemblies are supported by the canister bottom plate, not by the fuel tubes. Thermal stresses are considered to be negligible since the tubes are free to expand axially and radially. The handling load is taken as 10% of the dead load.

The weight of the fuel tube, with a load of 1.1g (to account for both the dead load and handling load) is carried by the tube cross-section. The cross sectional area of a PWR fuel tube is:

$$\text{Area} = (8.9 \text{ in})^2 - (8.9 \text{ in.} - 2 \times 0.048 \text{ in.})^2 = 1.7 \text{ in}^2$$

The bounding weight of the heaviest PWR fuel tube is about 200 pounds. Considering a g-load of 1.1, the maximum compressive and bearing stress in the fuel tube is about 129 psi (200 lb × 1.1 / 1.7 in^2). Limiting the compressive stress level in the tube to the material yield strength ensures the tube remains in position in storage conditions. The yield strength of Type 304 stainless steel is 17,300 psi at a conservatively high temperature of 750°F.

$$\text{MS} = 17{,}300/129 - 1 = +\text{Large}$$

The minimum cross-sectional area of a BWR fuel tube and oversized fuel tube is:

$$\text{Area} = (5.996 \text{ in})^2 - (5.9969 \text{ in.} - 2 \times 0.048 \text{ in.})^2 = 1.14 \text{ in}^2$$

The bounding weight of the heaviest BWR fuel tube and oversized fuel tube is about 100 pounds. Considering a g-load of 1.1, the maximum compressive and bearing stress in the fuel tube is about 96 psi (100 lb × 1.1 / 1.14 in.^{2}). Limiting the compressive stress level in the tube to the material yield strength ensures the tube remains in position in storage conditions. The yield strength of Type 304 stainless steel is 17,300 psi at a conservatively high temperature of 750°F.

$$\text{Margin of Safety} = 17{,}300/96 - 1 = +\text{Large}$$

Thus, the tubes are structurally adequate under normal storage and handing conditions.

3.4.4.1.11 Canister Closure Weld Evaluation

The closure weld for the canister is a 0.9-inch groove weld between the structural lid and the canister shell. The evaluation of this weld incorporates a 0.8 stress reduction factor in accordance with NRC Interim Staff Guidance (ISG) No. 15, Revision 0. The use of this factor is in accordance with ISG No. 15, since the strength of the weld material (E308) is greater than that of the base material (Type 304 or 304L stainless steel).

The stresses for the canister closure weld are evaluated using sectional stresses as permitted by Subsection NB of the ASME Code. The location of the section for the canister closure weld evaluation is shown in Figure 3.4.4.1-4 and corresponds to Section 13. The governing P_m, P_m+ P_b, and P + Q stress intensities for Section 13, and the associated allowables, are listed in Table 3.4.4.1-6, Table 3.4.4.1-7, and Table 3.4.4.1-8, respectively. The factored allowables, incorporating the 0.8 stress reduction factor, and the resulting controlling Margins of Safety are shown below.

This evaluation confirms that the canister closure weld is acceptable for normal operation conditions.

Stress Category	Analysis Stress Intensity (ksi)	0.8 × Allowable Stress (ksi)	Margin of Safety
P_m	1.75	13.36	6.63
$P_m + P_b$	2.41	20.04	7.32
P + Q	5.87	40.08	5.83

Critical Flaw Size for the Canister Closure Weld

The closure weld for the canister is comprised of multiple weld beads using a compatible weld material for Type 304L stainless steel. An allowable (critical) flaw evaluation has been performed to determine the critical flaw size in the weld region. The result of the flaw evaluation is used to define the minimum flaw size, which must be identifiable in the nondestructive examination of the weld. Due to the inherent toughness associated with Type 304L stainless steel, a limit load analysis is used in conjunction with a J-integral/tearing modulus approach.

The safety factor used in this evaluation is that defined in Section XI of the ASME Code.

The stress component used in the evaluation for the critical flaw size is the radial stress component in the weld region of the structural lid. For the normal operation condition, in accordance with ASME Code Section XI, a safety factor of 3 is required. For the purpose of identifying the stress for the flaw evaluation, the weld region corresponding to Section 13 in Figure 3.4.4.1-4 is considered. The radial stress corresponds to SX in Tables 3.4.4.1-1 through 3.4.4.1-10. The maximum reported radial tensile stress is 0.9 ksi.

To perform the flaw evaluation, a 10 ksi stress is conservatively used, resulting in a significantly larger actual safety factor than the required safety factor of 3. Using a 10 ksi stress as the basis for the evaluation of the structural lid weld, the critical flaw size is 0.52 inch for a flaw that extends 360 degrees around the circumference of the structural lid weld. Stress components for the circumferential (Z) and axial (Y) directions are also reported in Tables 3.4.4.1-1 through 3.4.4.1-10, which would be associated with flaws oriented in the radial or horizontal directions, respectively. As shown in Table 3.4.4.1-7 at Section No. 13 (the structural lid weld), the maximum tensile stress reported for these components (SY and SZ) is 1.12 ksi, which is also enveloped by the value of 10 ksi used in the critical flaw evaluation for stresses in the radial direction.

The 360-degree flaw employed for the circumferential direction is considered to be bounding with respect to any partial flaw in the weld, which could occur in the radial and horizontal directions. Therefore, using a minimum detectable flaw size of 0.375 inch is acceptable, since it is less than the very conservatively determined 0.52-inch critical flaw size.

The Type 304L stainless steel structural lid may be forged (SA-182 material), or fabricated from plate (SA-240 material). Since the forged material is required to have ultimate and yield strengths that are equal to, or greater than, the plate material, the critical flaw size determination is applicable to both materials.

Figure 3.4.4.1-1 Canister Composite Finite Element Model

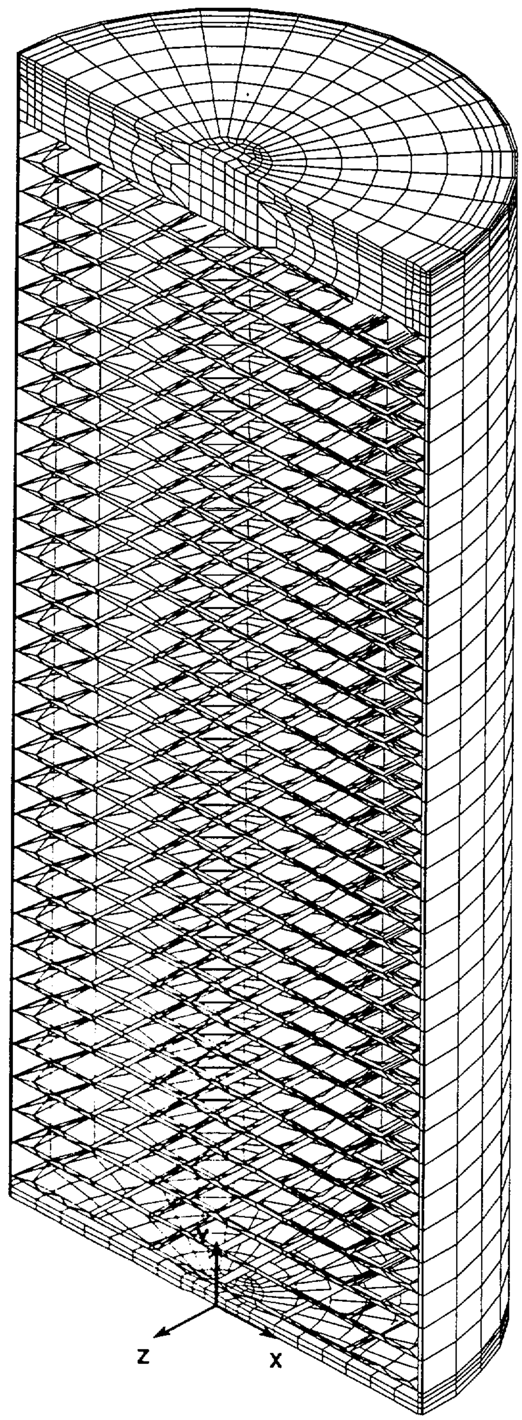


Figure 3.4.4.1-2 Weld Regions of Canister Composite Finite Element Model at Structural and Shield Lids

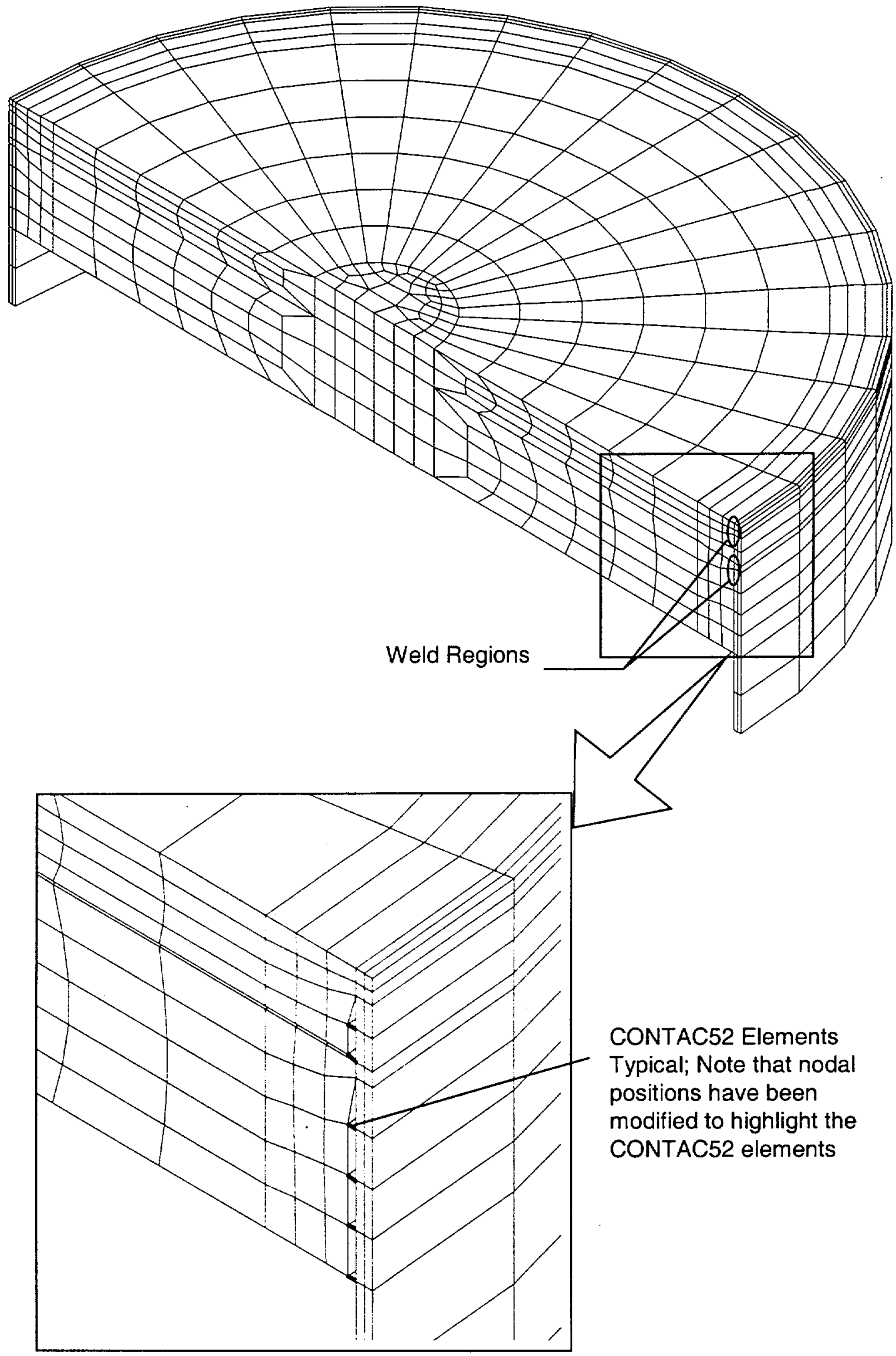


Figure 3.4.4.1-3 Bottom Plate of the Canister Composite Finite Element Model

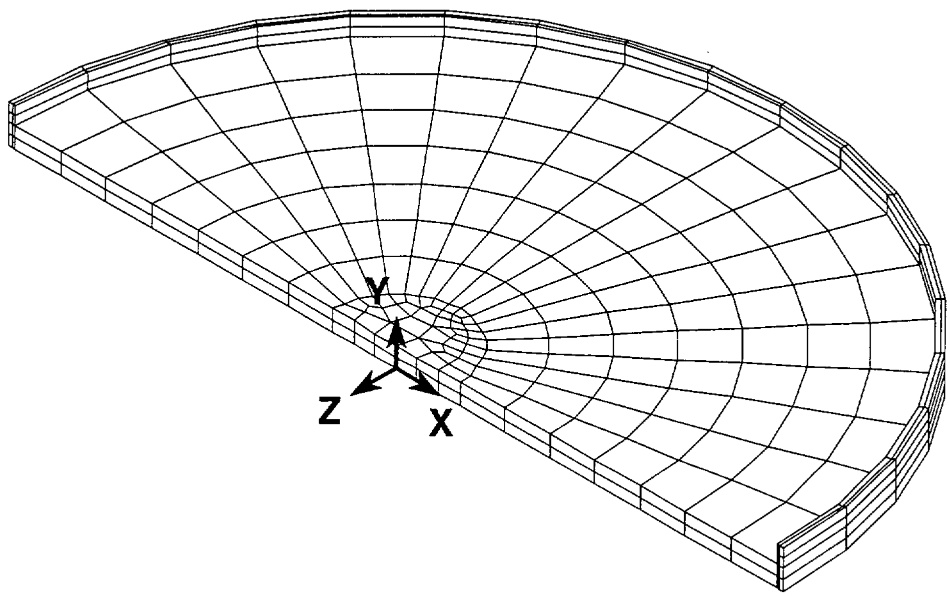
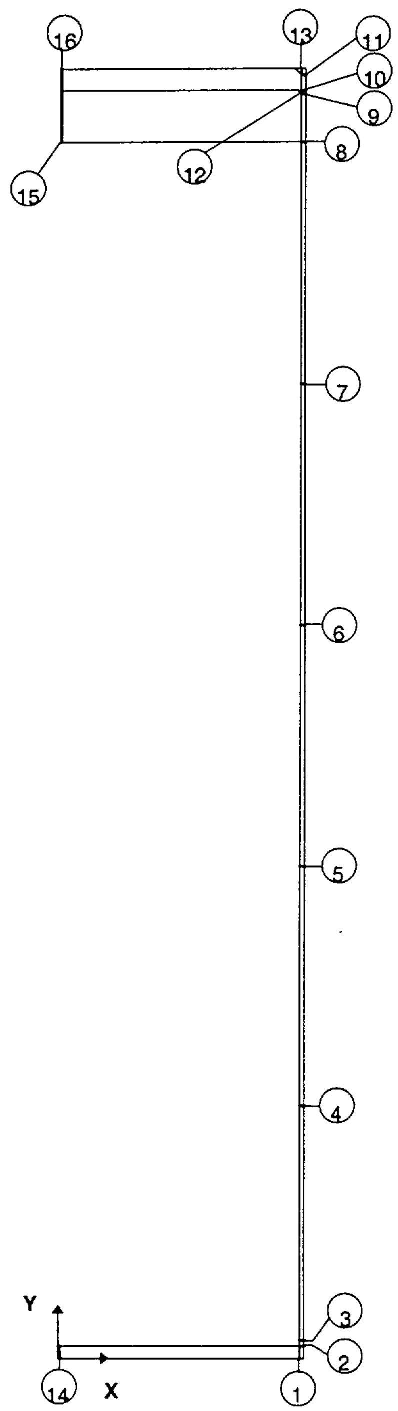
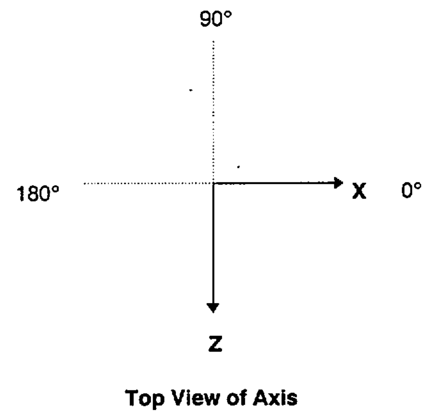


Figure 3.4.4.1-4 Locations for Section Stresses in the Canister Composite Finite Element Model





Section Coordinates at Z=0 and X>0

Axial Section	Node 1		Node 2	
	X	Y	X	Y
1	32.905	0.0	32.905	1.75
2	32.905	1.75	33.53	1.75
3	32.905	2.50	33.53	2.50
4	32.905	34.45	33.53	34.45
5	32.905	67.15	33.53	67.15
6	32.905	99.85	33.53	99.85
7	32.905	132.55	33.53	132.55
8	32.905	165.25	33.53	165.25
9	32.905	171.75	33.53	171.75
10	32.905	172.25	33.53	172.25
11	32.905	174.37	33.53	174.37
12	32.905	171.75	32.905	172.25
13	32.905	174.37	32.905	175.25
14	0.1	0.0	0.1	1.75
15	0.1	165.25	0.1	172.25
16	0.1	172.25	0.1	175.25

Figure 3.4.4.1-5 BWR Fuel Assembly Basket Showing Typical Fuel Basket Components

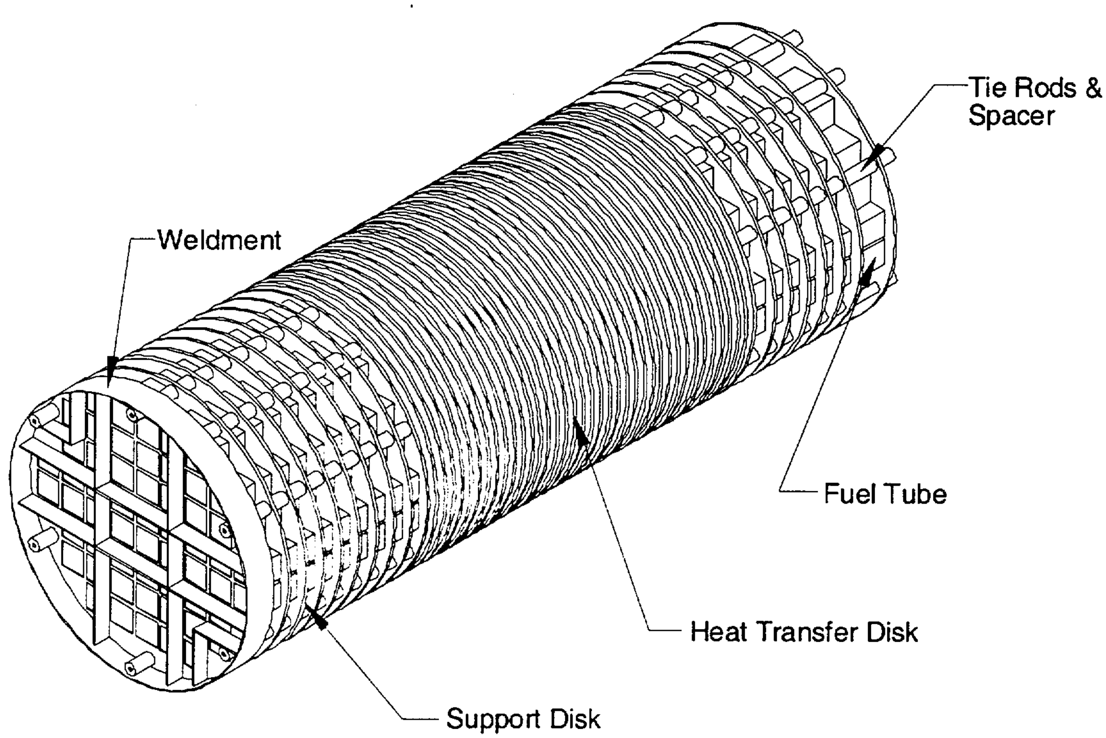


Figure 3.4.4.1-6 PWR Fuel Basket Support Disk Finite Element Model

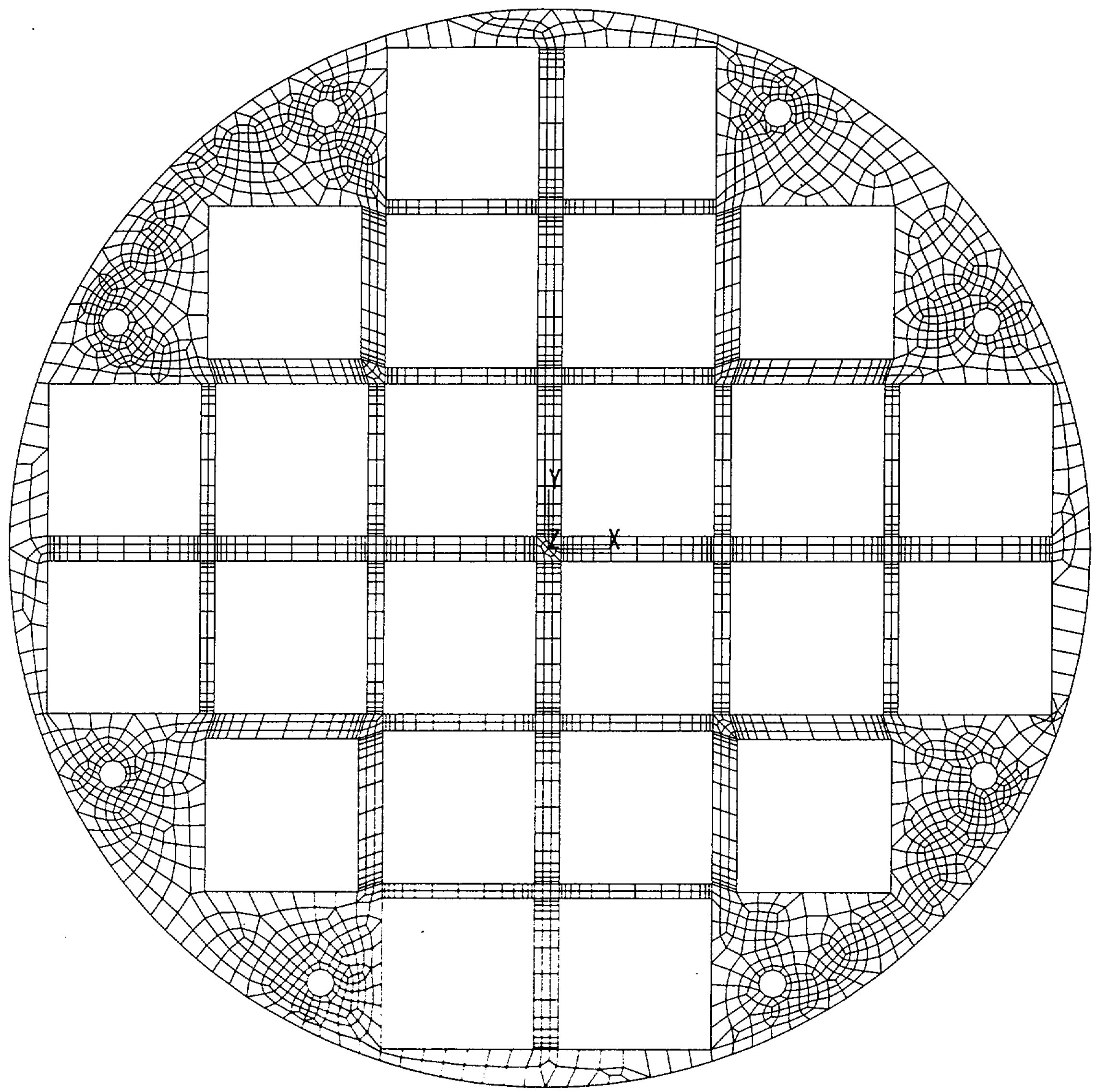


Figure 3.4.4.1-7 PWR Fuel Basket Support Disk Sections for Stress Evaluation (Left-Half)

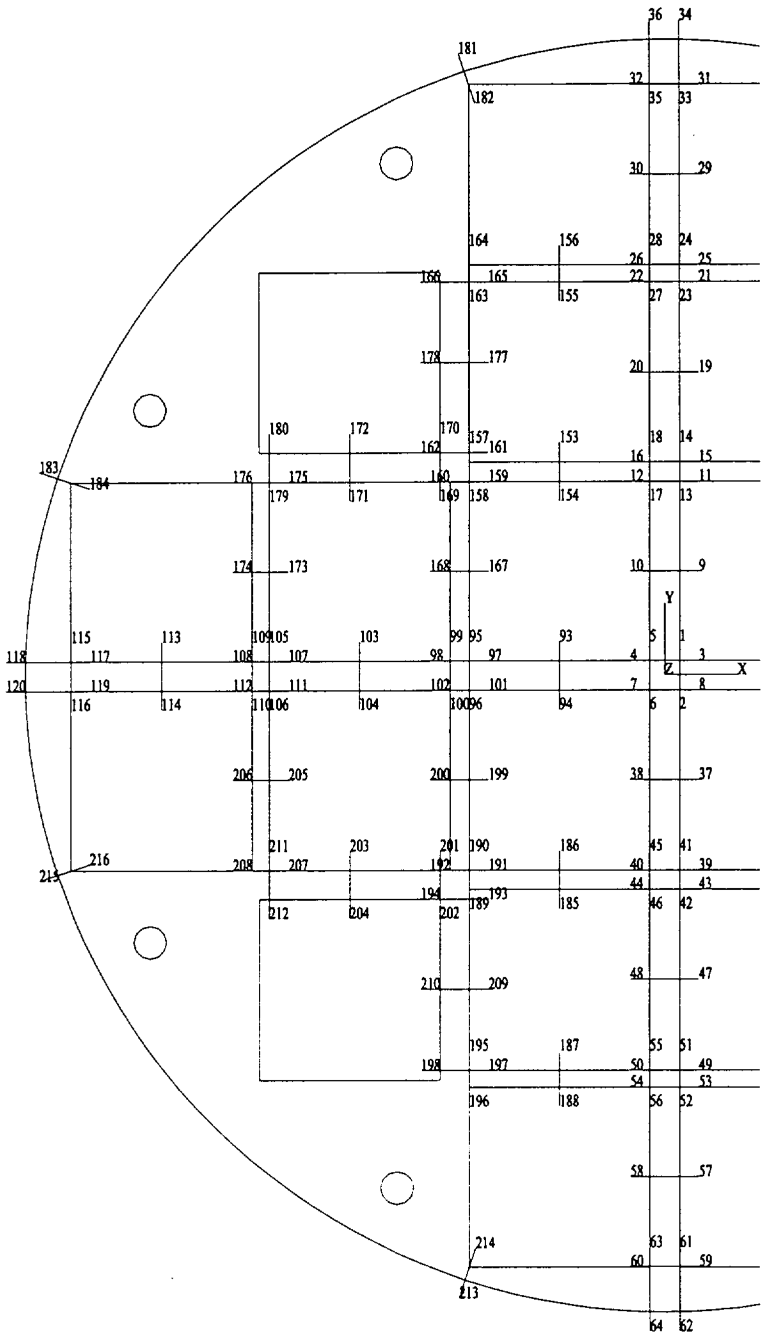


Figure 3.4.4.1-8 PWR Fuel Basket Support Disk Sections for Stress Evaluation (Right-Half)

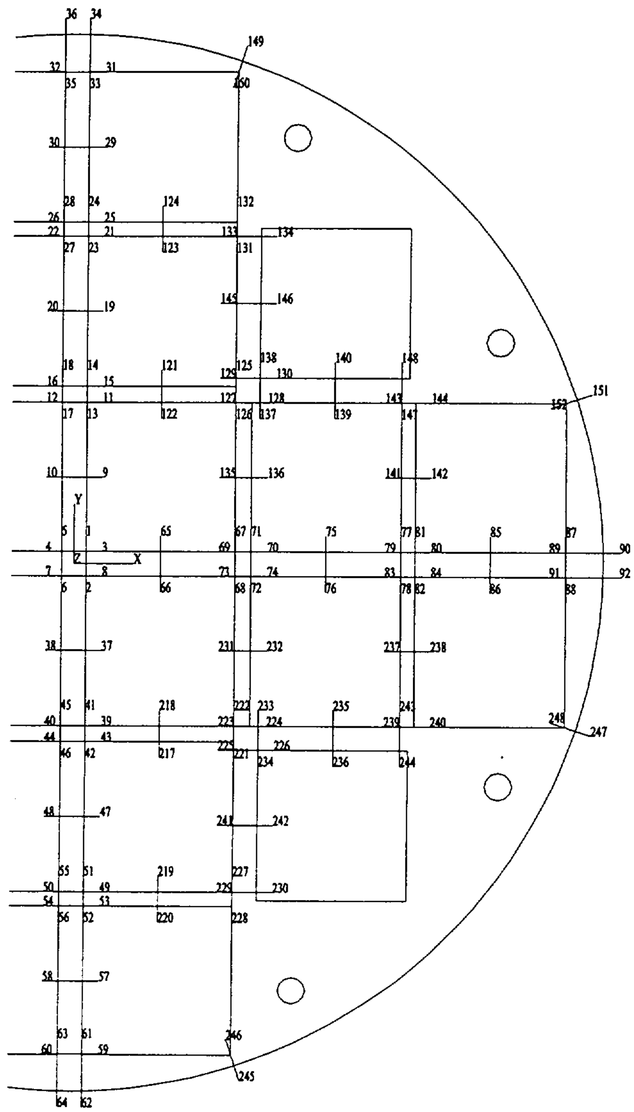


Figure 3.4.4.1-9 PWR Class 3 Fuel Tube Configuration

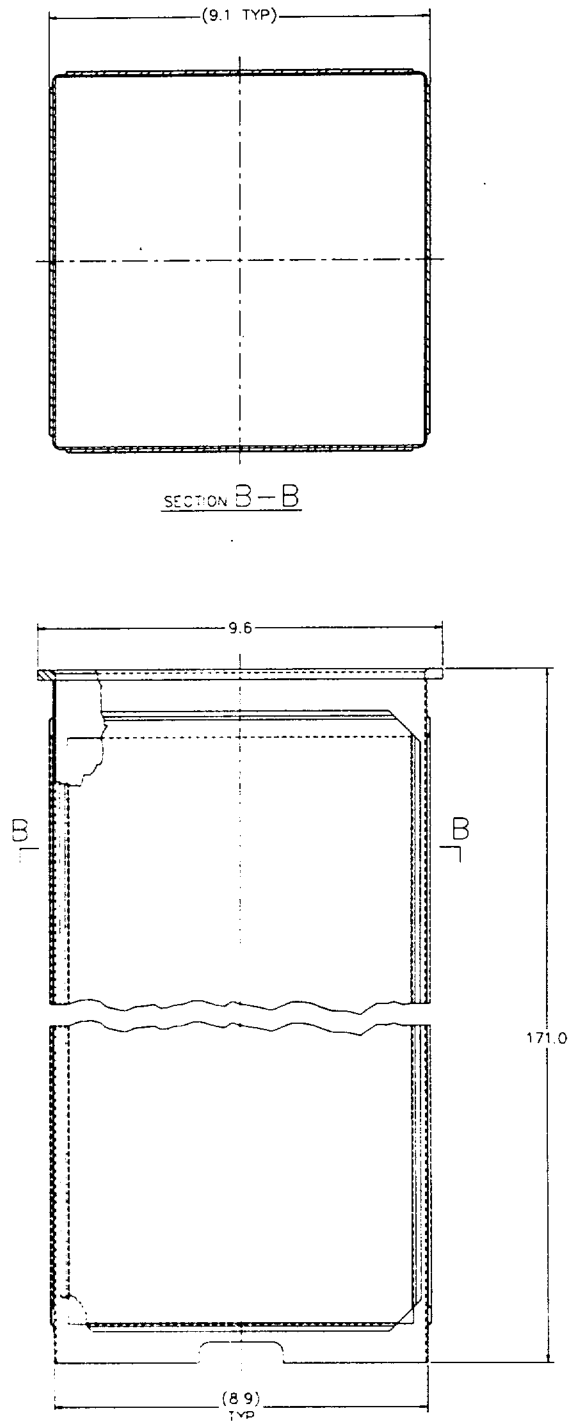


Figure 3.4.4.1-10 PWR Top Weldment Plate Finite Element Model

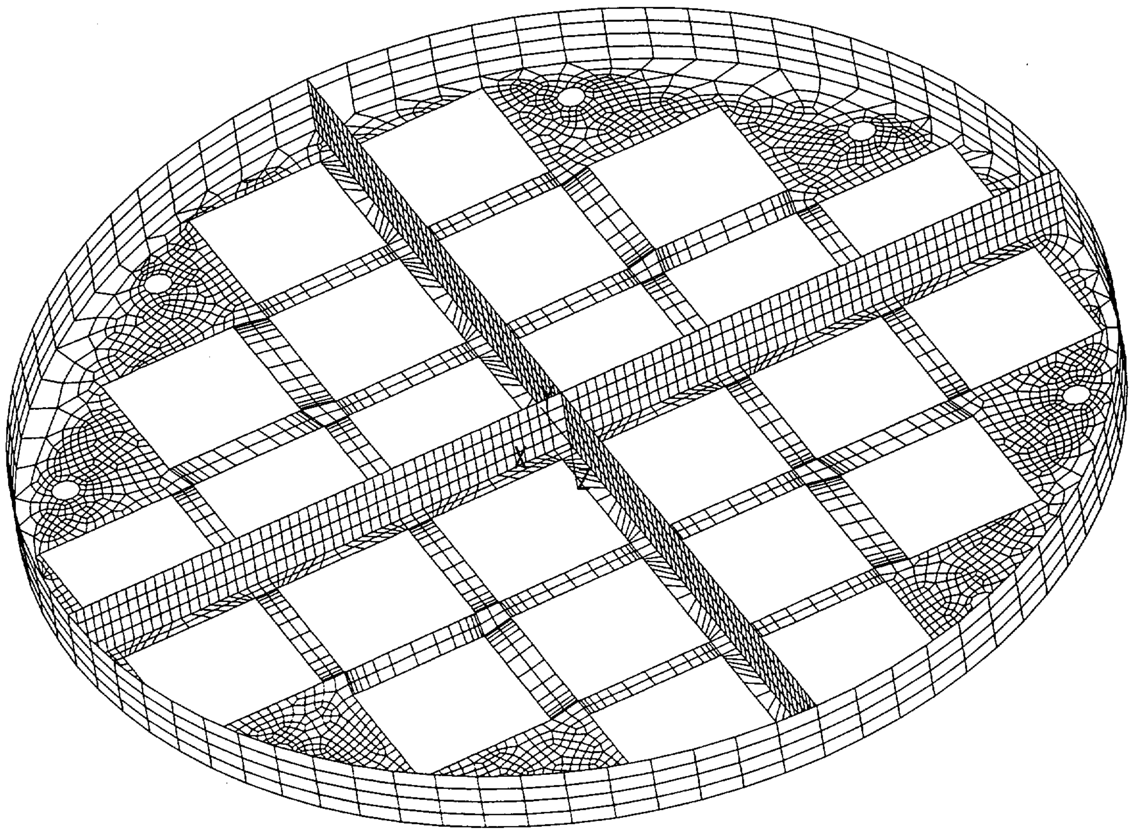
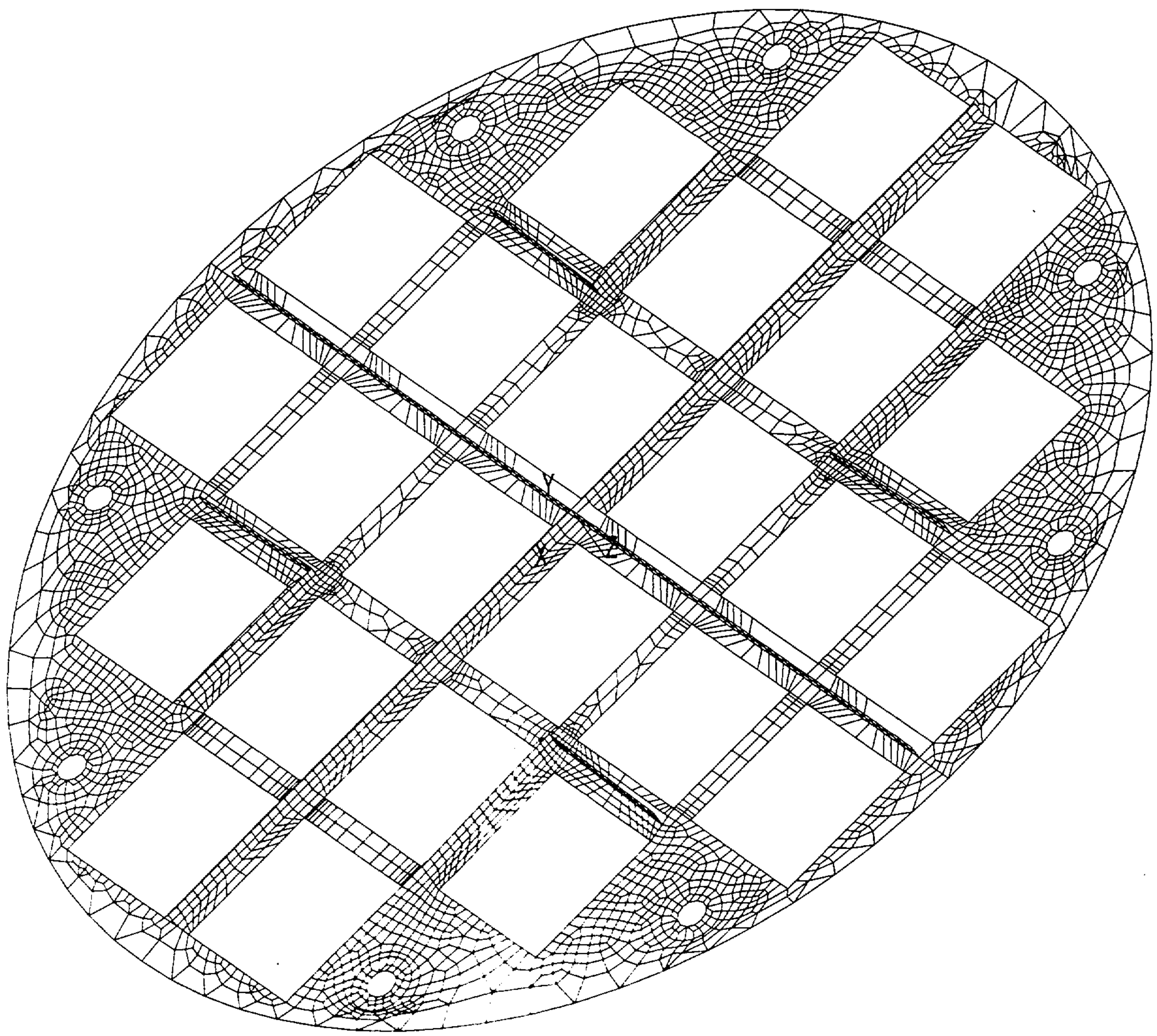


Figure 3.4.4.1-11 PWR Bottom Weldment Plate Finite Element Model



(Figure Inverted to Show Weldment Stiffeners)

Figure 3.4.4.1-12 BWR Fuel Basket Support Disk Finite Element Model

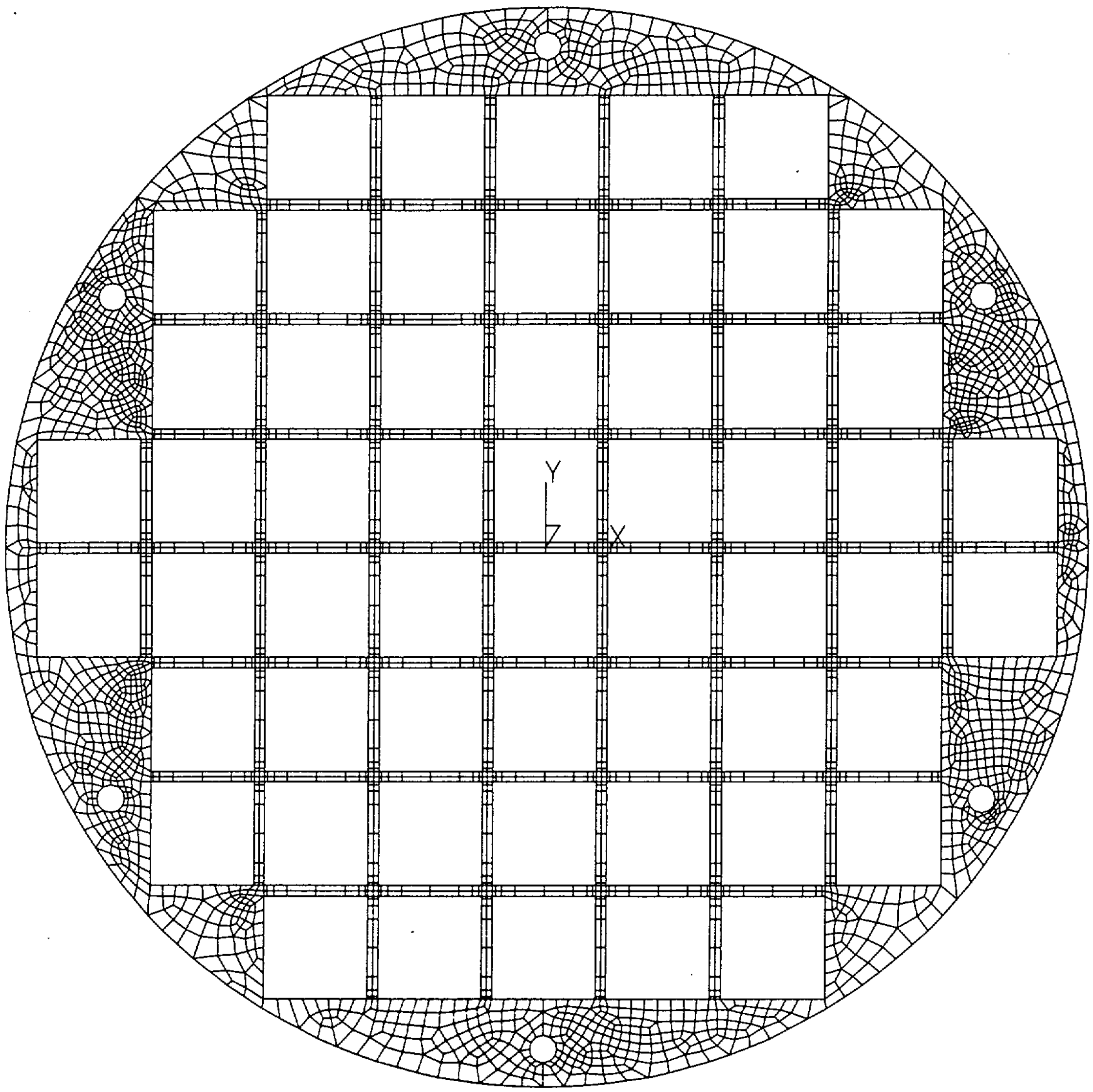


Figure 3.4.4.1-13 BWR Fuel Basket Support Disk Sections for Stress Evaluation (Quadrant I)

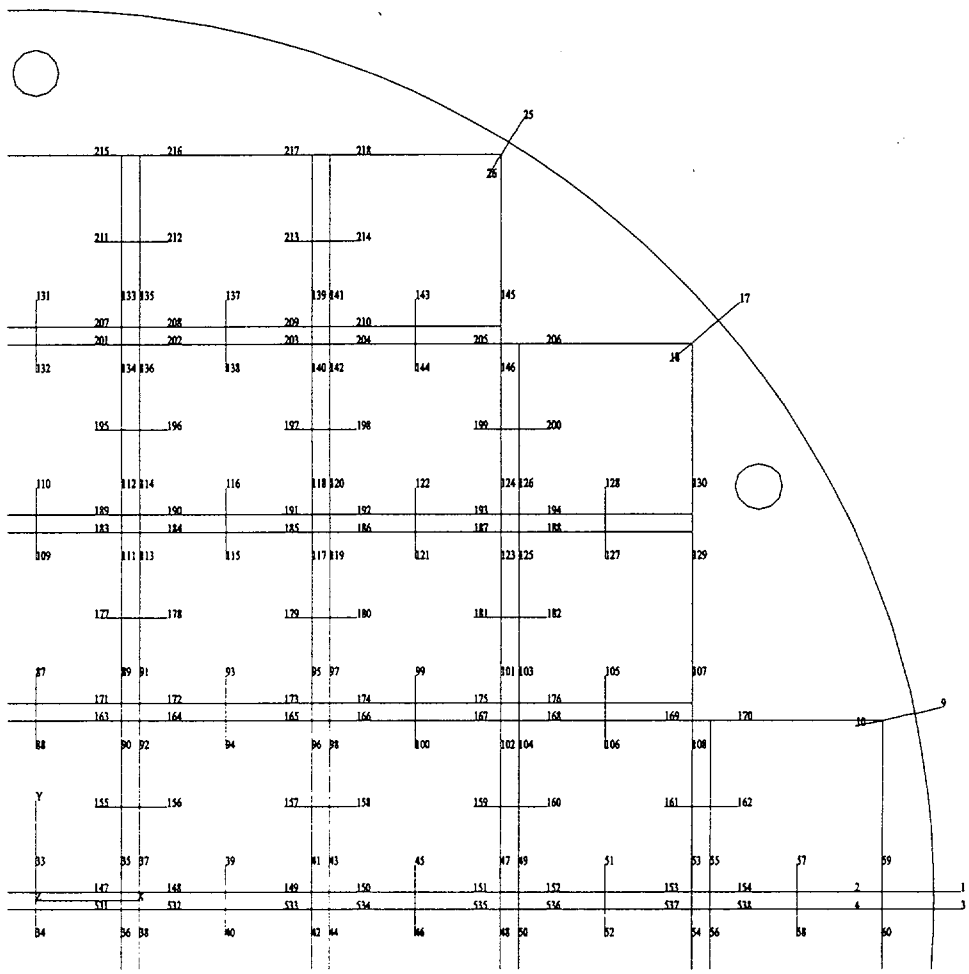


Figure 3.4.4.1-14 BWR Fuel Basket Support Disk Sections for Stress Evaluation (Quadrant II)

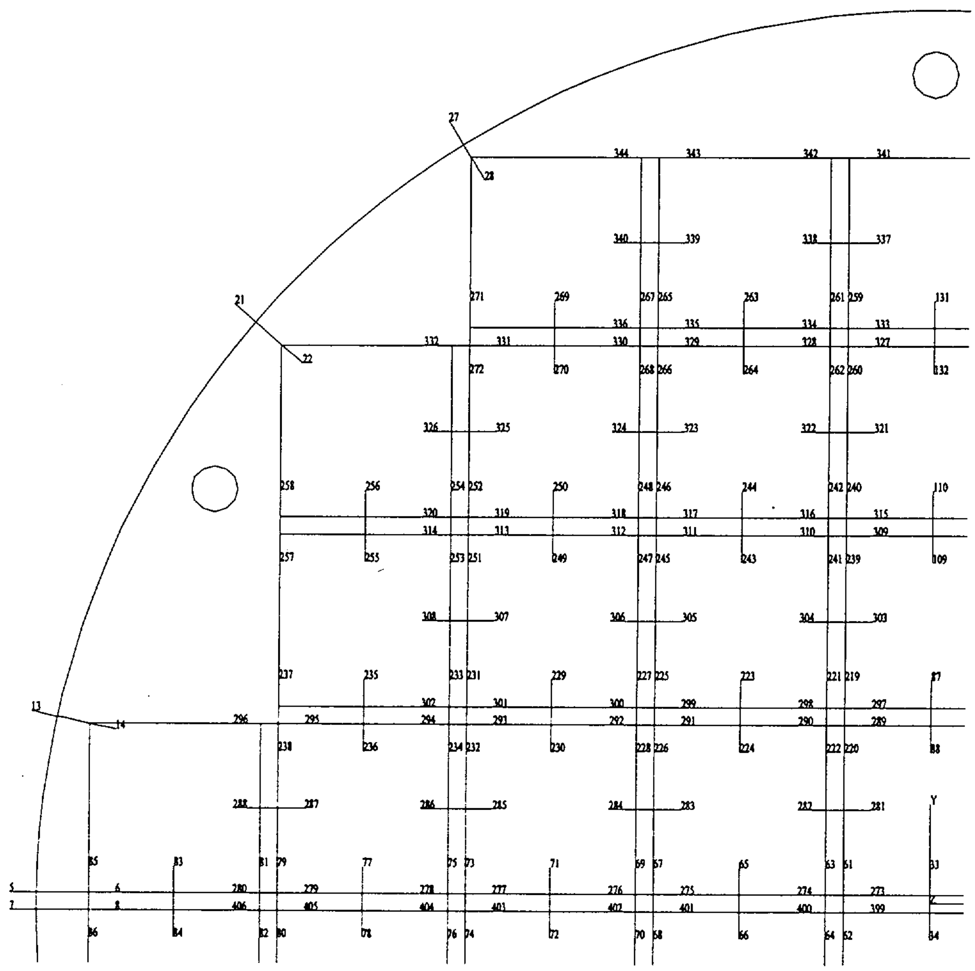


Figure 3.4.4.1-15 BWR Fuel Basket Support Disk Sections for Stress Evaluation (Quadrant III)

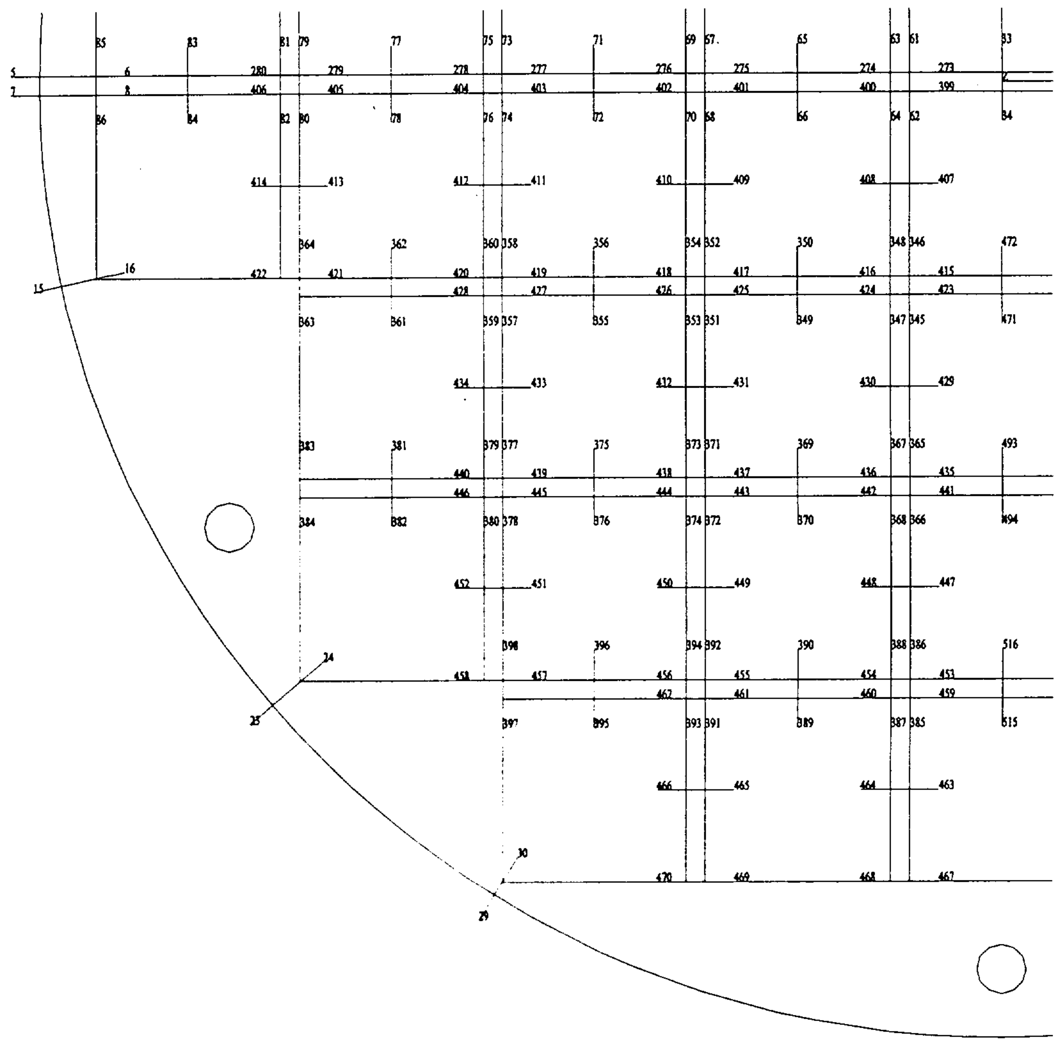


Figure 3.4.4.1-16 BWR Fuel Basket Support Disk Sections for Stress Evaluation (Quadrant IV)

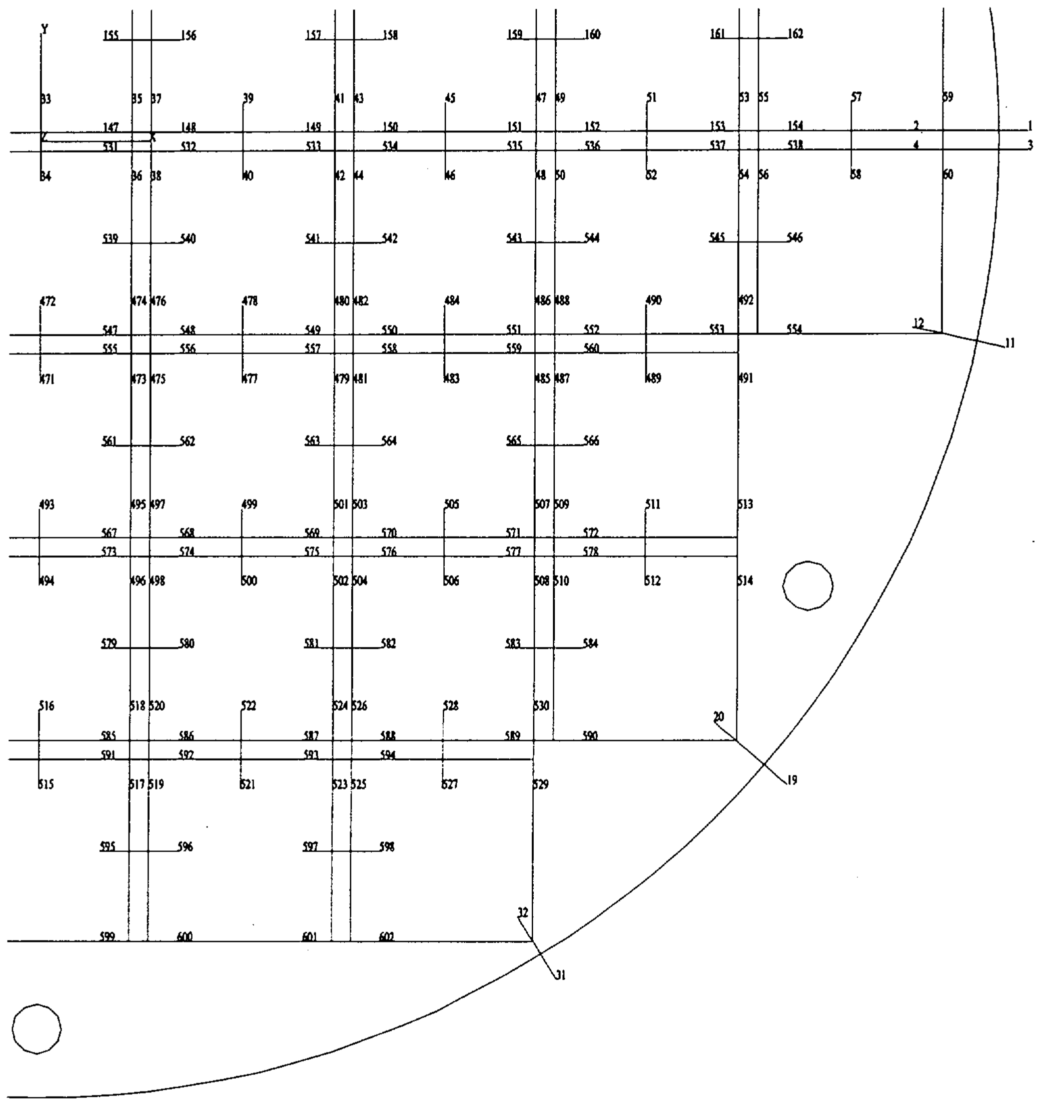


Figure 3.4.4.1-17 BWR Class 5 Fuel Tube Configuration

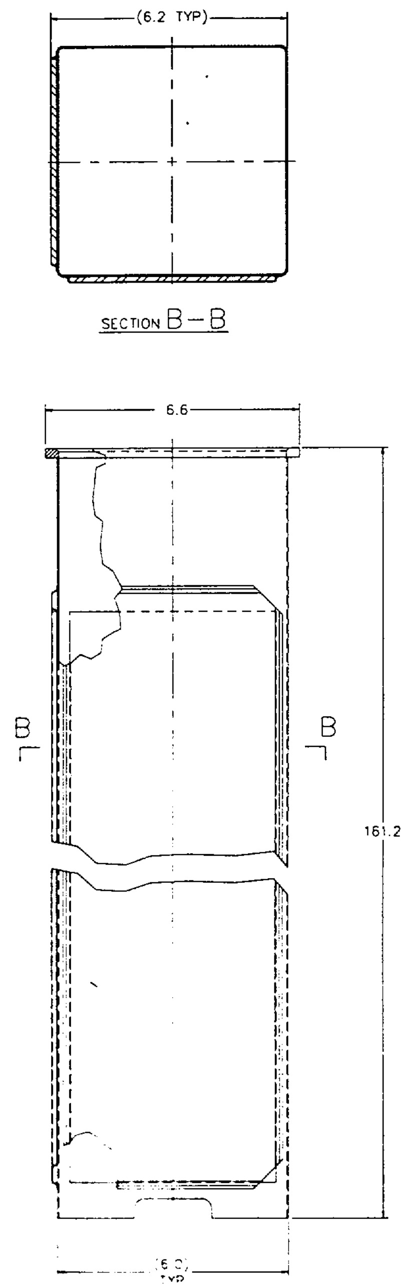


Figure 3.4.4.1-18 BWR Top Weldment Plate Finite Element Model

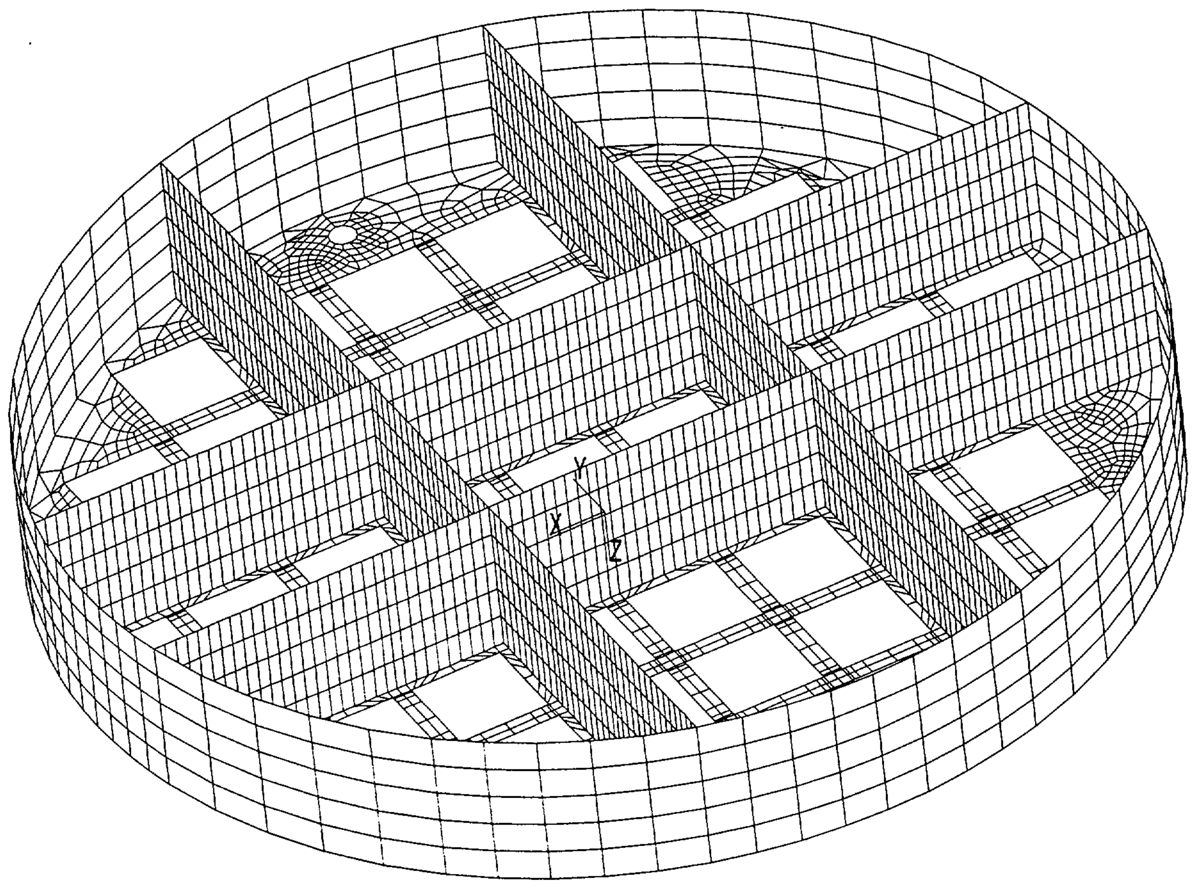
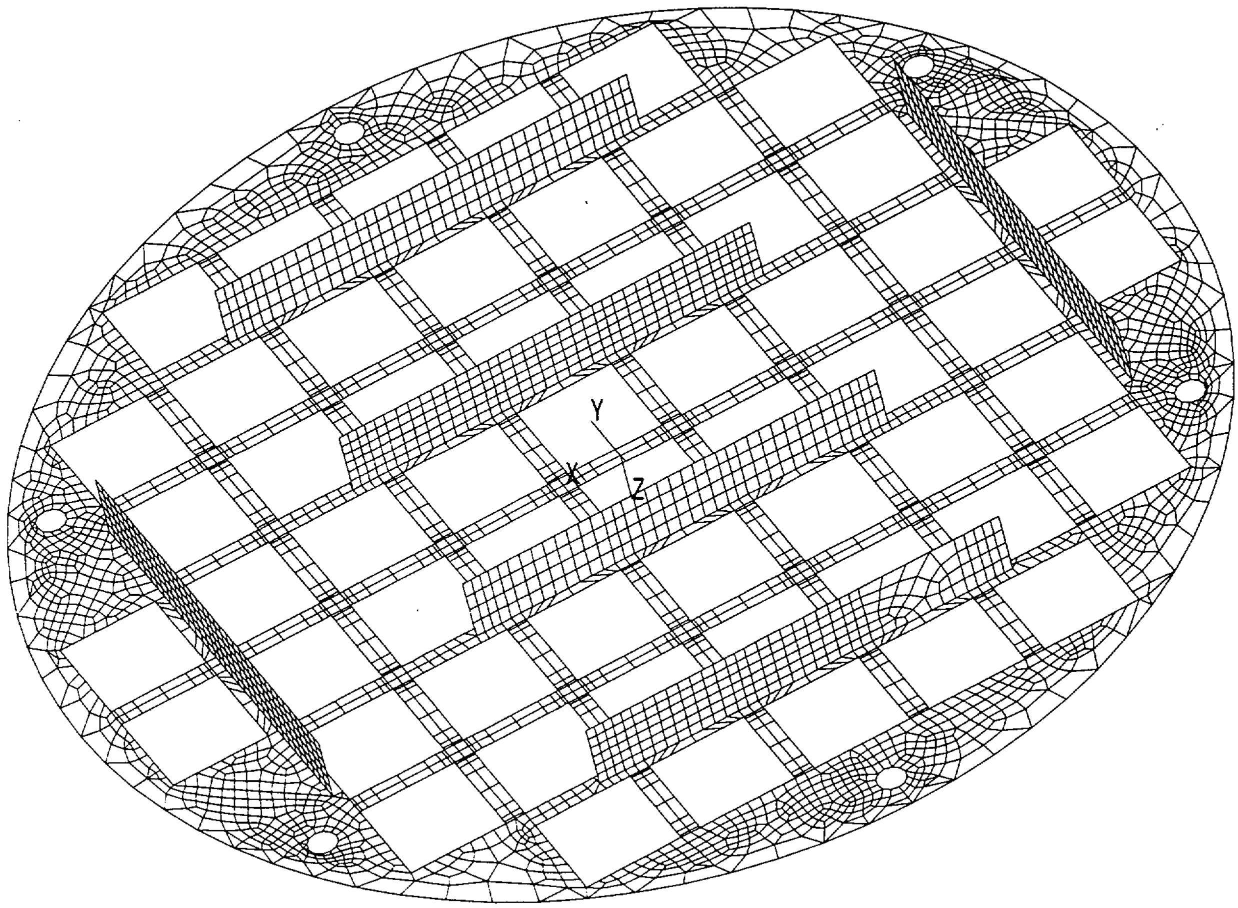


Figure 3.4.4.1-19 BWR Bottom Weldment Plate Finite Element Model



(Figure Inverted to Show Weldment Stiffeners)

Table 3.4.4.1-1 Canister Secondary (Thermal) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	-0.29	0.06	1.17	-0.10	0.03	0.13	1.52
2	0	0.16	-2.23	0.48	-0.18	0.03	0.03	2.73
3	0	-0.01	0.00	-0.01	0.00	0.01	0.00	0.03
4	0	0.00	-0.03	0.00	0.00	-0.01	0.00	0.04
5	0	-0.08	2.53	-0.86	0.00	0.00	-0.02	3.39
6	0	0.00	-0.03	0.00	0.00	0.01	0.00	0.04
7	180	-0.01	0.01	0.00	0.00	-0.01	0.00	0.03
8	180	0.01	0.16	-0.13	0.00	-0.01	0.01	0.29
9	0	3.44	1.68	1.40	1.20	-0.14	-0.04	3.02
10	180	-2.06	3.97	0.46	-0.78	-0.09	-0.16	6.24
11	0	1.96	-8.57	-1.93	0.57	-0.07	-0.29	10.61
12	0	-6.20	-1.44	-2.54	-0.80	0.02	0.21	5.04
13	180	-3.39	1.40	-0.47	-0.57	-0.07	-0.23	4.94
14	180	-23.84	-14.43	-22.56	-0.08	-1.40	-0.70	10.00
15	180	-8.11	-6.88	-7.65	0.00	-0.50	-0.19	1.58
16	0	0.38	-0.09	0.39	0.00	0.00	0.00	0.47

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-2 Canister Dead Weight Primary Membrane (P_m) Stresses (ksi), $P_{internal}$ = 0 psig

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	180	0.00	-0.05	0.04	0.00	0.00	0.00	0.09
2	0	0.03	-0.15	-0.08	-0.01	0.00	-0.01	0.18
3	90	0.00	-0.12	0.00	0.04	0.00	0.00	0.14
4	180	0.00	-0.14	-0.01	0.00	0.00	0.00	0.14
5	180	0.00	-0.14	-0.01	0.00	0.00	0.00	0.14
6	180	0.00	-0.14	-0.01	0.00	0.00	0.00	0.14
7	180	0.00	-0.12	-0.01	0.00	0.00	0.00	0.12
8	90	0.00	-0.06	0.00	-0.04	0.00	0.00	0.10
9	90	-0.04	-0.04	-0.01	-0.02	0.01	-0.01	0.06
10	0	0.03	-0.03	-0.04	0.01	0.00	0.00	0.07
11	0	-0.04	0.01	-0.03	0.00	0.00	0.00	0.05
12	0	0.02	0.05	-0.02	0.01	0.00	0.00	0.07
13	0	0.01	-0.04	-0.03	0.00	0.00	0.00	0.05
14	0	-0.02	-0.05	-0.15	-0.03	0.00	-0.35	0.72
15	0	0.00	-0.02	-0.06	0.03	0.00	-0.16	0.32
16	0	-0.01	-0.01	-0.05	0.01	0.00	-0.12	0.25

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-3 Canister Dead Weight Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi), $P_{internal}$ = 0 psig

Section No.[1]	**Angle (degrees)**	**SX**	**SY**	**SZ**	**SXY**	**SYZ**	**SXZ**	**Stress Intensity**
1	180	0.00	-0.08	0.03	0.01	0.00	0.00	0.11
2	0	0.01	-0.25	-0.11	-0.01	0.00	-0.01	0.27
3	90	0.00	-0.12	0.00	0.04	0.00	0.00	0.14
4	180	0.00	-0.14	-0.01	0.00	0.00	0.00	0.14
5	180	0.00	-0.15	-0.01	0.00	0.00	0.00	0.15
6	180	0.00	-0.14	-0.01	0.00	0.00	0.00	0.14
7	180	0.00	-0.12	-0.01	0.00	0.00	0.00	0.12
8	90	0.00	-0.07	0.01	-0.04	0.00	0.00	0.10
9	0	-0.01	-0.12	-0.08	-0.01	0.00	-0.01	0.12
10	0	0.02	-0.14	-0.07	0.00	0.00	-0.01	0.16
11	0	-0.03	0.10	0.00	-0.01	0.00	0.00	0.13
12	0	0.05	0.07	0.00	0.02	0.00	0.00	0.09
13	0	0.05	-0.02	-0.01	-0.01	0.00	0.00	0.07
14	0	-0.01	-0.05	-0.15	-0.05	0.00	-0.36	0.74
15	0	0.06	-0.02	-0.01	0.05	0.00	-0.21	0.43
16	0	0.02	0.00	-0.03	0.02	0.00	-0.15	0.30

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-4 Canister Normal Handling With No Internal Pressure Primary Membrane (P_m) Stresses, (ksi)

Section No. [1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	0.12	1.81	0.65	-0.26	0.02	0.05	1.77
2	0	1.18	-1.16	-1.73	-0.27	0.02	-0.22	2.97
3	0	0.00	0.54	-0.02	0.00	0.00	0.00	0.56
4	0	0.00	0.59	0.01	0.00	0.00	0.00	0.58
5	0	0.00	0.63	0.01	0.00	0.00	0.00	0.63
6	0	0.01	0.69	0.00	0.00	0.01	0.00	0.69
7	0	0.01	0.78	0.00	0.00	0.01	0.00	0.78
8	0	0.02	1.10	-0.01	0.00	0.06	0.00	1.12
9	0	0.08	1.48	0.36	0.08	0.14	0.03	1.43
10	0	-0.28	1.87	0.33	0.11	0.20	0.06	2.19
11	0	-0.61	1.08	0.63	-0.53	0.13	0.08	2.02
12	120	0.36	2.04	0.06	-0.09	-0.15	-0.28	2.18
13	120	0.80	-0.29	0.47	0.31	0.53	-0.29	1.64
14	0	0.28	-0.04	0.15	-0.03	-0.13	-0.34	0.79
15	0	-0.01	-0.03	-0.08	0.02	0.00	-0.18	0.37
16	0	0.00	-0.04	-0.05	0.00	0.00	-0.15	0.30

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-5 Canister Normal Handling With No Internal Pressure Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	1.33	4.38	-0.09	-0.02	0.02	-0.08	4.47
2	0	0.57	-8.40	-4.03	-0.61	0.04	-0.38	9.09
3	0	0.01	0.53	-0.07	0.00	0.01	-0.01	0.60
4	0	0.00	0.55	-0.10	0.00	0.01	-0.01	0.66
5	0	0.01	0.58	-0.15	0.00	0.01	-0.01	0.73
6	0	0.01	0.63	-0.18	0.00	0.01	-0.02	0.81
7	0	0.01	0.71	-0.20	0.00	0.01	-0.02	0.91
8	0	0.03	1.07	-0.12	0.00	0.05	-0.01	1.20
9	0	-0.06	1.55	0.29	0.00	0.19	0.00	1.64
10	0	-0.42	2.82	0.61	0.21	0.14	0.12	3.29
11	0	-0.86	1.07	0.58	-0.96	0.21	0.08	2.76
12	120	0.32	2.69	-0.20	-0.10	-0.17	-0.46	3.18
13	0	1.26	-0.68	1.41	-0.25	-0.04	0.24	2.31
14	0	6.63	0.16	6.50	0.00	-0.13	-0.34	6.75
15	0	-0.14	-0.01	-0.21	0.05	0.00	-0.22	0.46
16	0	0.27	-0.04	0.23	0.02	0.01	-0.14	0.44

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-6 Summary of Canister Normal Handling plus Normal Internal Pressure Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	0.22	3.27	1.23	-0.47	0.03	0.09	3.20	16.70	4.22
2	0	2.16	-2.11	-2.95	-0.48	0.04	-0.38	5.21	16.70	2.20
3	0	0.00	0.93	0.74	0.00	0.00	0.07	0.94	16.34	16.45
4	0	0.00	0.98	0.79	0.00	0.00	0.07	0.98	15.33	14.63
5	0	0.00	1.02	0.79	0.00	0.00	0.07	1.03	14.51	13.10
6	0	0.01	1.08	0.79	0.00	0.01	0.07	1.08	15.22	13.03
7	0	0.01	1.17	0.79	0.00	0.01	0.07	1.17	16.15	12.81
8	0	0.02	1.49	0.38	-0.01	0.07	0.03	1.47	16.70	10.33
9	0	0.06	1.74	0.48	0.06	0.14	0.04	1.71	16.70	8.78
10	0	-0.34	2.03	0.42	0.02	0.21	0.07	2.41	16.70	5.94
11	0	-0.35	0.97	0.86	-0.47	0.12	0.09	1.66	16.70	9.08
12	120	0.38	2.07	0.03	-0.05	-0.08	-0.33	2.25	16.70	6.44
13	120	1.06	0.08	0.51	0.29	0.50	-0.47	1.75	16.70	8.54
14	0	0.53	-0.05	0.40	-0.06	-0.23	-0.34	1.03	16.70	15.28
15	0	-0.06	-0.03	-0.13	0.02	0.00	-0.18	0.37	16.70	44.73
16	0	0.03	-0.01	-0.03	0.00	0.01	-0.15	0.30	16.70	54.24

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.
2. ASME Code Service Level A is used for material allowable stresses.

Table 3.4.4.1-7 Summary of Canister Normal Handling, Plus Normal Pressure Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	2.45	7.92	0.04	-0.04	0.04	-0.13	7.89	25.05	2.18
2	0	1.04	-15.21	-7.12	-1.08	0.08	-0.68	16.45	25.05	0.52
3	0	0.00	0.95	0.79	0.00	0.00	0.07	0.96	24.51	24.62
4	0	0.01	1.01	0.89	0.00	0.00	0.08	1.01	23.00	21.73
5	0	0.01	1.08	0.94	0.00	0.00	0.08	1.08	21.76	19.21
6	0	0.01	1.15	0.97	0.00	0.00	0.09	1.15	22.83	18.90
7	0	0.01	1.25	0.97	0.00	0.01	0.09	1.24	24.22	18.49
8	0	0.02	1.49	0.47	-0.01	0.08	0.04	1.48	25.05	15.91
9	0	-0.06	1.99	0.47	0.03	0.19	0.02	2.07	25.05	11.12
10	0	-0.47	2.88	0.68	0.11	0.14	0.13	3.38	25.05	6.42
11	0	-0.54	1.90	1.10	-0.94	0.20	0.11	3.11	25.05	7.07
12	120	0.35	2.70	-0.23	-0.05	-0.08	-0.51	3.23	25.05	6.76
13	120	1.56	-0.60	1.12	0.10	0.17	-0.38	2.41	25.05	9.39
14	0	11.74	0.31	11.62	-0.02	-0.23	-0.34	11.71	25.05	1.14
15	120	-0.26	-0.04	-0.33	0.05	0.00	-0.22	0.51	25.05	48.47
16	0	0.81	0.01	0.74	-0.02	0.01	-0.16	0.93	25.05	25.95

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.
2. ASME Code Service Level A is used for material allowable stresses.

Table 3.4.4.1-8 Summary of Maximum Canister Normal Handling, plus Normal Pressure, plus Secondary (P + Q) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	3.75	11.34	2.81	0.12	0.05	0.02	8.53	50.10	4.87
2	0	1.26	-18.39	-6.90	-1.23	0.12	-0.67	19.86	50.10	1.52
3	0	-0.01	0.95	0.78	0.00	0.01	0.07	0.97	49.02	49.58
4	0	0.01	1.04	0.91	0.00	0.01	0.08	1.04	46.00	43.27
5	0	-0.07	3.60	0.08	0.00	0.00	0.06	3.70	43.52	10.77
6	0	0.01	1.18	0.99	0.00	-0.01	0.09	1.18	45.66	37.76
7	0	0.01	1.26	0.97	0.00	0.00	0.09	1.26	48.45	37.42
8	0	0.02	1.64	0.34	-0.01	0.07	0.03	1.63	50.10	29.83
9	0	1.30	3.18	1.02	1.35	0.05	-0.01	3.29	50.10	14.25
10	0	-6.73	1.13	-1.95	-0.71	0.16	0.33	8.02	50.10	5.25
11	180	2.32	-10.28	-2.29	-0.69	-0.12	0.33	12.71	50.10	2.94
12	120	-3.12	1.23	-5.52	0.35	0.61	-2.10	8.09	50.10	5.19
13	180	-4.03	1.67	-0.41	-0.67	-0.08	-0.29	5.87	50.10	7.53
14	120	-13.23	-0.19	-13.14	-0.05	0.05	-0.55	13.55	50.10	2.70
15	180	-8.45	-6.91	-8.06	0.06	-0.50	-0.42	2.05	50.10	23.45
16	10	-0.06	-0.59	-0.09	-0.02	0.05	-0.18	0.71	50.10	69.88

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.
2. ASME Code Service Level A is used for material allowable stresses.

Table 3.4.4.1-9 Canister Normal Internal Pressure Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	0.10	1.46	0.57	-0.21	0.02	0.04	1.43
2	0	0.98	-0.95	-1.22	-0.21	0.02	-0.16	2.24
3	0	0.00	0.39	0.76	0.00	0.00	0.07	0.77
4	0	0.00	0.39	0.78	0.00	0.00	0.07	0.80
5	0	0.00	0.39	0.78	0.00	0.00	0.07	0.80
6	0	0.00	0.39	0.78	0.00	0.00	0.07	0.80
7	0	0.00	0.39	0.78	0.00	0.00	0.07	0.80
8	0	0.00	0.39	0.40	-0.01	0.00	0.04	0.41
9	0	0.04	0.29	0.20	0.03	0.00	0.02	0.26
10	0	-0.13	0.19	0.13	-0.04	0.00	0.02	0.34
11	40	0.14	-0.04	0.12	0.01	-0.01	-0.04	0.21
12	80	0.03	-0.19	-0.07	-0.01	0.06	0.02	0.25
13	0	-0.02	0.19	0.11	0.01	-0.01	0.01	0.22
14	0	0.25	-0.02	0.25	-0.02	-0.10	0.00	0.33
15	0	-0.03	-0.01	-0.03	0.00	0.00	0.00	0.02
16	120	0.02	0.00	0.02	0.00	0.00	0.00	0.03

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-10 Canister Normal Internal Pressure Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	1.12	3.53	0.12	-0.01	0.02	-0.05	3.41
2	0	0.47	-6.80	-3.08	-0.48	0.03	-0.29	7.36
3	0	0.00	0.39	0.77	0.00	0.00	0.07	0.78
4	0	-0.01	0.39	0.79	0.00	0.00	0.07	0.81
5	0	-0.01	0.39	0.79	0.00	0.00	0.07	0.81
6	0	0.00	0.39	0.79	0.00	0.00	0.07	0.81
7	0	0.00	0.39	0.79	0.00	0.00	0.07	0.81
8	0	0.00	0.44	0.42	-0.01	0.00	0.04	0.44
9	0	0.04	0.59	0.29	0.08	-0.01	0.02	0.58
10	0	-0.10	0.74	0.30	0.02	0.00	0.03	0.85
11	90	-0.04	-0.45	0.14	0.00	-0.02	0.00	0.59
12	80	-0.05	-0.35	-0.18	-0.02	0.10	0.02	0.36
13	0	-0.22	0.08	0.03	0.03	-0.01	0.02	0.31
14	180	5.09	0.13	5.10	-0.02	-0.10	0.00	4.97
15	0	-0.33	-0.02	-0.33	0.00	0.00	0.00	0.32
16	0	0.17	0.00	0.17	0.00	0.00	0.00	0.17

1. See Figure 3.4.4.1-4 for definition of locations of stress sections.

Table 3.4.4.1-11 Listing of Sections for Stress Evaluation of PWR Support Disk

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
1	1	2	0.75	0.75	0.75	-0.75
2	3	4	0.75	0.75	-0.75	0.75
3	5	6	-0.75	0.75	-0.75	-0.75
4	7	8	-0.75	-0.75	0.75	-0.75
5	9	10	0.75	5.39	-0.75	5.39
6	11	12	0.75	10.02	-0.75	10.02
7	13	14	0.75	10.02	0.75	11.02
8	15	16	0.75	11.02	-0.75	11.02
9	17	18	-0.75	10.02	-0.75	11.02
10	19	20	0.75	15.66	-0.75	15.66
11	21	22	0.75	20.29	-0.75	20.29
12	23	24	0.75	20.29	0.75	21.17
13	25	26	0.75	21.17	-0.75	21.17
14	27	28	-0.75	20.29	-0.75	21.17
15	29	30	0.75	25.81	-0.75	25.81
16	31	32	0.75	30.44	-0.75	30.44
17	33	34	0.75	30.44	0.75	32.74
18	35	36	-0.75	30.44	-0.75	32.74
19	37	38	0.75	-5.39	-0.75	-5.39
20	39	40	0.75	-10.02	-0.75	-10.02
21	41	42	0.75	-10.02	0.75	-11.02
22	43	44	0.75	-11.02	-0.75	-11.02
23	45	46	-0.75	-10.02	-0.75	-11.02
24	47	48	0.75	-15.66	-0.75	-15.66
25	49	50	0.75	-20.29	-0.75	-20.29
26	51	52	0.75	-20.29	0.75	-21.17
27	53	54	0.75	-21.17	-0.75	-21.17
28	55	56	-0.75	-20.29	-0.75	-21.17
29	57	58	0.75	-25.81	-0.75	-25.81
30	59	60	0.75	-30.44	-0.75	-30.44
31	61	62	0.75	-30.44	0.75	-32.74
32	63	64	-0.75	-30.44	-0.75	-32.74
33	65	66	5.39	0.75	5.39	-0.75
34	67	68	10.02	0.75	10.02	-0.75
35	69	70	10.02	0.75	11.02	0.75
36	71	72	11.02	0.75	11.02	-0.75
37	73	74	10.02	-0.75	11.02	-0.75
38	75	76	15.66	0.75	15.66	-0.75
39	77	78	20.29	0.75	20.29	-0.75
40	79	80	20.29	0.75	21.17	0.75
41	81	82	21.17	0.75	21.17	-0.75
42	83	84	20.29	-0.75	21.17	-0.75
43	85	86	25.81	0.75	25.81	-0.75
44	87	88	30.44	0.75	30.44	-0.75
45	89	90	30.44	0.75	32.74	0.75

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.

Table 3.4.4.1-11 Listing of Sections for Stress Evaluation of PWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
46	91	92	30.44	-0.75	32.74	-0.75
47	93	94	-5.39	0.75	-5.39	-0.75
48	95	96	-10.02	0.75	-10.02	-0.75
49	97	98	-10.02	0.75	-11.02	0.75
50	99	100	-11.02	0.75	-11.02	-0.75
51	101	102	-10.02	-0.75	-11.02	-0.75
52	103	104	-15.66	0.75	-15.66	-0.75
53	105	106	-20.29	0.75	-20.29	-0.75
54	107	108	-20.29	0.75	-21.17	0.75
55	109	110	-21.17	0.75	-21.17	-0.75
56	111	112	-20.29	-0.75	-21.17	-0.75
57	113	114	-25.81	0.75	-25.81	-0.75
58	115	116	-30.44	0.75	-30.44	-0.75
59	117	118	-30.44	0.75	-32.74	0.75
60	119	120	-30.44	-0.75	-32.74	-0.75
61	121	122	5.39	11.02	5.39	10.02
62	123	124	5.39	20.29	5.39	21.17
63	125	126	10.02	11.02	10.02	10.02
64	127	128	10.02	10.02	11.02	10.02
65	129	130	10.02	11.52	11.52	11.52
66	131	132	10.02	20.29	10.02	21.17
67	133	134	10.02	20.29	11.52	20.29
68	135	136	10.02	5.39	11.02	5.39
69	137	138	11.52	10.02	11.52	11.52
70	139	140	16.16	10.02	16.16	11.52
71	141	142	20.29	5.39	21.17	5.39
72	143	144	20.29	10.02	21.17	10.02
73	145	146	10.02	16.16	11.52	16.16
74	147	148	20.29	10.02	20.29	11.52
75	149	150	10.24	31.11	10.02	30.44
76	151	152	31.11	10.24	30.44	10.02
77	153	154	-5.39	11.02	-5.39	10.02
78	155	156	-5.39	20.29	-5.39	21.17
79	157	158	-10.02	11.02	-10.02	10.02
80	159	160	-10.02	10.02	-11.02	10.02
81	161	162	-10.02	11.52	-11.52	11.52
82	163	164	-10.02	20.29	-10.02	21.17
83	165	166	-10.02	20.29	-11.52	20.29
84	167	168	-10.02	5.39	-11.02	5.39
85	169	170	-11.52	10.02	-11.52	11.52
86	171	172	-16.16	10.02	-16.16	11.52
87	173	174	-20.29	5.39	-21.17	5.39
88	175	176	-20.29	10.02	-21.17	10.02
89	177	178	-10.02	16.16	-11.52	16.16
90	179	180	-20.29	10.02	-20.29	11.52

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.

Table 3.4.4.1-11 Listing of Sections for Stress Evaluation of PWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
91	181	182	-10.24	31.11	-10.02	30.44
92	183	184	-31.11	10.24	-30.44	10.02
93	185	186	-5.39	-11.02	-5.39	-10.02
94	187	188	-5.39	-20.29	-5.39	-21.17
95	189	190	-10.02	-11.02	-10.02	-10.02
96	191	192	-10.02	-10.02	-11.02	-10.02
97	193	194	-10.02	-11.52	-11.52	-11.52
98	195	196	-10.02	-20.29	-10.02	-21.17
99	197	198	-10.02	-20.29	-11.52	-20.29
100	199	200	-10.02	-5.39	-11.02	-5.39
101	201	202	-11.52	-10.02	-11.52	-11.52
102	203	204	-16.16	-10.02	-16.16	-11.52
103	205	206	-20.29	-5.39	-21.17	-5.39
104	207	208	-20.29	-10.02	-21.17	-10.02
105	209	210	-10.02	-16.16	-11.52	-16.16
106	211	212	-20.29	-10.02	-20.29	-11.52
107	213	214	-10.24	-31.11	-10.02	-30.44
108	215	216	-31.11	-10.24	-30.44	-10.02
109	217	218	5.39	-11.02	5.39	-10.02
110	219	220	5.39	-20.29	5.39	-21.17
111	221	222	10.02	-11.02	10.02	-10.02
112	223	224	10.02	-10.02	11.02	-10.02
113	225	226	10.02	-11.52	11.52	-11.52
114	227	228	10.02	-20.29	10.02	-21.17
115	229	230	10.02	-20.29	11.52	-20.29
116	231	232	10.02	-5.39	11.02	-5.39
117	233	234	11.52	-10.02	11.52	-11.52
118	235	236	16.16	-10.02	16.16	-11.52
119	237	238	20.29	-5.39	21.17	-5.39
120	239	240	20.29	-10.02	21.17	-10.02
121	241	242	10.02	-16.16	11.52	-16.16
122	243	244	20.29	-10.02	20.29	-11.52
123	245	246	10.24	-31.11	10.02	-30.44
124	247	248	31.11	-10.24	30.44	-10.02

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.

Table 3.4.4.1-12 $P_m + P_b$ Stresses for PWR Support Disk - Normal Conditions (ksi)

Section[1]	Sx	Sy	Sxy	Stress Intensity	Allow. Stress	Margin of Safety
66	0.7	0.3	0.3	0.8	52.7	64.8
72	0.3	0.7	0.3	0.8	52.7	64.8
120	0.3	0.7	-0.3	0.8	52.7	64.8
82	0.7	0.3	-0.3	0.8	52.7	64.8
12	-0.4	0.2	0.0	0.6	52.7	86.8
28	-0.4	0.2	0.0	0.6	52.7	86.8
26	-0.4	0.2	0.0	0.6	52.7	86.8
54	0.2	-0.4	0.0	0.6	52.7	86.8
14	-0.4	0.2	0.0	0.6	52.7	86.8
42	0.2	-0.4	0.0	0.6	52.7	86.8
40	0.2	-0.4	0.0	0.6	52.7	86.8
56	0.2	-0.4	0.0	0.6	52.7	86.8
90	0.4	0.1	-0.2	0.5	52.7	104.3
67	0.1	0.4	0.2	0.5	52.7	104.3
99	0.1	0.4	0.2	0.5	52.7	104.3
106	0.4	0.1	0.2	0.5	52.7	104.3
122	0.4	0.1	-0.2	0.5	52.7	104.3
74	0.4	0.1	0.2	0.5	52.7	104.3
83	0.1	0.4	-0.2	0.5	52.7	104.3
115	0.1	0.4	-0.2	0.5	52.7	104.3
88	0.2	0.2	-0.3	0.5	52.7	104.3
114	0.2	0.2	-0.3	0.5	52.7	104.3
104	0.2	0.2	0.2	0.5	52.7	104.3
98	0.2	0.2	0.2	0.5	52.7	104.3
4	-0.2	-0.4	-0.1	0.4	52.7	130.6
2	-0.2	-0.4	-0.1	0.4	52.7	130.6
3	-0.4	-0.2	-0.1	0.4	52.7	130.6
1	-0.4	-0.2	-0.1	0.4	52.7	130.6
37	-0.1	-0.4	0.1	0.4	52.7	130.6
35	-0.1	-0.4	-0.1	0.4	52.7	130.6
7	-0.4	-0.1	-0.1	0.4	52.7	130.6
49	-0.1	-0.4	0.1	0.4	52.7	130.6
51	-0.1	-0.4	-0.1	0.4	52.7	130.6
23	-0.4	-0.1	-0.1	0.4	52.7	130.6
21	-0.4	-0.1	0.1	0.4	52.7	130.6
9	-0.4	-0.1	0.1	0.4	52.7	130.6
11	-0.2	0.2	-0.1	0.4	52.7	130.6
25	-0.2	0.2	-0.1	0.4	52.7	130.6
53	0.2	-0.2	0.1	0.4	52.7	130.6
39	0.2	-0.2	0.1	0.4	52.7	130.6

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.
2. Stress allowables are taken at 800°F.

Table 3.4.4.1-13 $P_m + P_b + Q$ Stresses for the PWR Support Disk - Normal Conditions (ksi)

Section[1]	Sx	Sy	Sxy	Stress Intensity	Allow. Stress	Margin of Safety
44	-6.9	-29.3	6.1	30.8	105.3	2.42
58	-6.9	-29.3	6.1	30.8	105.3	2.42
75	23.5	2.2	-4.3	24.3	105.3	3.33
107	23.5	2.2	-4.2	24.3	105.3	3.33
108	2.1	23.3	-4.2	24.1	105.3	3.37
76	2.1	23.2	-4.1	24.0	105.3	3.39
123	20.6	2.0	5.4	22.1	105.3	3.76
124	1.9	20.6	5.4	22.1	105.3	3.76
92	1.8	20.6	5.3	22.0	105.3	3.79
91	20.5	1.9	5.4	22.0	105.3	3.79
7	-20.1	-6.7	-2.3	20.5	105.3	4.14
23	-20.1	-6.7	-2.3	20.5	105.3	4.14
49	-6.6	-20.0	2.3	20.4	105.3	4.16
37	-6.6	-20.0	2.3	20.4	105.3	4.16
9	-20.0	-6.7	2.3	20.4	105.3	4.16
21	-20.0	-6.7	2.3	20.4	105.3	4.16
35	-6.7	-20.0	-2.3	20.4	105.3	4.16
51	-6.7	-20.0	-2.3	20.4	105.3	4.16
17	20.6	-0.4	-1.2	21.1	105.3	3.99
32	20.6	-0.4	-1.2	21.1	105.3	3.99
45	-0.5	19.9	-1.4	20.7	105.3	4.09
60	-0.5	19.9	-1.4	20.7	105.3	4.09
80	-7.7	-19.5	2.4	19.9	105.3	4.29
112	-7.7	-19.5	2.4	19.9	105.3	4.29
31	19.6	-0.4	1.6	20.3	105.3	4.19
18	19.6	-0.4	1.6	20.3	105.3	4.19
79	-19.4	-7.6	2.3	19.9	105.3	4.29
111	-19.4	-7.6	2.3	19.9	105.3	4.29
95	-19.0	-7.7	-2.2	19.4	105.3	4.43
63	-19.0	-7.7	-2.2	19.4	105.3	4.43
96	-7.7	-18.8	-2.2	19.3	105.3	4.46
64	-7.7	-18.8	-2.2	19.3	105.3	4.46
59	-2.0	16.6	0.4	18.6	105.3	4.66
46	-2.0	16.6	0.4	18.6	105.3	4.66
30	-10.5	-11.3	4.5	15.3	105.3	5.88
16	-10.5	-11.3	4.5	15.3	105.3	5.88
6	-11.1	-9.3	-4.1	14.4	105.3	6.31
20	-11.1	-9.3	-4.1	14.4	105.3	6.31
48	-9.3	-11.0	-4.1	14.3	105.3	6.36
34	-9.3	-11.0	-4.1	14.3	105.3	6.36

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.
2. Stress allowables are taken at 800°F.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
1	1	2	32.74	0.33	30.85	0.33
2	3	4	32.74	-0.33	30.85	-0.33
3	5	6	-32.74	0.33	-30.85	0.33
4	7	8	-32.74	-0.33	-30.85	-0.33
5	9	10	32.03	6.85	30.85	6.6
6	11	12	32.03	-6.85	30.85	-6.6
7	13	14	-32.03	6.85	-30.85	6.6
8	15	16	-32.03	-6.85	-30.85	-6.6
9	17	18	24.87	21.30	23.89	20.46
10	19	20	24.87	-21.30	23.89	-20.46
11	21	22	-24.87	21.30	-23.89	20.46
12	23	24	-24.87	-21.30	-23.89	-20.46
13	25	26	17.27	27.83	17.00	27.39
14	27	28	-17.27	27.83	-17.00	27.39
15	29	30	-17.27	-27.83	-17.00	-27.39
16	31	32	17.27	-27.83	17.00	-27.39
17	33	34	0	0.33	0	-0.33
18	35	36	3.14	0.33	3.14	-0.33
19	37	38	3.79	0.33	3.79	-0.33
20	39	40	6.93	0.33	6.93	-0.33
21	41	42	10.07	0.33	10.07	-0.33
22	43	44	10.72	0.33	10.72	-0.33
23	45	46	13.86	0.33	13.86	-0.33
24	47	48	17	0.33	17	-0.33
25	49	50	17.65	0.33	17.65	-0.33
26	51	52	20.78	0.33	20.78	-0.33
27	53	54	23.92	0.33	23.92	-0.33
28	55	56	24.57	0.33	24.57	-0.33
29	57	58	27.71	0.33	27.71	-0.33
30	59	60	30.85	0.33	30.85	-0.33
31	61	62	-3.14	0.33	-3.14	-0.33
32	63	64	-3.79	0.33	-3.79	-0.33
33	65	66	-6.93	0.33	-6.93	-0.33
34	67	68	-10.07	0.33	-10.07	-0.33
35	69	70	-10.72	0.33	-10.72	-0.33
36	71	72	-13.86	0.33	-13.86	-0.33
37	73	74	-17	0.33	-17	-0.33
38	75	76	-17.65	0.33	-17.65	-0.33
39	77	78	-20.78	0.33	-20.78	-0.33
40	79	80	-23.92	0.33	-23.92	-0.33
41	81	82	-24.57	0.33	-24.57	-0.33
42	83	84	-27.71	0.33	-27.71	-0.33
43	85	86	-30.85	0.33	-30.85	-0.33
44	87	88	0	7.25	0	6.6
45	89	90	3.14	7.25	3.14	6.6
46	91	92	3.79	7.25	3.79	6.6
47	93	94	6.93	7.25	6.93	6.6
48	95	96	10.07	7.25	10.07	6.6
49	97	98	10.72	7.25	10.72	6.6
50	99	100	13.86	7.25	13.86	6.6

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
51	101	102	17	7.25	17	6.6
52	103	104	17.65	7.25	17.65	6.6
53	105	106	20.78	7.25	20.78	6.6
54	107	108	23.92	7.25	23.92	6.6
55	109	110	0	13.53	0	14.18
56	111	112	3.14	13.53	3.14	14.18
57	113	114	3.79	13.53	3.79	14.18
58	115	116	6.93	13.53	6.93	14.18
59	117	118	10.07	13.53	10.07	14.18
60	119	120	10.72	13.53	10.72	14.18
61	121	122	13.86	13.53	13.86	14.18
62	123	124	17	13.53	17	14.18
63	125	126	17.65	13.53	17.65	14.18
64	127	128	20.78	13.53	20.78	14.18
65	129	130	23.92	13.53	23.92	14.18
66	131	132	0	21.11	0	20.46
67	133	134	3.14	21.11	3.14	20.46
68	135	136	3.79	21.11	3.79	20.46
69	137	138	6.93	21.11	6.93	20.46
70	139	140	10.07	21.11	10.07	20.46
71	141	142	10.72	21.11	10.72	20.46
72	143	144	13.86	21.11	13.86	20.46
73	145	146	17	21.11	17	20.46
74	147	148	3.14	0.33	3.79	0.33
75	149	150	10.07	0.33	10.72	0.33
76	151	152	17	0.33	17.65	0.33
77	153	154	23.92	0.33	24.57	0.33
78	155	156	3.14	3.46	3.79	3.46
79	157	158	10.07	3.46	10.72	3.46
80	159	160	17	3.46	17.65	3.46
81	161	162	23.92	3.46	24.57	3.46
82	163	164	3.14	6.6	3.79	6.6
83	165	166	10.07	6.6	10.72	6.6
84	167	168	17	6.6	17.65	6.6
85	169	170	23.92	6.6	24.57	6.6
86	171	172	3.14	7.25	3.79	7.25
87	173	174	10.07	7.25	10.72	7.25
88	175	176	17	7.25	17.65	7.25
89	177	178	3.14	10.39	3.79	10.39
90	179	180	10.07	10.39	10.72	10.39
91	181	182	17	10.39	17.65	10.39
92	183	184	3.14	13.53	3.79	13.53
93	185	186	10.07	13.53	10.72	13.53
94	187	188	17	13.53	17.65	13.53
95	189	190	3.14	14.18	3.79	14.18
96	191	192	10.07	14.18	10.72	14.18
97	193	194	17	14.18	17.65	14.18
98	195	196	3.14	17.32	3.79	17.32
99	197	198	10.07	17.32	10.72	17.32
100	199	200	17	17.32	17.65	17.32

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
101	201	202	3.14	20.46	3.79	20.46
102	203	204	10.07	20.46	10.72	20.46
103	205	206	17	20.46	17.65	20.46
104	207	208	3.14	21.11	3.79	21.11
105	209	210	10.07	21.11	10.72	21.11
106	211	212	3.14	24.25	3.79	24.25
107	213	214	10.07	24.25	10.72	24.25
108	215	216	3.14	27.39	3.79	27.39
109	217	218	10.07	27.39	10.72	27.39
110	219	220	-3.14	7.25	-3.14	6.6
111	221	222	-3.79	7.25	-3.79	6.6
112	223	224	-6.93	7.25	-6.93	6.6
113	225	226	-10.07	7.25	-10.07	6.6
114	227	228	-10.72	7.25	-10.72	6.6
115	229	230	-13.86	7.25	-13.86	6.6
116	231	232	-17	7.25	-17	6.6
117	233	234	-17.65	7.25	-17.65	6.6
118	235	236	-20.78	7.25	-20.78	6.6
119	237	238	-23.92	7.25	-23.92	6.6
120	239	240	-3.14	13.53	-3.14	14.18
121	241	242	-3.79	13.53	-3.79	14.18
122	243	244	-6.93	13.53	-6.93	14.18
123	245	246	-10.07	13.53	-10.07	14.18
124	247	248	-10.72	13.53	-10.72	14.18
125	249	250	-13.86	13.53	-13.86	14.18
126	251	252	-17	13.53	-17	14.18
127	253	254	-17.65	13.53	-17.65	14.18
128	255	256	-20.78	13.53	-20.78	14.18
129	257	258	-23.92	13.53	-23.92	14.18
130	259	260	-3.14	21.11	-3.14	20.46
131	261	262	-3.79	21.11	-3.79	20.46
132	263	264	-6.93	21.11	-6.93	20.46
133	265	266	-10.07	21.11	-10.07	20.46
134	267	268	-10.72	21.11	-10.72	20.46
135	269	270	-13.86	21.11	-13.86	20.46
136	271	272	-17	21.11	-17	20.46
137	273	274	-3.14	0.33	-3.79	0.33
138	275	276	-10.07	0.33	-10.72	0.33
139	277	278	-17	0.33	-17.65	0.33
140	279	280	-23.92	0.33	-24.57	0.33
141	281	282	-3.14	3.46	-3.79	3.46
142	283	284	-10.07	3.46	-10.72	3.46
143	285	286	-17	3.46	-17.65	3.46
144	287	288	-23.92	3.46	-24.57	3.46
145	289	290	-3.14	6.6	-3.79	6.6
146	291	292	-10.07	6.6	-10.72	6.6
147	293	294	-17	6.6	-17.65	6.6
148	295	296	-23.92	6.6	-24.57	6.6
149	297	298	-3.14	7.25	-3.79	7.25
150	299	300	-10.07	7.25	-10.72	7.25

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
151	301	302	-17	7.25	-17.65	7.25
152	303	304	-3.14	10.39	-3.79	10.39
153	305	306	-10.07	10.39	-10.72	10.39
154	307	308	-17	10.39	-17.65	10.39
155	309	310	-3.14	13.53	-3.79	13.53
156	311	312	-10.07	13.53	-10.72	13.53
157	313	314	-17	13.53	-17.65	13.53
158	315	316	-3.14	14.18	-3.79	14.18
159	317	318	-10.07	14.18	-10.72	14.18
160	319	320	-17	14.18	-17.65	14.18
161	321	322	-3.14	17.32	-3.79	17.32
162	323	324	-10.07	17.32	-10.72	17.32
163	325	326	-17	17.32	-17.65	17.32
164	327	328	-3.14	20.46	-3.79	20.46
165	329	330	-10.07	20.46	-10.72	20.46
166	331	332	-17	20.46	-17.65	20.46
167	333	334	-3.14	21.11	-3.79	21.11
168	335	336	-10.07	21.11	-10.72	21.11
169	337	338	-3.14	24.25	-3.79	24.25
170	339	340	-10.07	24.25	-10.72	24.25
171	341	342	-3.14	27.39	-3.79	27.39
172	343	344	-10.07	27.39	-10.72	27.39
173	345	346	-3.14	-7.25	-3.14	-6.6
174	347	348	-3.79	-7.25	-3.79	-6.6
175	349	350	-6.93	-7.25	-6.93	-6.6
176	351	352	-10.07	-7.25	-10.07	-6.6
177	353	354	-10.72	-7.25	-10.72	-6.6
178	355	356	-13.86	-7.25	-13.86	-6.6
179	357	358	-17	-7.25	-17	-6.6
180	359	360	-17.65	-7.25	-17.65	-6.6
181	361	362	-20.78	-7.25	-20.78	-6.6
182	363	364	-23.92	-7.25	-23.92	-6.6
183	365	366	-3.14	-13.53	-3.14	-14.18
184	367	368	-3.79	-13.53	-3.79	-14.18
185	369	370	-6.93	-13.53	-6.93	-14.18
186	371	372	-10.07	-13.53	-10.07	-14.18
187	373	374	-10.72	-13.53	-10.72	-14.18
188	375	376	-13.86	-13.53	-13.86	-14.18
189	377	378	-17	-13.53	-17	-14.18
190	379	380	-17.65	-13.53	-17.65	-14.18
191	381	382	-20.78	-13.53	-20.78	-14.18
192	383	384	-23.92	-13.53	-23.92	-14.18
193	385	386	-3.14	-21.11	-3.14	-20.46
194	387	388	-3.79	-21.11	-3.79	-20.46
195	389	390	-6.93	-21.11	-6.93	-20.46
196	391	392	-10.07	-21.11	-10.07	-20.46
197	393	394	-10.72	-21.11	-10.72	-20.46
198	395	396	-13.86	-21.11	-13.86	-20.46
199	397	398	-17	-21.11	-17	-20.46
200	399	400	-3.14	-0.33	-3.79	-0.33

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1		Point 2	
			X	Y	X	Y
201	401	402	-10.07	-0.33	-10.72	-0.33
202	403	404	-17	-0.33	-17.65	-0.33
203	405	406	-23.92	-0.33	-24.57	-0.33
204	407	408	-3.14	-3.46	-3.79	-3.46
205	409	410	-10.07	-3.46	-10.72	-3.46
206	411	412	-17	-3.46	-17.65	-3.46
207	413	414	-23.92	-3.46	-24.57	-3.46
208	415	416	-3.14	-6.6	-3.79	-6.6
209	417	418	-10.07	-6.6	-10.72	-6.6
210	419	420	-17	-6.6	-17.65	-6.6
211	421	422	-23.92	-6.6	-24.57	-6.6
212	423	424	-3.14	-7.25	-3.79	-7.25
213	425	426	-10.07	-7.25	-10.72	-7.25
214	427	428	-17	-7.25	-17.65	-7.25
215	429	430	-3.14	-10.39	-3.79	-10.39
216	431	432	-10.07	-10.39	-10.72	-10.39
217	433	434	-17	-10.39	-17.65	-10.39
218	435	436	-3.14	-13.53	-3.79	-13.53
219	437	438	-10.07	-13.53	-10.72	-13.53
220	439	440	-17	-13.53	-17.65	-13.53
221	441	442	-3.14	-14.18	-3.79	-14.18
222	443	444	-10.07	-14.18	-10.72	-14.18
223	445	446	-17	-14.18	-17.65	-14.18
224	447	448	-3.14	-17.32	-3.79	-17.32
225	449	450	-10.07	-17.32	-10.72	-17.32
226	451	452	-17	-17.32	-17.65	-17.32
227	453	454	-3.14	-20.46	-3.79	-20.46
228	455	456	-10.07	-20.46	-10.72	-20.46
229	457	458	-17	-20.46	-17.65	-20.46
230	459	460	-3.14	-21.11	-3.79	-21.11
231	461	462	-10.07	-21.11	-10.72	-21.11
232	463	464	-3.14	-24.25	-3.79	-24.25
233	465	466	-10.07	-24.25	-10.72	-24.25
234	467	468	-3.14	-27.39	-3.79	-27.39
235	469	470	-10.07	-27.39	-10.72	-27.39
236	471	472	0	-7.25	0	-6.6
237	473	474	3.14	-7.25	3.14	-6.6
238	475	476	3.79	-7.25	3.79	-6.6
239	477	478	6.93	-7.25	6.93	-6.6
240	479	480	10.07	-7.25	10.07	-6.6
241	481	482	10.72	-7.25	10.72	-6.6
242	483	484	13.86	-7.25	13.86	-6.6
243	485	486	17	-7.25	17	-6.6
244	487	488	17.65	-7.25	17.65	-6.6
245	489	490	20.78	-7.25	20.78	-6.6
246	491	492	23.92	-7.25	23.92	-6.6
247	493	494	0	-13.53	0	-14.18
248	495	496	3.14	-13.53	3.14	-14.18
249	497	498	3.79	-13.53	3.79	-14.18
250	499	500	6.93	-13.53	6.93	-14.18

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-14 Listing of Sections for Stress Evaluation of BWR Support Disk (Continued)

Section Number[1]	Point 1	Point 2	Point 1 X	Point 1 Y	Point 2 X	Point 2 Y
251	501	502	10.07	-13.53	10.07	-14.18
252	503	504	10.72	-13.53	10.72	-14.18
253	505	506	13.86	-13.53	13.86	-14.18
254	507	508	17	-13.53	17	-14.18
255	509	510	17.65	-13.53	17.65	-14.18
256	511	512	20.78	-13.53	20.78	-14.18
257	513	514	23.92	-13.53	23.92	-14.18
258	515	516	0	-21.11	0	-20.46
259	517	518	3.14	-21.11	3.14	-20.46
260	519	520	3.79	-21.11	3.79	-20.46
261	521	522	6.93	-21.11	6.93	-20.46
262	523	524	10.07	-21.11	10.07	-20.46
263	525	526	10.72	-21.11	10.72	-20.46
264	527	528	13.86	-21.11	13.86	-20.46
265	529	530	17	-21.11	17	-20.46
266	531	532	3.14	-0.33	3.79	-0.33
267	533	534	10.07	-0.33	10.72	-0.33
268	535	536	17	-0.33	17.65	-0.33
269	537	538	23.92	-0.33	24.57	-0.33
270	539	540	3.14	-3.46	3.79	-3.46
271	541	542	10.07	-3.46	10.72	-3.46
272	543	544	17	-3.46	17.65	-3.46
273	545	546	23.92	-3.46	24.57	-3.46
274	547	548	3.14	-6.6	3.79	-6.6
275	549	550	10.07	-6.6	10.72	-6.6
276	551	552	17	-6.6	17.65	-6.6
277	553	554	23.92	-6.6	24.57	-6.6
278	555	556	3.14	-7.25	3.79	-7.25
279	557	558	10.07	-7.25	10.72	-7.25
280	559	560	17	-7.25	17.65	-7.25
281	561	562	3.14	-10.39	3.79	-10.39
282	563	564	10.07	-10.39	10.72	-10.39
283	565	566	17	-10.39	17.65	-10.39
284	567	568	3.14	-13.53	3.79	-13.53
285	569	570	10.07	-13.53	10.72	-13.53
286	571	572	17	-13.53	17.65	-13.53
287	573	574	3.14	-14.18	3.79	-14.18
288	575	576	10.07	-14.18	10.72	-14.18
289	577	578	17	-14.18	17.65	-14.18
290	579	580	3.14	-17.32	3.79	-17.32
291	581	582	10.07	-17.32	10.72	-17.32
292	583	584	17	-17.32	17.65	-17.32
293	585	586	3.14	-20.46	3.79	-20.46
294	587	588	10.07	-20.46	10.72	-20.46
295	589	590	17	-20.46	17.65	-20.46
296	591	592	3.14	-21.11	3.79	-21.11
297	593	594	10.07	-21.11	10.72	-21.11
298	595	596	3.14	-24.25	3.79	-24.25
299	597	598	10.07	-24.25	10.72	-24.25
300	599	600	3.14	-27.39	3.79	-27.39
301	601	602	10.07	-27.39	10.72	-27.39

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.

Table 3.4.4.1-15 $P_m + P_b$ Stresses for BWR Support Disk - Normal Conditions (ksi)

Section[1]	Sx	Sy	Sxy	Stress Intensity	Allow. Stress	Margin of Safety
129	1.0	0.3	0.2	1.0	40.5	39.5
54	1.0	0.2	0.2	1.0	40.5	39.5
171	0.2	1.0	0.1	1.0	40.5	39.5
300	0.2	1.0	0.1	1.0	40.5	39.5
65	0.9	0.3	-0.2	1.0	40.5	39.5
192	0.9	0.3	-0.2	1.0	40.5	39.5
257	0.8	0.4	-0.3	1.0	40.5	39.5
234	0.2	0.9	-0.1	1.0	40.5	39.5
108	0.2	0.9	-0.1	1.0	40.5	39.5
119	0.9	0.2	-0.2	1.0	40.5	39.5
246	0.9	0.2	-0.2	0.9	40.5	44.0
182	0.9	0.2	0.2	0.9	40.5	44.0
103	0.3	0.3	0.2	0.5	40.5	80.0
229	0.2	0.3	0.2	0.5	40.5	80.0
109	-0.1	0.4	0.0	0.5	40.5	80.0
77	0.2	-0.3	0.1	0.5	40.5	80.0
203	0.2	-0.3	0.1	0.5	40.5	80.0
140	0.2	-0.3	-0.1	0.5	40.5	80.0
295	0.2	0.3	-0.2	0.5	40.5	80.0
269	0.2	-0.3	-0.1	0.5	40.5	80.0
166	0.2	0.3	-0.2	0.5	40.5	80.0
301	-0.1	0.4	0.0	0.5	40.5	80.0
172	-0.1	0.4	0.0	0.5	40.5	80.0
134	0.0	0.2	-0.2	0.5	40.5	80.0
263	0.0	0.2	-0.2	0.5	40.5	80.0
197	0.0	0.2	0.2	0.5	40.5	80.0
71	0.0	0.2	0.2	0.5	40.5	80.0
235	-0.1	0.4	0.0	0.5	40.5	80.0
27	0.3	-0.2	-0.1	0.5	40.5	80.0
165	-0.2	-0.1	-0.2	0.5	40.5	80.0
228	-0.2	-0.1	0.2	0.5	40.5	80.0
294	-0.2	-0.1	-0.2	0.5	40.5	80.0
40	0.3	-0.2	0.1	0.5	40.5	80.0
102	-0.2	-0.1	0.2	0.5	40.5	80.0
73	0.1	0.3	0.2	0.5	40.5	80.0
199	0.1	0.3	0.2	0.5	40.5	80.0
124	-0.4	-0.1	-0.2	0.4	40.5	100.3
252	-0.4	-0.1	-0.2	0.4	40.5	100.3
60	-0.4	-0.1	0.2	0.4	40.5	100.3
187	-0.4	-0.1	0.2	0.4	40.5	100.3

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.
2. Stress allowables are taken at 800°F.

Table 3.4.4.1-16 $P_m + P_b + Q$ Stresses for BWR Support Disk - Normal Conditions (ksi)

Section[1]	Sx	Sy	Sxy	Stress Intensity	Allow. Stress	Margin of Safety
30	-8.8	-16.9	2.7	17.7	81.0	3.58
15	14.2	5.0	-6.4	17.4	81.0	3.66
43	-9.0	-16.6	2.7	17.4	81.0	3.66
13	14.0	5.1	-6.4	17.4	81.0	3.66
16	15.1	4.2	5.1	17.1	81.0	3.74
14	15.0	4.3	5.1	17.1	81.0	3.74
1	-1.8	14.0	-1.0	15.8	81.0	4.13
2	-1.8	14.0	-1.0	15.8	81.0	4.13
3	-1.8	13.9	-0.9	15.7	81.0	4.16
4	-1.8	13.9	-0.9	15.7	81.0	4.16
268	-7.4	-15.3	1.9	15.7	81.0	4.16
139	-7.4	-15.2	1.9	15.6	81.0	4.19
202	-7.4	-15.2	-1.9	15.6	81.0	4.19
76	-7.4	-15.2	-1.9	15.6	81.0	4.19
295	-0.6	-15.5	1.0	15.6	81.0	4.19
166	-0.5	-15.5	0.9	15.5	81.0	4.23
229	-0.8	-15.3	-1.0	15.4	81.0	4.26
103	-0.8	-15.3	-0.9	15.3	81.0	4.29
289	-4.4	-14.5	1.2	14.6	81.0	4.55
223	-4.5	-14.4	-1.2	14.6	81.0	4.55
160	-4.4	-14.4	1.2	14.5	81.0	4.59
97	-4.5	-14.4	-1.2	14.5	81.0	4.59
276	-5.6	-14.0	1.3	14.2	81.0	4.70
147	-5.6	-14.0	1.3	14.2	81.0	4.70
210	-5.5	-13.9	-1.3	14.1	81.0	4.74
84	-5.5	-13.9	-1.3	14.1	81.0	4.74
269	-6.7	-13.5	1.7	13.8	81.0	4.87
77	-6.5	-13.5	-1.6	13.8	81.0	4.87
140	-6.7	-13.5	1.7	13.8	81.0	4.87
203	-6.6	-13.5	-1.6	13.8	81.0	4.87
266	-8.3	-12.9	2.0	13.7	81.0	4.91
137	-8.3	-12.9	2.0	13.7	81.0	4.91
74	-8.2	-12.8	-2.0	13.6	81.0	4.96
18	-12.6	-7.2	2.4	13.6	81.0	4.96
200	-8.2	-12.8	-2.0	13.5	81.0	5.00
31	-12.6	-7.2	2.4	13.5	81.0	5.00
199	-13.0	-6.4	-1.5	13.3	81.0	5.09
73	-12.9	-6.3	-1.5	13.2	81.0	5.14
34	-12.4	-6.2	2.2	13.1	81.0	5.18
21	-12.4	-6.2	2.2	13.1	81.0	5.18

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.
2. Stress allowables are taken at 800°F.

Table 3.4.4.1-17 Summary of Maximum Stresses for PWR and BWR Fuel Basket Weldments - Normal Conditions (ksi)

Component	Stress Category	Maximum Stress Intensity[1]	Node Temperature (°F)	Stress Allowable[2]	Margin of Safety
PWR Top Weldment	$P_m + P_b$	0.5	297	28.1	+Large
	$P_m + P_b + Q$	52.4	292	56.1	0.07
PWR Bottom Weldment	$P_m + P_b$	0.6	179	30.0	+Large
	$P_m + P_b + Q$	20.9	175	60.0	+1.87
BWR Top Weldment	$P_m + P_b$	0.8	226	26.3	+Large
	$P_m + P_b + Q$	14.2	383	52.5	+Large
BWR Bottom Weldment	$P_m + P_b$	0.9	269	26.7	+Large
	$P_m + P_b + Q$	36.6	203	53.4	0.64

1. Nodal stresses are from the finite element analysis.
2. Conservatively, stress allowables are taken at 400°F for the PWR top weldment, 300°F for the PWR bottom weldment, 500°F for the BWR top weldment, and 300°F for the BWR bottom weldment.

3.4.4.2 Vertical Concrete Cask Analyses

The stresses in the concrete cask are evaluated in this section for normal conditions of storage. The evaluation for the steel base plate at the bottom of the cask is presented in Section 3.4.3.1. The stresses in the concrete due to dead load, live load, and thermal load are calculated in this section. The evaluations for off-normal and accident loading conditions are presented in Chapter 11.0. The radial dimensions of the concrete cask are the same for all cask configurations, only the height of the cask varies. Thus, the temperature differences through the concrete for all cask configurations vary only as a function of the heat source. Using the model described in this section, thermal analyses were run for both the maximum BWR and PWR heat loads for normal, off-normal, and accident conditions. The results of these analyses showed that the maximum temperature differences across the concrete cask wall occurred under normal operating conditions (76°F, with a 1.275 load factor) for the BWR casks and under accident conditions (133°F, with a load factor of 1.0) for the PWR casks. Thus, the structural analyses in this chapter use the temperature gradients from the BWR cask at 76°F and the analyses in Chapter 11 use the temperature differences for the PWR cask at 133°F. A summary of calculated stresses for the load combinations defined in Table 2.2-1 is presented in Table 3.4.4.2-1. As shown in Table 3.4.4.2-2, the concrete cask meets the structural requirements of ACI-349-85 [4].

The structural evaluation of the Universal Storage System is based on consideration of the bounding conditions for each aspect of the analysis. Generally, the bounding condition is represented by the component, or combination of components, of each configuration that is the heaviest. For reference, the bounding case used in each of the structural evaluations is presented in the following table.

Section	Aspect Evaluated	Bounding Condition	Configuration
3.4.4.2.1	Dead Load	Heaviest concrete cask	PWR Class 3
3.4.4.2.2	Live Load	Heaviest loaded transfer cask	BWR Class 5
	Snow Load	Same for all configurations	Not Applicable
3.4.4.2.3	Thermal Load	Highest temperature gradient under normal conditions	BWR Class 4

3.4.4.2.1 Dead Load

The concrete cask dead load evaluation is based on the PWR Class 3 concrete cask, which is the heaviest concrete cask. The weight used in this analysis bounds the calculated weight of the PWR Class 3 concrete cask, as shown in Tables 3.2-1 and 3.2-2. The dead load of the cask concrete is resisted by the lower concrete surface only. The concrete compression stress due to the weight of the concrete cask is:

$\sigma_v = -W/A = -25.6$ psi (compression)
(30.0 psi conservatively used in the loading combination, Table 3.4.4.2-1)

where:

W = 245,000 lb concrete cask bounding dead weight (maximum calculated weight = 238,400 lb)
OD = 136 in. concrete exterior diameter
ID = 79.5 in. concrete interior diameter
A $= \pi (OD^2 - ID^{2)} / 4 = 9{,}563$ in.^{2}

This evaluation of stress at the base of the concrete conservatively considers the weight of the empty concrete cask, rather than the concrete alone. The weight of the canister is not supported by the concrete.

3.4.4.2.2 Live Load

The concrete cask is subjected to two live loads: the snow load and the weight of the fully loaded transfer cask resting atop the concrete cask. These loads are conservatively assumed to be applied to the concrete portion of the cask. No loads are assumed to be taken by the concrete cask's steel liner. The loads from the canister and its contents are transferred to the steel support inside the concrete cask and are not applied to the concrete. The stress in the steel support is evaluated in Section 3.4.3.1. Under these conditions, the only stress component is the vertical compression stress.

Snow Load

The calculated snow load and the resulting stresses are the same for all five of the concrete cask configurations because the top surface areas are the same for all configurations. The snow load on the concrete cask is determined in accordance with ANSI/ASCE 7-93 [30].

The uniformly distributed snow load on the top of the concrete cask, P_f, is

$$P_f = 0.70\, C_e\, C_t\, I\, P_g = 101 \text{ lbf/ft}^2$$

The concrete cask top area,

$$A_{top} = \pi\, (D/2)^2 = 14{,}527 \text{ in.}^2 = 101 \text{ ft}^2$$

The maximum snow load, F_s, is,

$$F_s = P_f \times A_{top} = 101 \text{ lbf/ft}^2 \times (101 \text{ ft}^2) = 10{,}201 \text{ lbf.}$$

The snow load is uniformly distributed over the top surface of the concrete cask. This load is negligible.

Transfer Cask Load

The live load of the heaviest loaded transfer cask is bounded by the weight used in this analysis, which is much greater than the weight of the maximum postulated snow load. Consequently, the stress due to the snow load is bounded by the stress due to the weight of the heaviest transfer cask. As with the snow load, the calculated transfer cask load, and the resulting stresses, are the same for all five of the concrete cask configurations because the top surface areas are the same for all configurations.

W $\approx$ 210,000 lb-transfer cask weight (fully loaded)
D = 136 in.-concrete exterior diameter
ID = 79.5 in.-concrete interior diameter
A = $\pi (D^2 - ID^2)/4$ = 9563 in.^{2}

Compression stress at the base of the concrete is:

σ_v = W/A = -21.9 psi (compressive)
(25.0 psi conservatively used in loading combination, Table 3.4.4.2-1)

3.4.4.2.3 Thermal Load

A three dimensional finite element model, shown in Figure 3.4.4.2-1, comprised of SOLID45, LINK8 (elements which support uniaxial loads only—no bending), and CONTAC52 elements was used to determine the stresses in the concrete cask due to thermal expansion. The SOLID45 elements represented the concrete while the LINK8 elements were used to represent the hoop and the vertical reinforcement bars. The model of the reinforcement bars is shown in Figure 3.4.4.2-2. The concrete cask has two sets of vertical reinforcement. At the inner radius of the concrete cask, there are 36 sets of vertical reinforcement, while at the outer radius, 56 sets of vertical reinforcement are used. The finite element model is a 1/56th circumferential model (or 360/56 = 6.42°), and the vertical reinforcement is modeled at the angular center of the model. To compensate for the smaller number of reinforcement elements at the inner radial location, the cross sectional area of the LINK8 elements were factored by 36/56. The cross sectional area of the LINK8s at the outer radial location corresponds to a Number 6 reinforcement bar, which has a 0.75-in. diameter and a cross sectional area of 0.44 in^2. LINK8s are also employed for the hoop reinforcements. The hoop reinforcements at the inner radial location are modeled 8-in. on center, while the outer hoop reinforcements are modeled on 4-in. centers. The nodal locations of the SOLID45 elements also correspond to the reinforcement locations to allow for the correct placement of the LINK8 elements in the model.

To allow the reinforcement to contain the tension stiffness of the concrete, the SOLID45 elements having nodes at a specified horizontal plane were separated by a small vertical distance

(0.1 in.) and were connected by CONTAC52 elements. The model contains three horizontal planes located at points ¼, ½, and ¾ of the axial length of the model. The CONTAC52 elements transmit compression across the horizontal planes, which allows the concrete elements to be subjected to compression. The LINK8 elements maintain a continuous connection from top to bottom. The structural boundary conditions are shown in Figure 3.4.4.2-3. The side of the model at 0° is restrained from translation in the circumferential direction. At 6.4°, the circumferential reinforcing bar (LINK8) elements extend beyond the model boundary and are also restrained at their ends from circumferential translation. The remaining nodes at 6.4° are attached to the CONTAC52 elements that only support compressive loading. The steel inner liner is radially coupled to the concrete, since for the thermal conditions analyzed, the steel will expand more than the concrete. The boundary conditions used simulate a complete fracture of the concrete at the 6.4° plane and between each of the axial sections of the model.

Analysis of the thermal loads and conditions for all cask configurations showed that maximum temperature gradient across the concrete wall of the cask under normal conditions, 62.42°F, occurs for the BWR configuration. Thus, the steady-state, three-dimensional thermal conduction analysis used the surface temperature boundary conditions for the 76°F normal operating condition to determine the temperature field throughout the model. These temperatures were applied with a load factor of 1.275 along the steel liner interior and concrete shell.

After the thermal solution was obtained, the thermal model was converted to a structural model. The nodal temperatures developed from the heat transfer analysis became the thermal load boundary conditions for the structural model.

The membrane stresses occurring in each individual circumferential reinforcement bar (rebar) varied on the basis of the rebar location along the longitudinal axis of the cask. The maximum circumferential tensile stress, 5,839 psi, occurred in the outer rebar, 56.4 in. from the base of the concrete cask.

The membrane stresses occurring in the vertical rebar varied on the basis of the radial location within the concrete shell. The maximum vertical tensile stress, 4,853.0 psi, occurred in the outer rebar 140.3 in. from the base of the cask.

The maximum allowable stress in the ASTM A-706 rebar material is:

$F_c = 60{,}000$ psi

The maximum allowable stress for the rebar assembly in the concrete cask shell is:

$$\sigma_{rebar} = \phi\, F_c = (0.9)(60{,}000 \text{ psi}) = 54{,}000 \text{ psi}$$

where:

F_c = 60,000 psi, the allowable stress on the rebar, and

ϕ = 0.90, a load reduction factor based on the rebar configuration.

Thus, the margin of safety of the rebar in the BWR cask under normal operating conditions is

$$MS = \frac{54{,}000 \text{ psi}}{5{,}389 \text{ psi}} - 1 = +9.0$$

The concrete component of the shell carries the compressive loads in both the circumferential and the vertical direction. The maximum calculated compressive stress, which occurs 144 in. from base of cask, is 105 psi in the circumferential direction. The maximum compressive concrete stress in the vertical direction is 594 psi, which occurs 136.34 in. from base of the cask.

Tensile stresses were examined in both the axial and circumferential directions. Two vertical planes (at 0° and at 6.4° for circumferential stress) and three horizontal planes (bottom, middle and top, for axial stress) were examined at each of the four concrete sections modeled. The locations of the planes where the stress evaluations are performed are shown in Figures 3.4.4.2-4 and 3.4.4.2-5. The appropriate element stress is examined at each plane to determine if the stress is tensile or compressive. If the stress is tensile, the component stress and face area of that element are used to calculate an average concrete stress on the plane. If compressive, the element results are excluded from the calculation. Experimental studies show that the tensile strength of concrete is 8% to 15% of the concrete compressive strength [35]. Using a compressive strength of 4,000 psi and an 8% factor, an allowable tensile strength of 320 psi is used in the evaluation.

The results of the evaluation, presented in Tables 3.4.4.2-3 and 3.4.4.2-4, show that maximum tensile stress in the concrete is 129.8 psi and 222.1 psi, for the normal and accident conditions, respectively. These maximum stresses are less than the allowable stress (320 psi). Consequently, no cracking of the concrete will occur.

Applying the ACI 349-85 load reduction factor, the allowable bearing stress on the concrete shell is,

$$\sigma_{bearing} = \phi f_c' = (0.70)(4{,}000) = 2{,}800 \text{ psi}$$

where:

ϕ, the strength reduction factor for the concrete shell = 0.70

f_c', the nominal concrete compressive strength = 4,000 psi

The maximum 76°F normal operating thermally induced stress of 594 psi represents a margin of safety of

$$MS = \frac{2{,}800 \text{ psi}}{594 \text{ psi}} - 1 = +3.7$$

Figure 3.4.4.2-1 Concrete Cask Thermal Stress Model

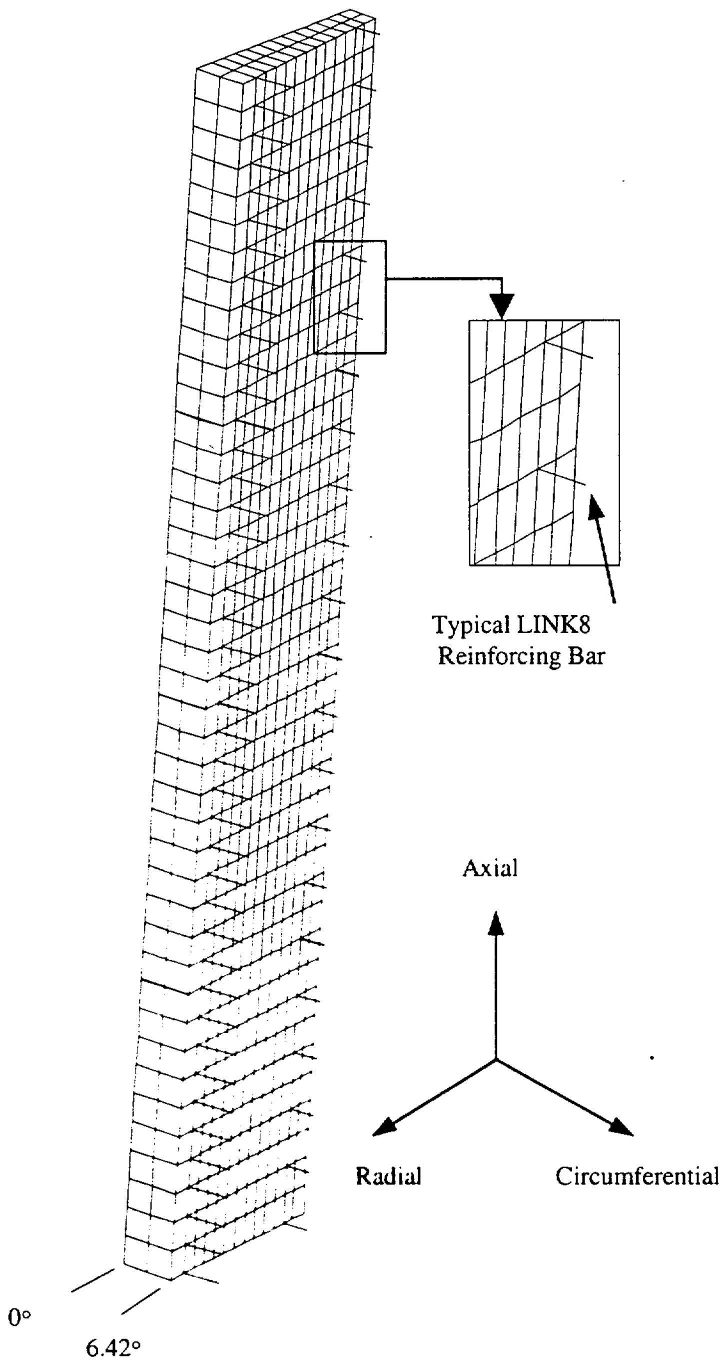


Figure 3.4.4.2-2 Concrete Cask Thermal Stress Model - Vertical and Horizontal Rebar Detail

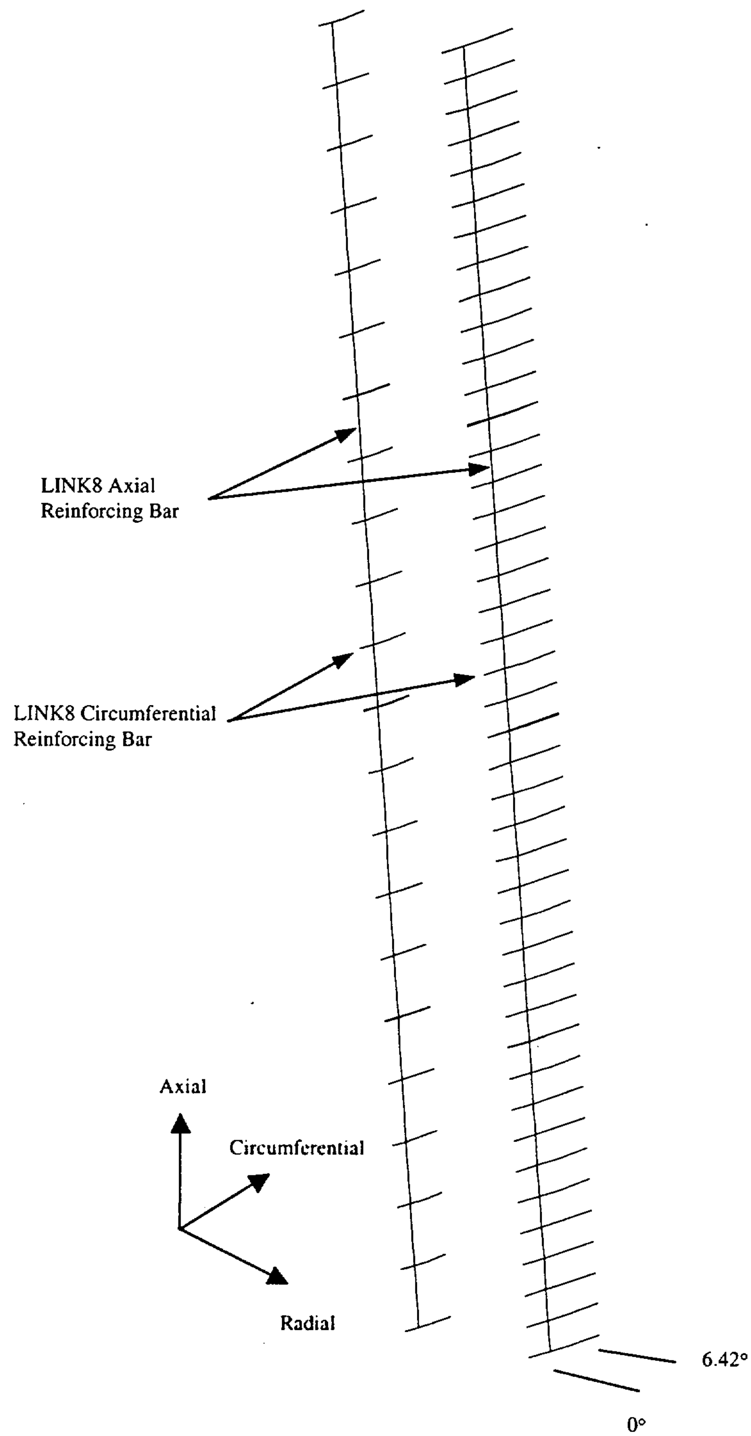
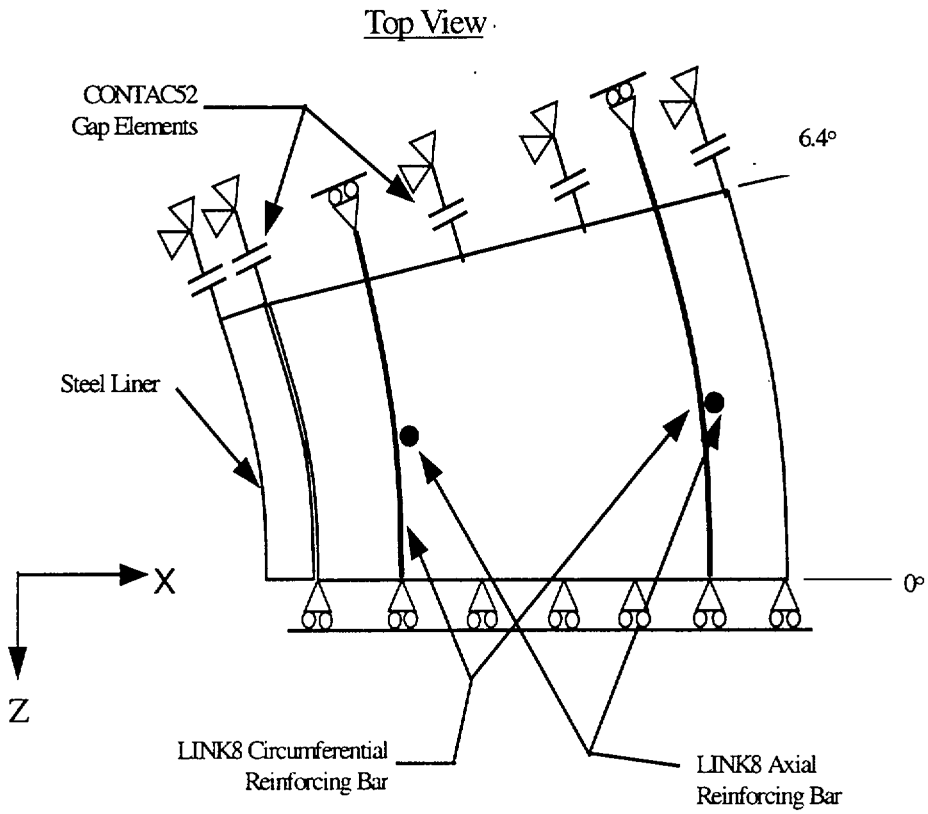


Figure 3.4.4.2-3 Concrete Cask Thermal Model Boundary Conditions



Note: CONTAC52 GAP Elements allow radial translation but don't transmit tensile loading

Figure 3.4.4.2-4 Concrete Cask Thermal Model Axial Stress Evaluation Locations

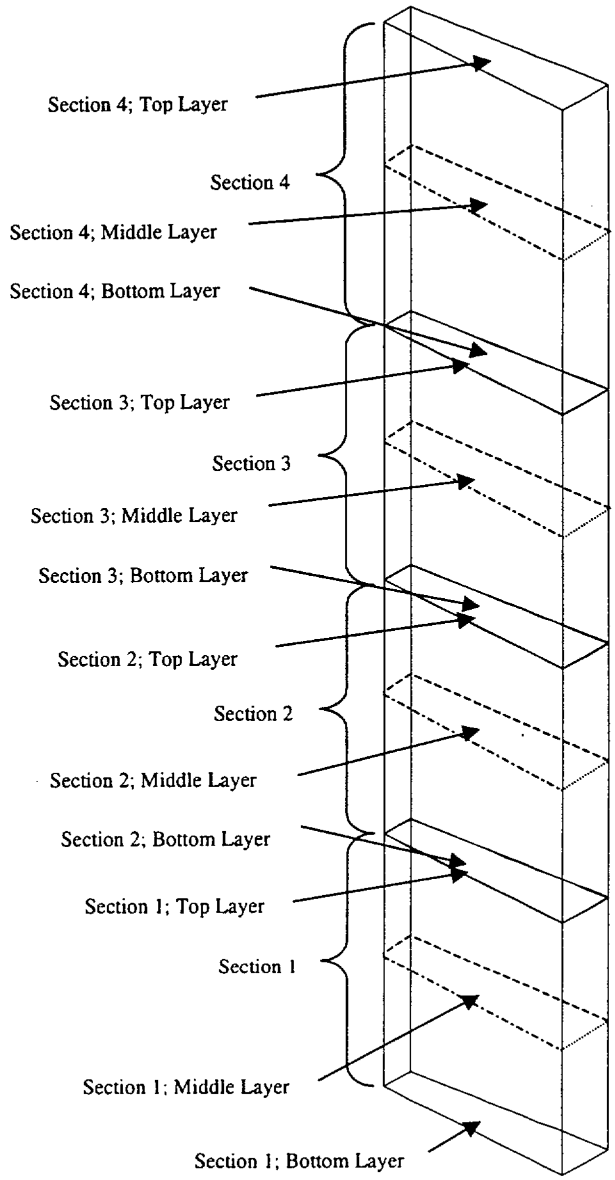


Figure 3.4.4.2-5 Concrete Cask Thermal Model Circumferential Stress Evaluation Locations

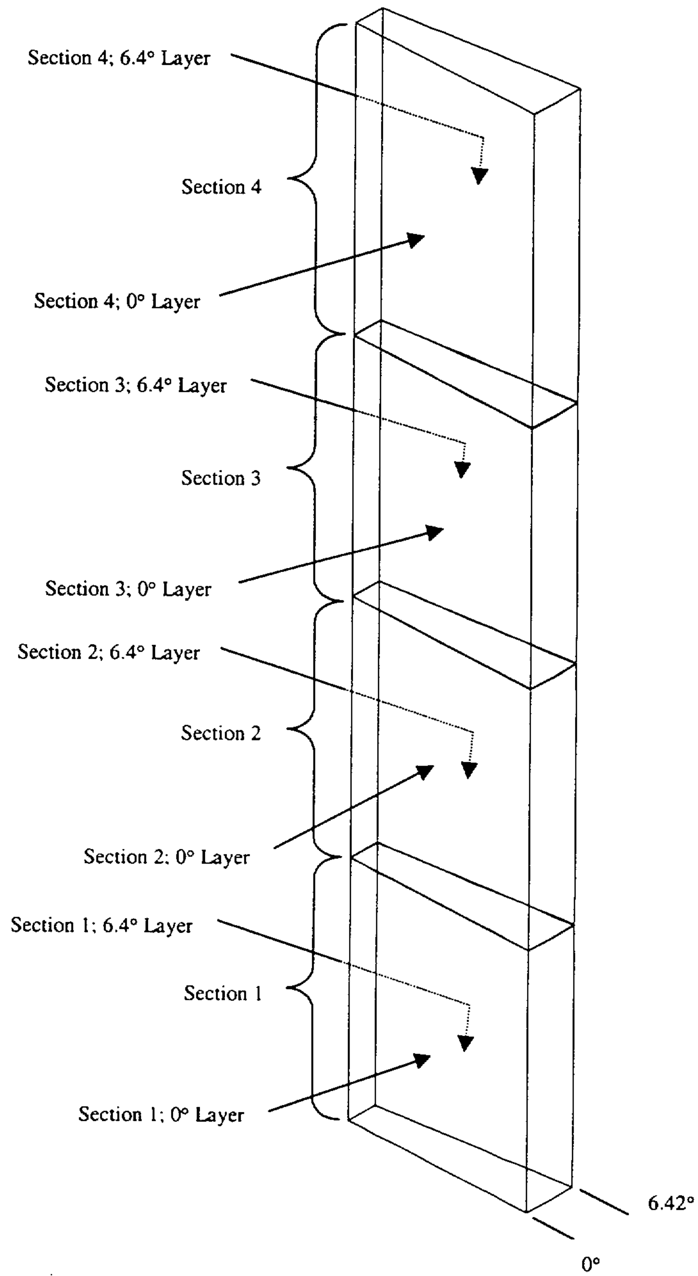


Table 3.4.4.2-1 Summary of Maximum Stresses for Vertical Concrete Cask Load Combinations

Load Comb[a]	Stress Direction	Stress [b] (psi)							
		Dead	Live	Wind [c]	Thermal [d]	Seismic [e]	Tornado [f]	Flood [g]	Total
Concrete Outside Surface:									
1	Vertical	-42.0	-43.0	—	—	—	—	—	-85.0
2	Vertical	-32.0	-32.0	—	—	—	—	—	-64.0
3	Vertical	-32.0	-32.0	-26.0	—	—	—	—	-90.0
4	Vertical	-30.0	-25.0	—	—	—	—	—	-55.0
5	Vertical	-30.0	-25.0	—	—	-131.0	—	—	-186.0
7	Vertical	-30.0	-25.0	—	—	—	—	-20.0	-75.0
8	Vertical	-30.0	-25.0	—	—	—	-20.0	—	-75.0
Concrete Inside Surface:									
1	Vertical	-42.0	-43.0	—	---	—	—	—	-85.0
	Circumferential	0.0	0.0	—	---	—	—	—	0.0
2	Vertical	-32.0	-32.0	—	-757.0	—	—	—	-821.0
	Circumferential	0.0	0.0	—	-134.0	—	—	—	-134.0
3	Vertical	-32.0	-32.0	-26.0	-757.0	—	—	—	-847.0
	Circumferential	0.0	0.0	0.0	-134.0	—	—	—	-134.0
4	Vertical	-30.0	-25.0	—	-655.0	—	—	—	-710.0
	Circumferential	0.0	0.0	—	-94.0	—	—	—	-94.0
5	Vertical	-30.0	-25.0	—	-594.0	-97.0	—	—	-746.0
	Circumferential	0.0	0.0	—	-105.0	—	—	—	-105.0
7	Vertical	-30.0	-25.0	—	-594.0	—	—	-20.0	-669.0
	Circumferential	0.0	0.0	—	-105.0	—	—	—	-105.0
8	Vertical	-30.0	-25.0	—	-594.0	—	-20.0	—	-669.0
	Circumferential	0.0	0.0	—	-105.0	—	—	—	-105.0

[a] Load combinations are defined in Table 2.2-1. See Sections 11.2.4 and 11.2.12 for evaluations of drop/impact and tipover conditions for load combination No. 6.

[b] Positive stress values indicate tensile stresses and negative values indicate compressive stresses.

[c] Stress results from Section 11.2.11 (tornado) are conservatively used with a load factor of 1.275.

[d] Tensile stresses (at concrete outside surface) are taken by the steel reinforcing bars and therefore are not shown in this Table. Stress Results for T_a (load combination #4) are obtained from Section 11.2.7.

[e] Stress results are obtained from Section 11.2.8.

[f] Stress results are obtained from Section 11.2.11 (tornado wind).

[g] Stress results are obtained from Section 11.2.9.

Table 3.4.4.2-2 Maximum Concrete and Reinforcing Bar Stresses

	Calculated (psi)	Allowable[1] (psi)	Margin of Safety
Concrete	847	2,800	+2.3
Reinforcing Bar			
Normal - vertical	4,853	54,000	+10
- hoop	5,389	54,000	+9
Accident[2] - vertical	6,017	54,000	+8
- hoop	7,154	54,000	+6.5

1 Allowable compressive stress for concrete is (0.7)(4,000 psi)=2,800 psi, where 0.7 is the strength reduction factor per ACI 349-85, Section 9.3; 4,000 psi is the nominal concrete strength. Allowable stress for reinforcing bar is determined in the calculation in this ACI Section.

2 Results are obtained from Section 11.2.11.

Table 3.4.4.2-3 Concrete Cask Average Concrete Axial Tensile Stresses

Stress Location	Normal Conditions			Accident Conditions		
	Calculated Stress (psi)	Allowable Stress (psi)	M.S.	Calculated Stress (psi)	Allowable Stress (psi)	M.S.
Section 1; Bottom Layer	34.8	320	8.2	135.5	320	1.36
Section 1; Middle Layer	24.1	320	12.3	41.9	320	6.6
Section 1; Top Layer	9.0	320	+Large	5.3	320	+Large
Section 2; Bottom Layer	77.5	320	3.1	121.3	320	1.6
Section 2; Middle Layer	38.3	320	7.3	81.6	320	2.9
Section 2; Top Layer	17.5	320	17.3	40.0	320	7.0
Section 3; Bottom Layer	69.9	320	3.6	109.0	320	1.9
Section 3; Middle Layer	60.3	320	4.3	123.3	320	1.6
Section 3; Top Layer	65.4	320	3.9	108.0	320	1.9
Section 4; Bottom Layer	33.2	320	8.6	59.3	320	4.4
Section 4; Middle Layer	53.4	320	5.0	105.9	320	2.0
Section 4; Top Layer	129.8	320	1.4	222.1	320	0.44

Table 3.4.4.2-4 Concrete Cask Average Concrete Hoop Tensile Stresses

Stress Location	Normal Conditions			Accident Conditions		
	Calculated Stress (psi)	Allowable Stress (psi)	M.S.	Calculated Stress (psi)	Allowable Stress (psi)	M.S.
Section 1; 0° Layer	26.1	320	11.3	45.2	320	6.1
Section 1; 6.42° Layer	25.2	320	11.7	39.3	320	7.1
Section 2; 0° Layer	51.5	320	5.2	81.3	320	2.9
Section 2; 6.42° Layer	53.7	320	4.9	77.6	320	3.1
Section 3; 0° Layer	78.7	320	3.1	103.5	320	2.1
Section 3; 6.42° Layer	77.6	320	3.1	98.6	320	2.2
Section 4; 0° Layer	55.9	320	4.7	72.6	320	3.4
Section 4; 6.42° Layer	52.3	320	5.1	67.2	320	3.76

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3.4.5 Cold

Severe cold environments are evaluated in Section 11.1.1. Stress intensities corresponding to thermal loads in the canister are evaluated by using a finite element model as described in Section 3.4.4.1. The thermal stresses that occur in the canister as a result of the maximum off-normal temperature gradients in the canister are bounded by the analysis of extreme cold in Section 11.1.1.

The PWR canister and basket are fabricated from stainless steel and aluminum, which are not subject to a ductile-to-brittle transition in the temperature range of interest. The BWR canister and basket are fabricated from stainless steel, aluminum, with carbon steel support disks. The carbon steel support disk thickness, 5/8 in., is selected to preclude brittle fracture at the design basis low temperature (-40°F). However, low temperature handling limits do apply to the transfer cask (See Section 12.2.2.9).

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3.5 Fuel Rods

The Universal Storage System is designed to limit fuel cladding temperatures to levels below those where Zircaloy degradation is expected to lead to fuel clad failure. As shown in Chapter 4, fuel cladding temperature limits for PWR and BWR fuel have been established at 380°C based on 5-year cooled fuel for normal conditions of storage and 570°C for short term off-normal and accident conditions.

As shown in Table 4.1-4 and 4.1-5, the calculated maximum fuel cladding temperatures are well below the temperature limits for all design conditions of storage.

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3.6 Structural Evaluation of Site Specific Spent Fuel

This section presents the structural evaluation of fuel assemblies or configurations, which are unique to specific reactor sites or which differ from the UMS® Storage System design basis fuel. These site specific configurations result from conditions that occurred during reactor operations, participation in research and development programs, and from testing programs intended to improve reactor operations. Site specific fuel includes fuel assemblies that are uniquely designed to accommodate reactor physics, such as axial fuel blanket and variable enrichment assemblies, and fuel that is classified as damaged. Damaged fuel includes fuel rods with cladding that exhibit defects greater than pinhole leaks or hairline cracks.

Site specific fuel assembly configurations are either shown to be bounded by the analysis of the standard design basis fuel assembly configuration of the same type (PWR or BWR), or are shown to be acceptable contents by specific evaluation.

3.6.1 Structural Evaluation of Maine Yankee Site Specific Spent Fuel for Normal Operating Conditions

This section describes the structural evaluation for site specific spent fuel configurations. As described in Sections 1.3.2.1 and 2.1.3.1, the inventory of site specific spent fuel configurations includes fuel classified as intact, intact with additional fuel and non fuel-bearing hardware, consolidated fuel and fuel classified as damaged. Damaged fuel is separately containerized in Maine Yankee fuel cans.

3.6.1.1 Maine Yankee Intact Spent Fuel

The description for Maine Yankee site specific fuel is in Section 1.3.2.1. The standard spent fuel assembly for the Maine Yankee site is the Combustion Engineering (CE) 14×14fuel assembly. Fuel of the same design has also been supplied by Westinghouse and by Exxon. The standard 14×14 fuel assemblies are included in the population of the design basis PWR fuel assemblies for the UMS® Storage System (see Table 2.1.1-1). The structural evaluation for the UMS® transport system loaded with the standard Maine Yankee fuels is bounded by the structural evaluations in Chapter 3 for normal conditions of storage and Chapter 11 for off-normal and accident conditions of storage.

With the Control Element Assembly (CEA) inserted, the weight of a standard CE 14×14 fuel assembly is 1,360 pounds. This weight is bounded by the weight of the design basis PWR fuel assembly (37,608/24 = 1,567 lbs) used in the structural evaluations (Table 3.2-1). The fuel configurations with removed fuel rods, with fuel rods replaced by solid stainless steel or Zircaloy rods, or with poison rods replaced by hollow Zircaloy rods, all weigh less than the standard CE 14×14 fuel assembly. The configuration with instrument thimbles installed in the center guide tube position weighs less than the standard assembly with the installed control element assembly. Consequently, this configuration is also bounded by the weight of the design basis fuel assembly. Since the weight of any of these fuel assembly configurations is bounded by the design basis fuel assembly weight, no additional analysis of these configurations is required.

The two consolidated fuel lattices are each constructed of 17×17 stainless steel fuel grids and stainless steel end fittings, which are connected by 4 stainless steel support rods. One of the consolidated fuel lattices has 283 fuel rods with 2 empty positions. The other has 172 fuel rods, with the remaining positions either empty or holding stainless steel rods. The calculated weight for the heaviest of the two consolidated fuel lattices is 2,100 pounds. Only one consolidated fuel lattice can be loaded into any one canister. The weight of the site specific 14×14 fuel assembly plus the CEA is approximately 1,360 lbs. Twenty-three (23) assemblies (at 1,360 lbs each) in addition to the consolidated fuel assembly (at approximately 2,100 lbs) would result in a total weight of 33,380 pounds.

Therefore, the design basis UMS® PWR fuel weight of 37,608 lbs bounds the site specific fuel and consolidated fuel by 12%. The evaluations for the Margin of Safety for the dead weight load of the fuel and the lifting evaluations in Section 3.4.4 bound the Margins of Safety for the Maine Yankee site specific fuel.

3.6.1.2 Maine Yankee Damaged Spent Fuel

The Maine Yankee fuel can, shown in Drawings 412-501 and 412-502, is provided to accommodate Maine Yankee damaged fuel. The fuel can fits within a standard PWR basket fuel tube. The primary function of the Maine Yankee fuel can is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the canister cavity volume.

The Maine Yankee fuel can is designed to hold an intact fuel assembly, a damaged fuel assembly, a fuel assembly with a burnup between 45,000 and 50,000 MWD/MTU and having a cladding oxidation layer thickness greater than 80 microns, or consolidated fuel in the Maine Yankee fuel inventory.

The fuel can is a square cross-section tube made of Type 304 stainless steel with a total length of 162.8 inches. The can walls are 0.048-inch thick sheet (18 gauge). The minimum internal width of the can is 8.52 inches. The bottom of the can is a 0.63-inch thick plate. Four holes in the plates, screened with a Type 304 stainless steel wire screen (250 openings/inch × 250 openings/inch mesh), permit water to be drained from the can during loading operations. Since the bottom surface of the fuel can rests on the canister bottom plate, additional slots are machined in the fuel can (extending from the holes to the side of the bottom assembly) to allow the water to be drained from the can. At the top of the can, the wall thickness is increased to 0.15-inches to permit the can to be handled. Slots in the top assembly side plates allow the use of a handling tool to lift the can and contents. To confine the contents within the can, the top assembly consists of a 0.88-inch thick plate with screened drain holes identical to those in the bottom plate. Once the can is loaded, the can and contents are inserted into the basket, where the can may be supported by the sides of the fuel assembly tube, which are backed by the structural support disks. Alternately, the empty fuel can may be placed in the basket prior to having the designated contents inserted in the fuel can.

In normal operation, the can is in a vertical position. The weight of the fuel can contents is transferred through the bottom plate of the can to the canister bottom plate, which is the identical load path for intact fuel. The only loading in the vertical direction is the weight of the can and the top assembly. The lifting of the can with its contents is also in the vertical direction.

Classical hand calculations are used to qualify the stresses in the Maine Yankee fuel can.

A conservative bounding temperature of 600°F is used for the evaluation of the fuel can for normal conditions of storage. A temperature of 300°F is used for the lifting components at the top of the fuel can and for the lifting tool.

Calculated stresses are compared to allowable stresses in accordance with ASME Code, Section III, Subsection NG. The ASME Code, Section III, Subsection NG allowable stresses used for stress analysis are:

Property	600°F	300°F
S_u	63.3 ksi	66.0 ksi
S_y	18.6 ksi	22.5 ksi
S_m	16.7 ksi	20.0 ksi
E	25.2×10^3 ksi	27.0×10^3 ksi

The Maine Yankee fuel can is evaluated for dead weight and handling loads for normal conditions of storage. Since the can is not restrained, it is free to expand. Therefore, the thermal stress is considered to be negligible.

The Maine Yankee fuel can lifting components and handling tools are designed with a safety factor of 3.0 on material yield strength.

3.6.1.2.1 Dead Weight and Handling Loading Evaluation

The weight of the Maine Yankee fuel can is 130 pounds. The maximum compressive stress acting in the tube of the fuel can is due to its own weight in addition to that of the top assembly. A 10% dynamic load factor is applied to the fuel can weight for an applied load of 143 pounds to account for loads due to handling. Based on the minimum cross sectional area of $(8.62)^2 - (8.52)^2 = 1.714$ in^2, the margin of safety at 300°F is:

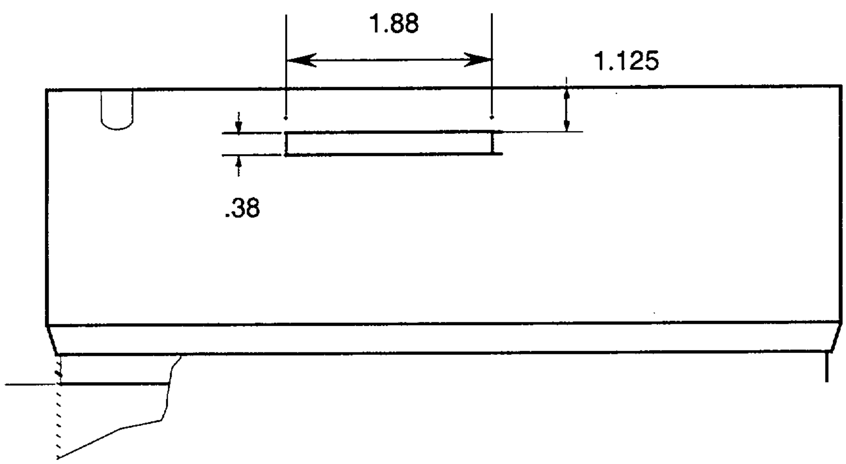
$$\text{M.S.} = 20{,}000/(143/1.714) - 1$$
$$\text{M.S.} = +\text{LARGE}$$

3.6.1.2.2 Lifting Evaluation

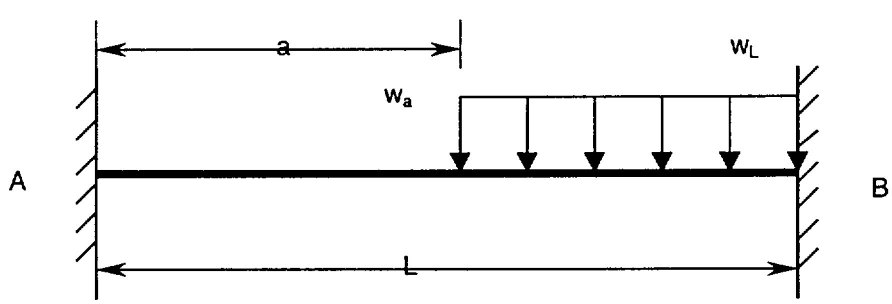
Based on the loaded weight of the fuel can, the lift evaluation does not require the use of the design criteria of ANSI N14.6 or NUREG-0612. However, for purposes of conservatism and good engineering practice, a factor of safety of three on material yield strength is used for the stress evaluations for the lift condition. Since a combined stress state results from the loading and the calculated stresses are compared to material yield strength, the Von Mises stress is computed.

Side Plates

The side plates will be subjected to bending, shear, and bearing stresses because of interaction with the lifting tool during handling operations. The lifting tool engages the 1.875-inch × 0.38-inch lifting slots with lugs that are 1-inch wide and lock into the four lifting slots. For this evaluation, the handling load is the weight of the consolidated fuel assembly (2,100 lbs design weight) plus the Maine Yankee fuel can weight (130 lbs), amplified by a dynamic load factor of 10%. Although the four slots are used to lift the can, the analysis assumes that the entire design load is shared by only two lift slots.



The stress in the side plate above the slot is determined by analyzing the section above the slot as a 0.15-inch wide × 1.875-inch long × 1.125-inch deep beam that is fixed at both ends. The lifting tool lug is 1 inch wide and engages the last 1 inch of the slot. The following figure represents the configuration to be evaluated:



where:

a = 0.875 in.
L = 1.875 in.
w_a = w_L = (2,230 lbs/2)(1.10)/1.0 in. = 613.3 lbs/in, use 620 lbs/in.

Reactions and moments at the fixed ends of the beam are calculated per Roark's Formula, Table 3, Case 2d.

The reaction at the left end of the beam (R_A) is:

$$R_A = \frac{w_a}{2L^3}(L-a)^3(L+a)$$

$$= \frac{620}{2(1.875)^3}(1.875-0.875)^3(1.875+0.875) = 129.3 \text{ lbs}$$

The moment at the left end of the beam (M_A) is:

$$M_A = \frac{-w_a}{12L^2}(L-a)^3(L+3a)$$
$$= \frac{-620}{12(1.875)^2}(1.875-0.875)^3(1.875+3(0.875)) = -66.1 \text{ lbs} \cdot \text{in.}$$

The reaction at the right end of the beam (R_B) is:

$$R_B = w_a(L-a) - R_A = 620(1.875-0.875) - 164.2 = 490.7 \text{ lbs}$$

The moment at the right end of the beam (M_B) is:

$$M_B = R_A L + M_A - \frac{w_a}{2}(L-a)^2$$
$$= 129.3(1.875) + (-66.1) - \frac{620}{2}(1.875-0.875)^2 = -133.7 \text{ lbs} \cdot \text{in.}$$

The maximum bending stress (σ_b) in the side plate is:

$$\sigma_b = \frac{Mc}{I} = \frac{133.7(0.5625)}{0.0178} = 4{,}224 \text{ psi}$$

The maximum shear stress (τ) occurs at the right end of the slot:

$$\tau = \frac{R_B}{A} = \frac{490.7}{1.125(0.15)} = 2{,}908 \text{ psi}$$

The Von Mises stress (σ_{max}) is:

$$\sigma_{max} = \sqrt{\sigma_b^2 + 3\tau^2} = \sqrt{4{,}224^2 + 3(2{,}908)^2} = 6{,}573 \text{ psi}$$

The yield strength (S_y) for Type 304 stainless steel is 22,500 psi at 300°F. The factor of safety is calculated as:

$$FS = \frac{22{,}500}{6{,}573} = 3.4 > 3$$

The design condition requiring a safety factor of 3 on material yield strength is satisfied.

Tensile Stress

The tube body will be subjected to tensile loads during lifting operations. The load (P) includes the can contents (2,100 lbs design weight), the tube body weight (78.77 lbs), and the bottom assembly weight (12.98 lbs) for a total of 2,191.8 pounds. A load of 2,200 lbs with a 10% dynamic load factor is used for the analysis.

The tensile stress (σ_t) is then:

$$\sigma_t = \frac{1.1P}{A} = \frac{1.1(2{,}200 \text{ lb})}{1.714 \text{ in.}^2} = 1{,}412 \text{ psi}$$

where:

A = tube cross-section area = $8.62^2 - 8.52^2 = 1.714 \text{ in}^2$

The factor of safety (FS) based on the yield strength at 600°F (18,000 psi) is:

$$FS = \frac{18{,}600 \text{ psi}}{1{,}412} = 13.2 > 3$$

Weld Evaluation

The welds joining the tube body to the bottom weldment and to the side plates are full penetration welds (Type III, paragraph NG-3352.3). In accordance with NG-3352-1, the weld quality factor (n) for a Type III weld with visual surface inspection is 0.5.

The weld stress (σ_w) is:

$$\sigma_w = \frac{1.1(P)}{A} = \frac{1.1(2{,}200)}{1.714} = 1{,}412 \text{ psi}$$

where:

P = the combined weight of the tube body, bottom weldment, and can contents
A = cross sectional area of thinner member joined

The factor of safety (FS) is:

$$FS = \frac{n \cdot S_y}{\sigma_w} = \frac{0.5(18{,}600 \text{ psi})}{1{,}412 \text{ psi}} = +6.6 > 3$$

3.7 References

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3.8 Carbon Steel Coatings Technical Data

This section presents the technical data sheets for Carboline 890, Keeler & Long E-Series Epoxy Enamel, Keeler & Long Kolor-Poxy Primer No. 3200, and Acrythane Enamel Y-1 Series top coating. These coatings are applied to protect exposed carbon steel surfaces of the transfer cask and the vertical concrete cask. Also provided is a description of the electroless nickel coating that is applied to the BWR support disks. Each coating meets the service and performance requirements that are established for the coating by the design and service environment of the component to be covered.

The service and performance requirements for the coatings of the carbon steel components of the transfer cask, the vertical concrete cask, and the BWR support disks are similar and require that the coating:

- be applied to carbon steel
- be submersible for up to a week in clean water
- is rated Service Level 1 or 2 (EPRI TR-106160 for paints)
- does not contain Zinc
- have a service temperature of at least 200°F in water and 600°F in a dry environment
- generate no hydrogen, or minimal hydrogen, when submersed in water
- have no, or limited, special processes required for proper application or curing
- have a service environment in a high radiation field.

Either Carboline 890 or Keeler & Long E-Series Epoxy Enamel may be used on the exposed carbon steel surfaces of the transfer cask, transfer cask extension and the 100-ton transfer cask. These coatings are listed in EPRI TR 106160, "Coating Handbook for Nuclear Power Plants," June 1996 [36], as meeting the requirements for Service Level 1 or 2.

Electroless nickel coating is used on the carbon steel BWR support disks to provide a submersible, passive protective finish. This coating has a history of acceptance and successful performance in similar service conditions.

No coating characteristics that may enhance the performance of the coated components (such as better emissivity) are considered in the analyses of these components. Therefore, no adverse effect on system performance results from incidental scratching or flaking of the coating, and no touchup of the coating on the BWR support disks or the storage cask liner is required.

3.8.1 Carboline 890

product data sheet

carboline

CARBOLINE® 890

VOC

SELECTION DATA

GENERIC TYPE: Two component, cross-linked epoxy.

GENERAL PROPERTIES: CARBOLINE 890 is a high solids, high gloss, high build epoxy topcoat that can be applied by spray, brush, or roller. The cured film provides a tough, cleanable and esthetically pleasing surface. Available in a wide variety of clean, bright colors. Features include:

- Good flexibility and lower stress upon curing than most epoxy coatings.
- Very good weathering resistance for a high gloss epoxy.
- Very good abrasion resistance.
- Excellent performance in wet exposures.
- Meets the most stringent VOC (Volatile Organic Content) regulations.

RECOMMENDED USES: Recommended where a high performance, attractive, chemically resistant epoxy topcoat is desired. Offers outstanding protection for interior floors, walls, piping, equipment and structural steel or as an exterior coating for tank farms, railcars, structural steel and equipment in various corrosive environments. Recommended industrial environments include Chemical Processing, Offshore Oil and Gas, Food Processing and Pharmaceutical, Water and Waste Water Treatment, Pulp and Paper, Power Generation among others. May be used as a two coat system direct to metal or concrete for Water and Municipal Waste Water immersion. CARBOLINE 890 has been accepted for use in areas controlled by USDA regulations for incidental food contact. Consult Carboline Technical Service Department for other specific uses.

NOT RECOMMENDED FOR: Strong acid or solvent exposures, or immersion service other than recommended.

TYPICAL CHEMICAL RESISTANCE:

Exposure	Immersion	Splash and Spillage	Fumes
Acids	NR	Very Good	Very Good
Alkalies	NR	Excellent	Excellent
Solvents	NR	Very Good	Excellent
Salt Solutions	Excellent	Excellent	Excellent
Water	Excellent	Excellent	Excellent

*NR = Not recommended

TEMPERATURE RESISTANCE:
Continuous: 200° F (93° C)
Non-continuous: 250° F (121° C)

At 300° F, coating discoloration and loss of gloss is observed, without loss of film integrity.

SUBSTRATES: Apply over suitably prepared metal, concrete, or other surfaces as recommended.

COMPATIBLE COATINGS: May be applied directly over inorganic zincs, weathered galvanizing, catalyzed epoxies, phenolics or other coatings as instructed. A test patch is recommended before use over existing coatings. May be used as a tiecoat over inorganic zincs. A mist coat of CARBOLINE 890 is required when applied over inorganic zincs to minimize bubbling. May be topcoated to upgrade weathering resistance. Not recommended over chlorinated rubber or latex coatings. Consult Carboline Technical Service Department for specific recommendations.

April 91 Replaces Oct. 90

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:*

	By Volume
CARBOLINE 890	75%±2%

VOLATILE ORGANIC CONTENT:*
As Supplied: 1.78 lbs./gal.(214 gm/liter)
Thinned: The following are nominal values utilizing:

% Thinned	Fluid Ounces/Gal.	Pounds/ Gallon	Grams/ Liter
CARBOLINE Thinner # 2 (spray application)			
10%	12.8	2.26	271
CARBOLINE Thinner #33 (brush & roller application)			
12%	16	2.38	285

*Varies with color

RECOMMENDED DRY FILM THICKNESS PER COAT:
4-6 mils(100-150 microns).
5-7 mils (125-175 microns) DFT for a more uniform gloss over inorganic zincs.
Dry film thicknesses in excess of 10 mils(250 microns) per coat are not recommended. Excessive film thickness over inorganic zinc may increase damage during shipping or erection.

THEORETICAL COVERAGE PER MIXED GALLON:
1203 mil sq. ft. (30 sq. m/l at 25 microns)
241 sq. ft. at 5 mils(6.0 sq. m/l at 125 microns)
Mixing and application losses will vary and must be taken into consideration when estimating job requirements.

STORAGE CONDITIONS: Store Indoors
Temperature: 40-110° F (4-43° C)
Humidity: 0-100%

SHELF LIFE: Twenty-four months minimum when stored at 75° F (24° C).

COLORS: Available in Carboline Color Chart colors. Some colors may require two coats for adequate hiding. Colors containing lead or chrome pigments are not USDA acceptable. Consult your local Carboline representative or Carboline Customer Service for availability.

* See notice under DRYING TIMES.

GLOSS: High gloss (Epoxies lose gloss and eventually chalk in sunlight exposure).

ORDERING INFORMATION

Prices may be obtained from your local Carboline Sales Representative or Carboline Customer Service Department.

APPROXIMATE SHIPPING WEIGHT:

	2 Gal. Kit	10 Gal. Kit
CARBOLINE 890	29 lbs. (13 kg)	145 lbs. (66 kg)
THINNER #2	8 lbs. in 1's (4 kg)	39 lbs. in 5's (18 kg)
THINNER #33	9 lbs. in 1's (4 kg)	45 lbs. in 5's (20 kg)

FLASHPOINT: (Pensky-Martens Closed Cup)

CARBOLINE 890 Part A	73° F (23° C)
CARBOLINE 890 Part B	71° F (22° C)
THINNER #2	24° F (−5° C)
THINNER #33	98° F (37° C)

APPLICATION INSTRUCTIONS
CARBOLINE® 890

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

SURFACE PREPARATION: Remove oil or grease from surface to be coated with clean rags soaked in CARBOLINE Thinner #2 or Surface Cleaner #3 (refer to Surface Cleaner #3 instructions) in accordance with SSPC-SP 1.

Steel: Normally applied over clean, dry recommended primers. May be applied directly to metal. For immersion service, abrasive blast to a minimum Near White Metal Finish in accordance with SSPC-SP10, to a degree of cleanliness in accordance with NACE #2 to obtain a 1.5-3 mil (40-75 micron) blast profile. For non-immersion, abrasive blast to a Commercial Grade Finish in accordance with SSPC-SP6, to a degree of cleanliness in accordance with NACE #3 to obtain a 1.5-3 mil (40-75 micron) blast profile.

Concrete: Apply over clean, dry recommended surfacer or primer. Can be applied directly to damp(not visibly wet) or dry concrete where an uneven surface can be tolerated. Remove laitance by abrasive blasting or other means.

Do not coat concrete treated with hardening solutions unless test patches indicate satisfactory adhesion. Do not apply coating unless concrete has cured at least 28 days at 70° F (21° C) and 50% RH or equivalent time.

MIXING: Mix separately, then combine and mix in the following proportions:

	2 Gal. Kit	10 Gal. Kit
CARBOLINE 890 Part A	1 gallon	5 gallons
CARBOLINE 890 Part B	1 gallon	5 gallons

THINNING: For spray applications, may be thinned up to 10% (12.8 fl. oz./gal.) by volume with CARBOLINE Thinner #2.

For brush and roller application may be thinned up to 12 % (16 fl. oz./gal.) by volume with CARBOLINE Thinner #33.

Refer to Specification Data for VOC information.

Use of thinners other than those supplied or approved by Carboline may adversely affect product performance and void product warranty, whether express or implied.

POT LIFE: Three hours at 75° F (24° C) and less at higher temperatures. Pot life ends when material loses film build.

APPLICATION CONDITIONS:

	Material	Surfaces	Ambient	Humidity
Normal	60-85° F (16-29° C)	60-85° F (16-29° C)	60-90° F (16-32° C)	0-80%
Minimum	50° F (10° C)	50° F (10° C)	50° F (10° C)	0%
Maximum	90° F (32° C)	125° F (52° C)	110° F (43° C)	80%

Do not apply when the surface temperature is less than 5° F (or 3° C) above the dew point

Special thinning and application techniques may be required above or below normal conditions.

SPRAY: This is a high solids coating and may require slight adjustments in spray techniques. Wet film thicknesses are easily and quickly achieved. The following spray equipment has been found suitable and is available from manufacturers such as Binks, DeVilbiss and Graco.

Conventional: Pressure pot equipped with dual regulators, 3/8" I.D. minimum material hose, .070" I.D. fluid tip and appropriate air cap.

Airless:
Pump Ratio: 30:1 (min.)*
GPM Output: 3.0 (min.)
Material Hose: 3/8"I.D.(min.)
Tip Size: .017-.021"
Output psi: 2100-2300
Filter Size: 60 mesh

*Teflon packings are recommended and are available from the pump manufacturer.

BRUSH OR ROLLER: Use medium bristle brush, or good quality short nap roller, avoid excessive rebrushing and rerolling. Two coats may be required to obtain desired appearance, hiding and recommended DFT. For best results, tie-in within 10 minutes at 75° F (24° C).

DRYING TIMES: These times are at 5 mils (125 microns) dry film thickness. Higher film thicknesses will lengthen cure times.

Dry to Touch 2 1/2 hours at 75° F (24° C)
Dry to Handle 6 1/2 hours at 75° F (24° C)

Temperature	Dry to Topcoat**	Final Cure
50° F (10° C)	24 hours	3 days
60° F (16° C)	16 hours	2 days
75° F (24° C)	8 hours	1 day
90° F (32° C)	4 hours	16 hours

**When recoating with CARBOLINE 890, recoat times will be drastically reduced. Contact Carboline Technical Service for specific recommendation.

Recommended minimum cure before immersion service is 5 days at 75° F (24° C).

EXCESSIVE HUMIDITY OR CONDENSATION ON THE SURFACE DURING CURING MAY RESULT IN SURFACE HAZE OR BLUSH; ANY HAZE OR BLUSH MUST BE REMOVED BY WATER WASHING BEFORE RECOATING.

CLEANUP: Use CARBOLINE Thinner #2.

CAUTION: READ AND FOLLOW ALL CAUTION STATEMENTS ON THIS PRODUCT DATA SHEET AND ON THE MATERIAL SAFETY DATA SHEET FOR THIS PRODUCT.

CAUTION: CONTAINS FLAMMABLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES

carboline®
350 Hanley Industrial Ct • St. Louis MO 63144-1599
an RPM company • 314-644-1000

3.8.2 Keeler & Long E-Series Epoxy Enamel

March, 1995

SSU-1

KEELER & LONG INC.

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PROTECTIVE COATING SYSTEMS FOR NUCLEAR POWER PLANTS

INTRODUCTION

In the 1960's Keeler & Long made the commitment to develop Protective Coating Systems for Nuclear Power Plants. Coating Systems were developed and qualified in accordance with accepted standards, with emphasis upon their usage and specification for NEW construction projects. These systems were applied directly to either concrete or carbon steel substrates utilizing ideal surface preparation.

Presently, there is a necessity to apply these same coating systems or newly formulated systems over the original systems or over substrates which cannot be ideally prepared. Several years ago, Keeler & Long initiated a test program in order to test and qualify systems in conjunction with competitors products and/or with methods of preparation which are considered less than ideal. This test program provides OPERATING Nuclear Plants with qualified methods of preparation and a variety of qualified mixed coating systems.

HISTORY

In 1967, we embarked upon a testing program in order to comply with standards being prepared by the experts in the field and under the jurisdiction of The American National Standards Institute (ANSI). Earlier testing had involved research in order to determine the radiation tolerance and the decontamination properties of a variety of generic coating types including zinc rich, alkyds, chlorinated rubbers, vinyls, latex emulsions, and epoxies. This testing was conducted by various independent laboratories, such as Oak Ridge National Laboratory, Idaho Nuclear, and The Western New York Nuclear Research Center. It was concluded from these tests that almost any generic coating type would produce satisfactory radiation resistance and decontaminability.

Upon completion of the first ANSI Standards, however, it became evident that only Epoxy Coatings would meet the specific minimum acceptance criteria set forth in these standards. The single most important change from the earlier testing was the inclusion of a test which simulates the operation of the emergency core cooling system. This test is referred to as the Loss of Coolant Accident (LOCA) or the Design Basis Accident Condition (DBA). The test involves a high pressure, high temperature, alkaline, immersion environment.

Simultaneous with the preparation of these standards, we prepared to test Epoxy Systems in order to comply with the requirements. First hand knowledge of these standards was available since our personnel assisted in the development of these documents. Equipment was designed and built by our laboratory in order to conduct in-house DBA tests. The required physical and chemical tests were either conducted by us or by universities through research grants.

In 1972, the testing program was taken a step further in order to establish more credibility. The Franklin Institute of Philadelphia constructed an apparatus in order to simulate various Design Basis Accident Conditions and we prepared blocks and panels for an independent evaluation. The test results were among the "First" from an independent source, and these tests substantiated more than two years of in-house testing.

The Franklin Institute tests, along with our in-house testing program, were used as a basis for qualification until 1976. During this period also the following ANSI standards were revised and/or developed:

- ANSI N5.9-1967 "Protective Coatings (Paints) for the Nuclear Industry" (Rev. ANSI N512-1974)
- ANSI N101.2-1972 "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities"
- ANSI N101.4-1972 "Quality Assurance for Protective Coatings Applied to Nuclear Facilities"

Simultaneously, we developed a written Quality Assurance Program in compliance with ANSI N101.4 - 1972, Appendix B 10CFR50 of the Federal Register, and ANSI N45.2-1971 "Quality Assurance Program Requirements For Nuclear Power Plants".

In 1976, Oak Ridge national Laboratory (ORNL) established a testing program in order to conduct Radiation, Decontamination, and DBA tests under one roof. Keeler & Long, under contract with ORNL, conducted a series of tests in compliance with the parameters established by a major engineering firm and the ANSI standards. These tests, and similar series of tests conducted two years later in 1978, became the basis for the qualification of several of our concrete and carbon steel coating systems. From 1978 to the present day we have continued to qualify through ORNL and several other independent testing agencies any modifications to existing formulas and any changes in surface preparation or application requirements. We have also maintained an in-house testing program used to screen new products as well as modifications of existing systems. Furthermore, progress has continued in the revision of the ANSI standards during this time frame. Revision of these documents is presently under the jurisdiction of the American Society for Testing and Materials (ASTM) as outlined in D3842-80 "Standard Guide for Selection of Test Methods for Coatings Used in Light-Water Nuclear Power Plants".

The future dictates significantly less construction of new Nuclear Plants and much more emphasis upon the repair and maintenance of existing facilities. Our commitment remains the same as it was in 1965; that is, to meet the coating requirements of Nuclear Power Plants.

NUCLEAR COATINGS

SSU-1

Level One Coating Systems

The following Coating Systems are qualified for Coating Service Level One of a Nuclear Power Plant. "Coating Service Level One pertains to those systems applied to structures, systems and other safety related components which are essential to the prevention of, or the mitigation of the consequences of postulated accidents that could cause undue risk to the health and safety of the public."

SYSTEM IDENTIFICATION	COATING SYSTEMS	DRY FILM THICKNESS RANGE
CARBON STEEL COATING SYSTEMS		
System S-1		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	3.0 - 14.0 mils DFT
Finish	No. E-1 SERIES EPOXY ENAMEL	2.5 - 6.0 mils DFT
System S-10		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	5.0 - 12.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 6.0 mils DFT
System S-11		
Primer/Finish	No. 6548/7107 EPOXY WHITE PRIMER	8.0 - 18.0 mils DFT
System S-12		
Primer/Finish	No. 4500 EPOXY SELF-PRIMING SURFACING ENAMEL	5.0 - 18.0 mils DFT
System S-14 (FLOORS ONLY)		
Finish	No. 5000 EPOXY SELF-LEVELING FLOOR COATING	10.0 - 25.0 mils DFT
System S-15		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	2.5 - 6.0 mils DFT
Finish	No. 9600 N KEELOCK	5.0 - 8.0 mils DFT
CONCRETE COATING SYSTEMS		
System KL-2		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548-S EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. E-1 SERIES EPOXY ENAMEL	2.5 - 6.0 mils DFT
System KL-8		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548-S EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	4.0 - 8.0 mils DFT
System KL-9		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548/7107 EPOXY WHITE PRIMER	5.0 - 10.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 8.0 mils DFT
System KL-10		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 4000 EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 6.0 mils DFT
System KL-12		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer/Finish	No. 4500 EPOXY SELF-PRIMING SURFACING ENAMEL	10.0 - 50.0 mils DFT
System KL-14 (FLOORS ONLY)		
Primer/Sealer	No. 6129 EPOXY CLEAR PRIMER/SEALER	1.5 - 2.5 mils DFT
Finish	No. 5000 EPOXY SELF-LEVELING FLOOR COATING	35.0 - 50.0 mils DFT

SUMMARY OF QUALIFICATION TEST RESULTS

KEELER & LONG maintains a complete file of Nuclear Test Reports which substantiate the specification of the carbon steel and concrete coating systems listed in this bulletin. This file was initiated in the early 1970's and provides complete qualification in accordance with ANSI Standards N512 and N101.2. Results for radiation tolerance, decontamination, and the Design Basis Accident Condition are reported as performed by independent Laboratories. Also reported are the chemical and physical tests which were conducted by the Keeler & Long Laboratory in compliance with the ANSI Standards.

TEST REPORT REFERENCE

K&L COATING SYSTEM	SUBSTRATE	KEELER & LONG TEST REPORT NO.						
		78-0728-1	78-0810-1	85-0404	85-0524	90-0227	93-0818	93-0601
S-1	Steel	•	•					
S-10	Steel		•					
S-11	Steel		•					
S-12	Steel			•				
S-14	Steel					•		
S-15	Steel						•	
KL-2	Concrete	•	•					
KL-8	Concrete	•						
KL-9	Concrete	•	•					
KL-10	Concrete		•					
KL-12	Concrete				•			
KL-14	Concrete					•		•

E.340

KEELER & LONG INC

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EPOXY ENAMEL
E-SERIES

GENERIC TYPE: POLYAMIDE EPOXY

PRODUCT DESCRIPTION: A two component, polyamide epoxy enamel formulated to provide excellent chemical resistance, as well as being extremely resistant to abrasion and direct impact, for interior exposures.

RECOMMENDED USES: As a topcoat for concrete and steel surfaces subject to radiation, decontamination, and loss-of-coolant accidents in Coating Service Level I Areas of nuclear power plants.

NOT RECOMMENDED FOR: Areas other than the above, as the J-SERIES can be utilized in Coating Service Level II and III Areas, as well as Balance of Plant, of nuclear power plants, with attendant cost savings.

COMPATIBLE UNDERCOATS:
Epoxy White Primer
Epoxy Surfacer

PRODUCT CHARACTERISTICS:

Solids by Volume:	53% ± 3%
Solids by Weight:	66% ± 3%
Recommended Dry Film Thickness:	2.0 - 2.5 mils
Theoretical Coverage:	425 Sq. Ft./Gallon @ 2.0 mils DFT
Finish:	Full Gloss (E-1), Semi-Gloss (E-2)
Available Colors:	White, light tints, and dark red
Drying Time @ 72°F	
To Touch:	4 Hours
To Handle:	8 Hours
To Recoat:	48 Hours
VOC Content:	3.4 Pounds/Gallon 407 Grams/Liter

June, 1994

TECHNICAL BULLETIN

E-SERIES

E 340

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	10.2 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F± 2°
	Shelf Life:	1 Year
	Pot Life @ 72°F:	8 Hours
	Temperature Resistance:	350°F
	Viscosity @ 77°F:	85 ± 5 (Krebs Units)
	Gloss (60° meter):	95 ± 5 (E-1)
	Storage Temperature:	55 - 95°F
	Mixing Ratio (Approx. by Volume):	4:1
APPLICATION DATA:	Application Procedure Guide:	APG-2
	Wet Film Thickness Range:	4.0 - 5.0 mils
	Dry Film Thickness Range:	2.0 - 2.5 mils
	Temperature Range:	55 - 120°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	Primed
	Induction Time @ 72°F:	1 Hour
	Recommended Solvent	
	@ 50 - 85°F:	No. 4093
	@ 86 - 120°F:	No. 2200

Application Methods

Air Spray	
Tip Size:	.055"
Pressure:	30 - 60 PSIG
Thin:	1.0 - 2.0 Pts/Gal
Airless Spray	
Tip Size:	.011" - .017"
Pressure:	2500 - 3000 PSIG
Thin:	0.5 - 1.5 Pts/Gal
Brush or Roller	
Thin:	1.0 - 2.0 Pts/Gal

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KOLORS

SSPC SUSTAINING MEMBER

3.8.3 Description of Electroless Nickel Coating

This section provides a description of the electroless Nickel coating process as prepared by the ASM Committee on Nickel Plating. The electroless Nickel coating is used to provide corrosion protection of the BWR carbon steel support disks during the short time period from placement of the BWR canister in the spent fuel pool to the time of completion of vacuum drying and inerting with helium. The coating is applied in accordance with ASTM B733-SC3, Type V, Class 1 [37].

Electroless nickel is a nickel/phosphorus alloy that is produced by the use of a chemical reducing agent a hot aqueous solution to deposit nickel on a catalytic surface without the use of an electric current. The chemical reduction process produces a uniform, predicable coating thickness. Adhesion of the nickel coating to properly cleaned carbon steel is excellent with reported bond strength in the range of 40 to 60 ksi [38].

Electroless nickel coating is highly corrosion resistant because of its non-porous structure that seals off the coated surface from the environment. During the time following completion of the coating of the UMS BWR support disk until actual use, the nickel surface bonds with oxygen atoms in the air to create a passive nickel oxide layer on the surfaces of the support disk. Thus, very few free electrons are available on the surface to cathodically react with water and produce hydrogen gas. Test data for electroless nickel coated steel have been reported to show corrosion rates from 1 to 2 μm per year in water [39].

The coating classification of SC3 provides a minimum thickness of 25 μm (0.001 inch).

Nonelectrolytic Nickel Plating

*By the ASM Committee on Nickel Plating**

THREE METHODS may be employed for depositing nickel coatings without the use of electric current:

1 Immersion plating
2 Chemical reduction of nickelous oxide at 1600 to 2000 F
3 Autocatalytic chemical reduction of nickel salts by hypophosphite anions in an aqueous bath at 190 to 205 F ("electroless" nickel plating).

All three methods are, under certain limited conditions, useful substitutes for nickel electroplating; they are particularly useful in applications in which electroplating is impracticable or impossible because of cost or technical difficulties. Of the three methods, electroless nickel plating is in widest use, and is the method to which the most attention is devoted in this article.

Immersion Plating

The composition and operating conditions of an aqueous immersion plating bath are as follows:

Nickel chloride ($NiCl_2 \cdot 6H_2O$) ...	80 oz per gal
Boric acid (H_3BO_3)	4 oz per gal
pH	3.5 to 4.5
Temperature	160 F

When using this bath, it is desirable, but not mandatory, to move the work at a rate of about 16 ft per min.

This solution is capable of depositing a very thin (about 0.025 mil) and uniform coating of nickel on steel in periods of up to 30 min. The coating is porous and possesses only moderate adhesion, but these conditions can be improved by heating the coated part at 1200 F for 45 min in a nonoxidizing atmosphere. (Higher temperatures will promote diffusion of the coating.)

High-Temperature Chemical-Reduction Coating

By the reduction of a mixture of nickelous oxide and dibasic ammonium phosphate in hydrogen or other reducing atmosphere at 1600 to 2000 F, a nickel coating can be deposited without the use of electric current. This method (U. S. Patent 2,633,631) consists of applying a slurry of the two chemicals to all or selected surfaces of the workpiece, drying the slurry in air, and performing the chemical reduction at elevated temperature. No special tanks or other plating facilities are required. Some diffusion of nickel and phosphorus into the basis metal occurs at elevated temperature; when the coating is applied to steel, it will consist of nickel, iron, and about 3% phosphorus. The slurry may be used for brazing.

Electroless Nickel Plating

The electroless nickel plating process employs a chemical reducing agent (sodium hypophosphite) to reduce a nickel salt (such as nickel chloride) in hot aqueous solution and to deposit nickel on a catalytic surface. The deposit obtained from an electroless nickel solution is an alloy containing from 4 to 12% phosphorus and is quite hard. (As indicated later in this article, the hardness of the as-plated deposit can be increased by heat treatment.) Because the deposit is not dependent on current distribution, it is uniform in thickness, regardless of the shape or size of the plated surface.

Electroless nickel deposits may be applied to provide the basis metal with resistance to corrosion or wear, or for the buildup of worn areas. Typical applications of electroless nickel for these purposes are given in Table 1, which also indicates plate thicknesses and postplating heat treatments.

Surface Cleaning. In general, the methods employed for cleaning and preparing metal surfaces for electroless nickel plating are the same as those used for conventional electroplating. Heavy oxides are removed mechanically, and oils and grease are removed by vapor degreasing. A typical precleaning cycle might consist of alkaline cleaning (either agitated soak or anodic) and acid pickling, both followed by water rinsing.

Prior to electroless plating, the surfaces of all stainless steel parts must be chemically activated in order to obtain satisfactory adhesion of the plate. One activating treatment consists of immersing the work for about 3 min in a hot (200 F) solution containing equal volumes of water and concentrated sulfuric acid. Another treatment consists of immersing the work for 2 to 3 min in the following solution at 160 F:

Sulfuric acid (66° Bé)	25% by volume
Hydrochloric acid (18° Bé)..	5% by volume
Ferric chloride hexahydrate..	0.83 oz per gal

Pretreatments that are unique to electroless nickel plating include:

1 A strike copper plate must be applied to parts made of or containing lead, tin, cadmium or zinc, to insure adequate coverage and to prevent contamination of the electroless solution.
2 Massive parts are preheated to bath temperature to avoid delay in the deposition of nickel from the hot electroless bath.

Bath Characteristics. A simplified equation that describes the formation of electroless nickel deposits is:

$$NiSO_4 + NaH_2PO_2 + H_2O \xrightarrow[\text{catalyst}]{\text{heat}} Ni + NaH_2PO_3 + H_2SO_4$$

The essential *requirements for any* electroless nickel solution are:

1 A salt to supply the nickel
2 A hypophosphite salt to provide chemical reduction
3 Water
4 A complexing agent
5 A buffer to control pH
6 Heat
7 *A catalytic surface to be plated.*

Detailed discussions of the chemical characteristics of electroless baths, and of the critical concentration limits of the various reactants, can be found in several of the references listed at the end of this article.

Both alkaline (pH, 7.5 to 10) and acid (pH, 4.5 to 6) electroless nickel baths are used in industrial production. Although the acid baths are easier to maintain and are more widely used, the alkaline baths are reported to have greater compatibility with sensitive substrates (such as magnesium, silicon and aluminum).

Catalysis. Nickel and hypophosphite ions can exist together in a dilute solution without interaction, but will react on a catalytic surface to form a deposit. Furthermore, the surface of the deposit is also catalytic to the reaction, so that the catalytic process continues until any reasonable plate thickness is applied. This autocatalytic effect is the principle upon which all electroless nickel solutions are based.

Metals that catalyze the plating reaction are members of group VIII in the periodic table, which group includes nickel, cobalt and palladium. A deposit will begin to form on surfaces of these metals by simple contact with the solution. Other metals, such as aluminum or low-alloy steel, first form an

* See page 432 for committee list.

Table 1. Typical Applications of Electroless Nickel Plating

Part and basis metal	Typical plate thickness, mils	Postplating heat treatment(a)
Plate Applied for Corrosion Resistance		
Valve body, cast iron	5.0	None
Printing rolls, cast iron	1.0	None
Electronic chassis, 1010 steel	1.0	None
Railroad tank cars, 1020 steel	3.5	1 hr at 1150 F
Reactor vessels, 1020 steel	4.0	1 hr at 1150 F
Pressure vessel, 4130 steel	1.5	3 hr at 350 F
Tubular shaft, 4340 steel	1.5	3 hr at 375 F
Plate Applied for Wear Resistance		
Centrifugal pump, steel	1.0	2 hr at 400 F
Plastic extrusion dies, steel	2.0	2 hr at 375 F
Printing-press bed, steel	1.0	None
Valve inserts, steel	0.5	2 hr at 1150 F
Hydraulic pistons, 4340 steel	1.0	1 hr at 750 F
Screws, 410 stainless	0.2	None
Stator and rotor blades, 410 stainless	0.8 to 1.0	1 hr at 750 F
Spray nozzles, brass	0.5	None
Plate Applied for Buildup of Worn Areas		
Carburized gear (bearing journal)	0.8 to 1.0	5 hr at 275 F
Splined shaft (ID spline), 16-25-6 stainless	0.5	1 hr at 750 F
Connecting arm (dowel-pin holes), type 410	5.0	1 hr at 750 F

(a) Heat treatments above 450 F should be carried out in an inert or reducing atmosphere.

immersion deposit of nickel on their surfaces, which then catalyzes the reaction; still others, such as copper, require a galvanic nickel deposit in order to be plated. Such a galvanic nickel deposit can be formed by the plating solution itself, if the copper is in contact with steel or aluminum.

Plastics, glass, ceramics and other nonmetallics also can be plated, if their surfaces can be made catalytic. This usually is done by the application of traces of a strongly catalytic metal to the nonmetallic surface by chemical or mechanical means.

There is, however, a group of metals that not only do not display any catalytic action, but also interfere with all plating activity. The salts of these metals, if dissolved in a solution even in comparatively small amounts, are poisons and stop the plating reaction on all metals, thus necessitating the discarding of the solution and the formulation of a new one. Examples of these anticatalysts are Pb, Sn, Zn, Cd, Sb, As and Mo.

Table 2. Alkaline Electroless Nickel Baths

Constituent or condition	Bath 1	Bath 2	Bath 3
Composition, Grams per Liter			
Nickel chloride	30	45	30
Sodium hypophosphite	10	11	10
Ammonium chloride	50	50	50
Sodium citrate	..	100	..
Ammonium citrate	..	..	65
Ammonium hydroxide	to pH	to pH	to pH
Operating Conditions			
pH	8 to 10	8.5 to 10	8 to 10
Temperature, F	195 to 205	195 to 205	195 to 205
Plating rate (approx), mil per hr	0.3	0.4	0.3

Paradoxically, the deliberate introduction of extremely minute traces of poisons has been practiced by a number of users of electroless nickel, with the intent of stabilizing the solution. Being an inherently metastable mixture, electroless nickel solutions are likely to decompose spontaneously, with the nickel and hypophosphite reacting on trace amounts of solid impurities present in any plating bath. In order to minimize this problem, a poisoning element is added in trace concentrations of parts per million (or per trillion) to the original make-up of the solution. The poison is adsorbed on the solid impurities in quantities large enough to destroy their catalytic nature. This selective adsorption on catalytic centers decreases the concentration of the catalytic poison to a level below the critical threshold, so that normal deposition of nickel is not impeded, although the rate of deposition is somewhat reduced. The deliberate introduction of catalytic poisons for the purpose of stabilization is covered by several patents, including U. S. Patents 2,762,723 and 2,847,327.

Alkaline Baths. Most alkaline baths in commercial use today are based on the original formulations developed by Brenner and Riddell. They contain a nickel salt, sodium hypophosphite, ammonium hydroxide, and an ammonium salt; they may also contain sodium citrate or ammonium citrate. The ammonium salt serves to complex the nickel and buffer the solution. Ammonium hydroxide is used to maintain the pH between 7.5 and 10. Table 2 gives the compositions and operating conditions of three alkaline electroless baths.

At the operating temperatures of these baths (about 200 F), ammonia losses are considerable. Thorough ventilation and frequent adjustment of pH are required. The alkaline solutions are inherently unstable and are particularly sensitive to the poisoning effects of anticatalysts such as lead, tin, zinc, cadmium, antimony, arsenic and molybdenum — even when these elements are present in only trace quantities. However, when depletion occurs, these solutions undergo a definite color change from blue to green, indicating the need for addition of ammonium hydroxide.

Acid baths are more widely used in commercial installations than alkaline baths. Essentially, acid baths contain a nickel salt, a hypophosphite salt, and a buffer; some solutions also contain a chelating agent. Frequently, wetting agents and stabilizers also are added.

These baths are more stable than alkaline solutions, are easier to control, and usually provide a higher plating rate. Except for the evaporation of water, there is no loss of chemicals when acid baths are heated to their operating range. Table 3 gives the compositions and operating conditions of several acid electroless baths.

Solution Control. In order to assure optimum results and consistent plating rates, the composition of the plating solution should be kept relatively constant; this requires periodic analyses for the determination of pH, nickel content, and phosphite and hypophosphite concentrations. The rate at which these analyses should be made depends on the quantity of work being plated and the volume and type of solution being used. The following methods have been employed:

pH — Standard electrometric method

Nickel — Any one of the colorimetric, gravimetric or volumetric methods is satisfactory; the cyanide method is probably the most popular.

Phosphite — A 10-ml sample of the plating solution is combined with 20 ml of a 6% solution of sodium bicarbonate and cooled in an ice bath. Next, 50 ml of 0.1*N* iodine solution is added and the flask containing this mixture is stoppered and permitted to stand for 2 hr at room temperature. Then the flask is cooled for 15 min in ice water, after which it is unstoppered, the mixture is acidified with acetic acid, and the excess iodine is titrated with 0.1*N* sodium thiosulfate, with starch as an indicator. Determination is then made as follows:

$$NaH_2PO_3 \text{ per liter} = \frac{\text{net ml of 0.1}N\text{ iodine} \times 6.3}{\text{ml of plating solution}}$$

Hypophosphite (U. S. Patent 2,697,651) — A 25-ml sample of the plating solution is diluted to 1 liter. A 6-ml aliquot of the

Table 3. Acid Electroless Nickel Plating Baths(a)

Constituent or condition	Bath 4	Bath 5	Bath 6	Bath 7	Bath 8	Bath 9
Composition, Grams per Liter						
Nickel chloride	30	..	..	30	..	30
Nickel sulfate	..	21	20	..	15	..
Sodium hypophosphite	10	24	27	10	14	12
Sodium acetate	..	..	..	..	12	..
Sodium hydroxyacetate	50	..	..	10	..	..
Sodium succinate	..	..	16	..	..	..
Lactic acid (80%)	..	34 ml	..	..	..	..
Propionic acid (100%)	..	2.2 ml	..	..	..	10
Operating Conditions						
pH	4 to 6	4.3 to 4.6	4.5 to 5.5	4 to 6	5 to 6	4.5 to 5.5
Temperature, F	190 to 210	203	200 to 210	190 to 210	190 to 210	190 to 210
Plating rate (approx), mil per hr	0.8	1.0	1.0	0.4	0.7	0.6

(a) Baths 4 and 7 are covered by U. S. Patent 2,532,283 (a public patent assigned to the National Bureau of Standards); bath 5, by U. S. Patents 2,822,293 and 2,822,294, and bath 6 by U. S. Patents 2,658,841 and 2,658,842.

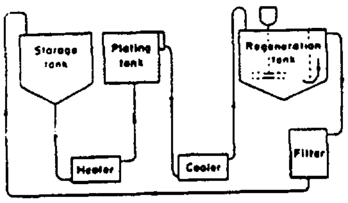


Fig. 1. Schematic of continuous-type system for electroless nickel plating. See text.

dilution is combined with 10 ml of a 10% solution of ammonium molybdate and 10 ml of fresh 6% sulfurous acid. The sample is covered and heated to boiling, and a deep blue color develops. The sample is cooled and diluted to 100 ml, and transmittance at a wave length of 440 microns is determined. The calibration curve on semilog paper is linear.

Hypophosphite (alternative method) — A 5-ml sample of the plating solution is mixed in a beaker with 5 ml of methyl orange solution made up of 1 gram of methyl orange in 1 liter of water. In another beaker is placed 15 ml of an acid solution made up by (a) dissolving 40 grams of sodium metabisulfate in 200 ml of water, (b) slowly adding the sodium metabisulfate solution to a cold solution of 82 ml of sulfuric acid in 650 ml of water, and then (c) diluting this mixture with water to 1 liter. When the acid solution and the solution containing the sample and methyl orange reach a temperature of 77 F in a thermostat, the two solutions are mixed. The time between mixing and the disappearance of the red color is recorded. The hypophosphite concentration is a function of this time and is read from a concentration-time curve made from known standards.

Equipment Requirements. The precleaning and post-treating equipment for an electroless nickel line is comparable to that employed in conventional electrodeposition. The plating tank itself, however, is unique.

The preferred plating tank for batch operations is constructed of stainless steel or aluminum and is lined with a coating of an inert material, such as tetrafluoroethylene or a phenolic-base organic. The size and shape of the tank are usually dictated by the parts to be plated, but the surface area of the plating solution should not be so large that excessive heat loss occurs as a result of evaporation.

A large heat-transfer area and a low temperature gradient are necessary between the heating medium and the plating solution. This combination provides for a reasonable heat-up time without local hot spots that could decompose the solution. It is accepted practice to surround the plating tank with a hot-water jacket or to immerse it in a tank containing hot water. Heating jackets using low-pressure steam also have been used successfully. The use of immersed steam coils is not favored, however, because it entails the sacrifice of a large amount of working area in the tank.

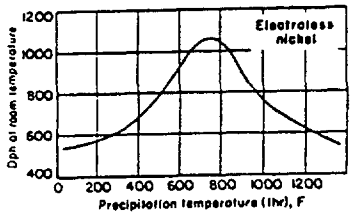
Accessory equipment required or recommended for the tank includes:

1 An accurate temperature controller
2 A filter to remove any suspended solids
3 A pH meter
4 An agitator to prevent gas streaking
5 On small tanks, a cover, to minimize heat loss and exclude foreign particles.
6 On large tanks, a separate small tank to dissolve and filter additives before they are put into the plating tank.

Considerably more equipment is required for a continuous-type system, such as that shown in Fig. 1. The bath is prepared and stored in a separate tank and flows through a heater (which raises its temperature to 205 F) into the plating tank. From the plating tank, the solution is pumped through a cooler, which decreases its temperature to 175 F or below, and then to an agitated regeneration tank, where reagents are added in controlled amounts to restore the solution to its original composition. The solution is then directed past a vertical underflow baffle and out of the regeneration tank to a filter, and then returned to storage.

In externally heated continuous-type systems such as the one shown in Fig. 1, the plating tank and other components of the system that come in contact with the plating solution are constructed of type 304 stainless steel and are not lined or coated; these components are periodically deactivated by chemical treatment. Details of this type of system are covered by several patents, including U. S. Patents 2,941,902; 2,658,839 and 2,874,073.

Properties of the Deposit. Electroless nickel is a hard, lamellar, brittle, uniform deposit. As plated, the hardness



Effect of temperature of 1-hr precipitation heat treatment on room-temperature hardness of a typical electroless nickel deposit (Eberbach tester, 100-gram load). Above 450 F, heat treatment was in an inert atmosphere.

Fig. 2. Heat treatment of coating

varies over a considerable range (425 to 575 dph), depending primarily on phosphorus content, which ranges from 4 to 12%. This hardness can be increased by a precipitation heat treatment. As indicated in Fig. 2, which shows temperature-hardness relationships for a typical deposit, by heating at 750 F for ½ to 1 hr, hardness can be increased to about 1000 dph.

The corrosion resistance of electroless nickel deposits is superior to that of electrodeposited nickel of comparable thickness, but this superiority varies with exposure conditions. Outdoor exposure and salt spray corrosion data indicate that about 25% more resistance is given a steel panel by electroless nickel than by electrolytic.

Table 4. Physical Properties of Electroless Nickel Deposits

Property	Value
Specific gravity	7.8 to 8.6
Melting point	1635 to 1850 F
Electrical resistivity	60 microhm-cm
Thermal expansion	13 × 10⁻⁶ per °C
Thermal conductivity	0.0105 to 0.0135 cal/cm sec/°C

Table 5. Costs for Electroless Nickel Plating (Example 2) (a)

Cost factor	Cost per year(b)
Original investment	$18,000
Fixed costs:	
Depreciation (10 years)	$ 1,800
Insurance	450
Floor space (200 sq ft)	192
Repairs and maintenance	450
Variable costs:	
Raw material	6,100
Utilities	740
Labor costs:	
Direct	10,400
Indirect	2,630
Total	$22,762
Total cost per hr	$9.48
Total cost per sq ft coated to 1 mil	$1.00

(a) Exclusive of costs for: overhead and administration; racking, cleaning and unracking; and preplating and postplating processes. (b) Based on deposition of 1 mil on 0.1-sq-ft parts at rate of 0.8 mil per hr (capacity: 117 pieces, or 9.4 sq-ft/mil, per hr), on a schedule of 10 hr per day, 20 days per month, 2400 hr per year.

Some of the physical properties of electroless nickel are listed in Table 4.

Advantages and Limitations. Some advantages of electroless nickel are:

1 Good resistance to corrosion and wear
2 Excellent uniformity
3 Solderability and brazability
4 Good oxidation resistance.

Limitations of electroless nickel are:

1 High cost
2 Brittleness
3 Poor welding characteristics
4 Lead, tin, cadmium and zinc must be copper strike plated before electroless nickel can be applied
5 Slower plating rate (in general), as compared to electrolytic methods
6 Full brightness in deposit cannot be obtained without extreme brittleness.

Cost. Electroless nickel is considerably more expensive than electrodeposited nickel. Actual costs for electroless nickel plating, as reported by two users, are given in the following examples.

Example 1. Based on the experience of one manufacturing plant, it costs $1.20 to deposit an electroless nickel coating 1 mil thick on a square foot of surface area: 37¢ for chemicals, 59¢ for labor, and 24¢ for equipment and maintenance.

Example 2. Another manufacturing plant reports that it costs $1 per sq ft to plate a 1-mil thickness of electroless nickel on specific parts with a surface area of 0.1 sq ft, on the basis of data obtained over a one-year period (2400 working hours). An analysis of their costs is given in Table 5.

Selected References

A. Brenner, Electroless Plating Comes of Age, *Metal Finishing*, November 1954, p 68-76; December 1954, p 61-68

A. Brenner and G. Riddell, Nickel Plating on Steel by Chemical Reduction, *J Res Nat Bur Stds*, July 1946, p 31-34, and *Proc Am Electroplaters' Soc*, 1946, p 23-30; Deposition of Nickel and Cobalt by Chemical Reduction, *J Res Nat Bur Stds*, Nov 1947, p 385-395, and *Proc Am Electroplaters' Soc*, 1948, p 156-160

G. Gutzeit, Industrial Nickel Coating by Chemical Catalytic Reduction, *Trans Inst Metal Finishing*, 33, 383-423 (1955-1956), and *Corrosion Technol*, 3, 208 (1956)

G. Gutzeit, An Outline of the Chemistry Involved in the Process of Catalytic Nickel Deposition from Aqueous Solution, *Plating*, Oct 1959, p 1158-1164; Nov 1959, p 1275-1278; Dec 1959, p 1377-1378; Jan 1960, p 63-70

C. H. de Minjer and A. Brenner, Studies on Electroless Nickel Plating, *Plating*, December 1957, p 1297-1305

Symposium on Electroless Nickel Plating (Catalytic Deposition of Nickel-Phosphorus Alloys by Chemical Reduction in Aqueous Solution), ASTM STP No. 265 (1959)

3.8.4 Keeler & Long Kolor-Poxy Primer No. 3200

E.140

KEELER & LONG INC.

HEADQUARTERS:
P. O. Box 460
856 Echo Lake Road
Watertown, CT 06795
Tel (860) 274-6701
Fax (860) 274-5857

KOLOR-POXY PRIMER
No. 3200

GENERIC TYPE: POLYAMIDE EPOXY

PRODUCT DESCRIPTION: A two component, high solids, polyamide epoxy primer/topcoat formulated to provide a high-build; abrasion, impact and chemical resistant coating.

RECOMMENDED USES: As a high-build primer for steel and concrete surfaces exposed to a wide range of conditions. No. 3200 is certified by the National Sanitation Foundation (NSF) and Ministry of Environment (Ontario and Saskatchewan, CN)** for application to the interior of potable water tanks.* No. 3200 is also accepted by the USDA for application to incidental food contact surfaces.

NOT RECOMMENDED FOR: Immersion in strong acids.

COMPATIBLE TOPCOATS:
- Kolor-Poxy Primers and Enamels
- Kolor-Poxy Hi-Solids Primer
- Kolor-Poxy Hi-Build Enamels
- Poly-Silicone Enamels
- Hydro-Poxy Enamels
- Kolor-Sil Enamels
- Acrythane Enamels
- Kolorane Enamels
- Tri-Polar Silicone Enamels

PRODUCT CHARACTERISTICS:

Solids by Volume:	66% ± 3%
Solids by Weight:	82% ± 3%
Recommended Dry Film Thickness:	2.5 - 6.0 mils
Theoretical Coverage:	350 Sq. Ft./Gallon @ 3.0 mils DFT
Finish:	Flat
Available Colors:	White and tints
Drying Time @ 72°F	
To Touch:	4 Hours
To Handle:	8 Hours
To Recoat:	24 Hours
To Immersion:	10 Days
VOC Content:	2.52 Pounds/Gallon 302 Grams/Liter

*
White or light gray only
5000 gallon tanks or larger
Up to four coats - Total DFT 24 mils maximum
Use No. 3700 Thinner up to 25% by volume

** Substrate temperature; 45°F (70°C) minimum during cure. Thorough rinse required after final cure.

June, 1994

TECHNICAL BULLETIN

No. 3200 E-140

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	13.6 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F
	Shelf Life:	2 Years
	Pot Life @ 72°F:	8 Hours
	Temperature Resistance:	350°F
	Viscosity @ 77°F:	87 ± 5 (Krebs Units)
	Gloss (60° meter):	6 ± 5
	Storage Temperature:	50 - 95°F
	Mixing Ratio (Approx. by Volume):	4:1
APPLICATION DATA:	Application Procedure Guide:	APG-3
	Wet Film Thickness Range:	3.8 - 9.1 mils
	Dry Film Thickness Range:	2.5 - 6.0 mils
	Temperature Range:	50 - 120°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	SSPC-SP6, SP10, SP5
	Induction Time @ 72°F:	45 Minutes
	Recommended Solvent	
	@ 50 - 85°F:	No. 3700
	@ 86 - 120°F:	No. 2200

Application Methods

Air Spray	
Tip Size:	.055" - .073"
Pressure:	30 - 60 PSIG
Thin:	1.0 - 2.0 Pts/Gal
Airless Spray	
Tip Size:	.015" - .019"
Pressure:	2500 PSIG
Thin:	0.5 - 1.5 Pts/Gal
Brush or Roller	
Thin:	0.5 - 1.5 Pts/Gal

KEELER & LONG INC.

P. O. Box 460, 856 Echo Lake Road
Watertown, CT 06795
Tel: (860) 274-6701 Fax: (860) 274-5857

KOLORS

SSPC SUSTAINING MEMBER

3.8.5 Acrythane Enamel Y-1 Series Top Coating

U.150

HEADQUARTERS:
P. O. Box 460
856 Echo Lake Road
Watertown, CT 06795
Tel (860) 274-6701
Fax (860) 274-5857

ACRYTHANE ENAMEL
Y-1-SERIES

GENERIC TYPE: ACRYLIC URETHANE

PRODUCT DESCRIPTION: A two component, acrylic urethane high-gloss enamel formulated to provide maximum appearance and protective qualities when exposed to an exterior environment. It produces the ultimate in long term color and gloss retention.

RECOMMENDED USES: As a topcoat for exterior structural steel, tanks, piping, conveyors, equipment, and other similar surfaces, as well as interior and exterior concrete surfaces.

NOT RECOMMENDED FOR: Immersion service; splash and spillage of strong acids and alkalies.

COMPATIBLE UNDERCOATS:
Kolorane Aluminum Primer
Kolorane Zinc Rich Primer
Kolor-Poxy Primers and Enamels
Kolor-Poxy Hi-Solids Primer
Acrythane Intermediate Primer
Kolor-Poxy Surfacer

PRODUCT CHARACTERISTICS:

Solids by Volume:	52% ± 5%
Solids by Weight:	67% ± 5%
Recommended Dry Film Thickness:	2.0 - 4.0 mils
Theoretical Coverage:	278 Sq. Ft./Gallon @ 3.0 mils DFT
Finish:	Full Gloss
Available Colors:	Unlimited
Drying Time @ 72°F	
To Touch:	6 Hours
To Handle:	12 Hours
To Recoat:	24 Hours
VOC Content:	< 3.5 Pounds/Gallon < 420 Grams/Liter

June, 1995

TECHNICAL BULLETIN

Y-SERIES U.150

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	10.5 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F
	Shelf Life:	1 Year
	Pot Life @ 72°F:	6 Hours
	Temperature Resistance:	250°F
	Viscosity @ 77°F:	75 ± 5 (Krebs Units)
	Gloss (60° meter):	90 ± 5 (Y-1)
	Storage Temperature:	45 - 95°F
	Mixing Ratio (Approx. by Volume):	4.2:1 (White only)
APPLICATION DATA:	Application Procedure Guide:	APG-5
	Wet Film Thickness Range:	3.5 - 7.0 mils
	Dry Film Thickness Range:	2.0 - 4.0 mils
	Temperature Range:	45 - 100°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	Primed
	Induction Time @ 72°F:	None
	Recommended Solvent	
	@ 45 - 85°F:	No. 1200
	@ 86 - 100°F:	No. 0700

Application Methods

Air Spray	
Tip Size:	.055"
Pressure:	30 - 60 PSIG
Thin:	0.5 - 2.0 Pts/Gal
Airless Spray	
Tip Size:	.011" - .015"
Pressure:	2000 - 2500 PSIG
Thin:	0.0 - 1.5 Pts/Gal
Brush or Roller	Recommended only with limitations
Thin (No. 0700):	0.5 - 1.5 Pts/Gal

KEELER & LONG INC.
P. O. Box 460, 856 Echo Lake Road
Watertown, CT 06795
Tel: (860) 274-6701 Fax: (860) 274-5857

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