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CHAPTER 3

STRUCTURAL EVALUATION

3.1 Structural Design

3.1.1 Discussion

This section summarizes the structural analysis of the TN-68 storage cask. For purposes of structural analysis, the cask has been divided into four components: the cask body (consisting of confinement vessel and gamma shielding), the basket, the trunnions and the neutron shield outer shell. The following information is provided: a brief description of the components, the design bases and criteria, the method of analysis, a summary of stresses for the highest stressed locations, and a comparison with the allowable stress criteria.

The cask body is described in Section 1.2. Drawings 972-70-1, 972-70-2 and 972-70-3 show the cask body. The confinement shell, bottom and lid materials are SA-203, Grade E and SA-350 Grade LF3. The gamma shielding cylinder is SA-266, Class 2 and the bottom is SA-266 Class 2 or SA-516 Gr. 70.

In order to obtain a close fit between the confinement vessel and the gamma shielding for heat transfer, the gamma shielding is heated prior to assembly with the confinement shell. As the gamma shielding cools, a gap forms between the confinement vessel flange and the gamma shielding. This gap is filled with shims as shown on Drawing 972-70-3. The shims are machined to fill the gap and act as a backing plate for the 0.50 inch weld between the confinement flange and the gamma shield shell. The shims are typically less than 0.25 inches and no more than 0.50 inches thick and are made from SA-516, Gr. 70 material. The shims are sized so there is no more than 0.03 inch gap between the shims and the flange or the shims and the gamma shield shell.

The TN-68 confinement vessel is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB of the ASME Code(1) to the maximum practical extent. Exceptions taken to the ASME code are specified in the TN-68 Technical Specifications. The confinement boundary consists of the inner shell and bottom plate, shell flange, lid outer plate, lid bolts, vent and drain cover plates and bolts.

Other structural and structural attachment welds are examined by the liquid penetrant or the magnetic particle method in accordance with Section V, Article 6 of the ASME Code(1). The magnetic particle and liquid penetrant examination acceptance standards are in accordance with Section III, Subsection NF, Paragraphs NF-5340 and NF-5350(1).

Seal welds are examined visually or by liquid penetrant or magnetic particle methods in accordance with Section V of the ASME Code(1). Electrodes, wire, and fluxes used for fabrication comply with the applicable requirements of the ASME Code, Section II, Part C(1).

The welding procedures, welders and weld operators are qualified in accordance with Section IX of the ASME Code(1).

The basket is a welded assembly of stainless steel boxes and designed to accommodate 68 fuel assemblies. The fuel compartment stainless steel box sections are attached through fusion welds to 304 SST plates sandwiched between box sections. The fusion welds are spaced intermittently along the box sections. Neutron poison plates composed of a boron-aluminum alloy or a boron carbide - aluminum metal matrix composite are sandwiched between the stainless steel walls of adjacent box sections and adjacent stainless steel plates. The 304 stainless steel members are the primary structural components. The neutron poison plates provide the heat conduction path from the fuel assemblies to the cask cavity wall, and also provide criticality control. The bottom row of plates which are 304 SST (no poison) are also sandwiched between fuel compartment box sections and provide structural support of the basket. Drawings 972-70-4 and 972-70-5 show details of the basket.

The basket is supported laterally by 6061-T6 aluminum rails (shown in Drawing 972-70-2). The rails are attached to the periphery of the basket by welded studs.

Tangential alignment between the basket and cask cavity is maintained by a key at the perimeter of the basket. This key is designed to prevent the basket from rotating in the cask cavity wall under normal lateral inertial loadings.

The two lower trunnions are cylindrical SA-105 forgings that are welded to the cask body gamma shielding. The two upper trunnions are SA-182, Gr. F6NM forgings and are designed to lift the loaded TN-68 cask vertically. The upper trunnions are bolted to the cask body with a flange connection using 12-1 ½" diameter bolts of SA-320-L43. The lower trunnions provide capability to rotate the cask prior to loading of spent fuel. The upper trunnions are designed to meet the requirements of ANSI N14.6.(2) The trunnions are shown in Drawing 972-70-2.

The outer shell of the neutron shield consists of a cylindrical shell section with closure plates at each end. The closure plates are welded to the outer surface of the cask body gamma shielding. The outer shell provides an enclosure for the resin-filled aluminum containers and maintains the resin in the proper location with respect to the active length of the fuel assemblies in the cask cavity. The outer shell has no other structural function. The shell is painted carbon steel.

The top neutron shield consists of a disk of commercial grade polypropylene. The top neutron shield is attached to and rests on the cask lid. It is protected from the environment by the protective cover.

3.1.2 Design Criteria

This section describes the TN-68 analyses performed under the various loading conditions identified in Section 2.2. These loadings include all of the normal events that are expected to occur regularly. In addition, they include severe natural phenomena and man-induced low probability events postulated because of their potential impact on the immediate environs. The loading from the hypothetical tipping accident that is shown not to occur, is also analyzed in this chapter.

The TN-68 loadings are summarized in Table 2.2-4 and described in Chapter 2.
The loads selected for analysis of the cask are discussed in Section 2.2.5.2, 2.2.5.3 and 2.2.5.4. Numerical values of these loads are listed in Tables 2.2-2 and 2.2-3.

The TN-68 components have been evaluated using numerical analysis. Finite element models of the cask body and basket have been developed, and detailed computer analyses have been performed using the ANSYS computer program(3). The stress analysis of the lid bolts is performed based on the methodology of NUREG/CR-6007(4). Other components such as trunnions are analyzed using conventional textbook methods. Table 3.1-1 lists the specific individual load cases analyzed for each major TN-68 component. The sections describing the analyses and the tables listing the stress results, where applicable, are also indicated. TN-68 components are not subjected to any significant cyclic loads such as pressure or temperature fluctuations resulting in an appreciable fatigue usage factor. Also, in the operating temperature range, the materials selected are not subject to significant creep.

3.1.2.1 Confinement Boundary

The confinement boundary consists of the inner shell (both cylinder and bottom) and closure flange out to the seal seating surface and the lid assembly outer plate. The lid bolts and seals are also part of the confinement boundary. The confinement boundary is designed to the maximum practical extent as an ASME Class I component in accordance with the rules of the ASME Code, Section III, Subsection NB. Exceptions to the ASME Code are discussed in Chapter 7.

The stresses due to each load are categorized as to the type of stress induced, e.g. membrane, bending, etc., and the classification of stress, e.g. primary, secondary, etc. Stress limits for confinement vessel components, other than bolts, for Normal (Design and Level A) and Hypothetical Accident (Level D) Loading Conditions are given in Table 3.1-2. The stress limits used for Level D conditions, determined on an elastic basis, are based on the entire structure (confinement shell and gamma shielding material) resisting the accident load. Local yielding is permitted at the point of contact where the load is applied.

The allowable stress limits for the confinement bolts are listed in Table 3.1-3. The allowable stress limits for the lid bolts are listed separately in Tables 3A.3-3 and -4.

The allowable stress intensity value, S_m, as defined by the Code, is taken at the maximum temperature calculated for each service load condition.

3.1.2.2 Non-Confinement Structure

Certain components such as the gamma shielding, the neutron shield outer shell and the trunnions are not part of the cask confinement boundary but do have structural functions. These components, referred to as non-confinement structures, are required to react to the confinement or environmental loads and in some cases share loadings with the confinement structure. The stress limits for the non-confinement structures (excluding the basket) are given in Table 3.1-4. The top neutron shield and the radial neutron shielding including the carbon steel enclosure have not been designed to withstand all of the hypothetical accident loads. The shielding may degrade during the fire or due to cask burial. Also there may be local damage due to tornado impacts or cask tipover. Therefore a bounding analysis assuming that the exterior neutron shielding is completely removed, has been performed. This analysis shows that the site boundary accident dose rates are not exceeded. These accidents are described in Chapter 11.

3.1.2.3 Basket

The basket is designed, fabricated and inspected in accordance with the ASME Code Subsection NG to the maximum practical extent. The following exceptions are taken:

The poison and aluminum plates are not used for structural analysis. Therefore, the materials are not required to be code materials. The quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are imposed in lieu of NCA-3800. The basket will not be code stamped. Therefore the requirements of NCA are not imposed. Fabrication and inspection surveillance is performed by the owner and design organization in lieu of an authorized nuclear inspector.

The fuel basket rail material is not a Class 1 material. It was selected for its properties. Aluminum has excellent thermal conductivity and a high strength to weight ratio provided that temperatures do not exceed 400°F.

NUREG-3854 and 1617 allow materials other than ASME Code materials to be used in the cask fabrication. ASME Code does provide the material properties for the aluminum alloy up to 400°F and also allows the material to be used for Section III applications (Class 2 or 3) up to 400°F temperature. The construction of the aluminum rails will meet the requirements of Section III, Subsection NG.

If an automated welding process is used for the box seam welds, PT examination in accordance with Section III, Subsection NG, Para. NG-5233 will be performed in lieu of the requirements of Section III, Subsection NG, Para. NG-5231.

The stress limits for the basket are summarized in Table 3.1-5. The basket fuel compartment wall thickness is established to meet heat transfer, nuclear criticality, and structural requirements. The basket structure must provide sufficient rigidity to maintain a subcritical configuration under the applied loads. The 304 stainless steel members in the TN-68 basket are the primary structural components. The neutron poison plates are the primary heat conductors and also provide the necessary criticality control.

The basis for the 304 stainless steel fuel compartment box and fusion welds stress allowables are Section III, Division I, Subsection NG of the ASME Code. The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the basket for Normal (Design and Level

A) load conditions. The average primary shear stress across a section is limited to 0.6 S_m. The fusion weld shear stress allowable is limited to 0.3 * 0.6 S_m= 0.18 S_m

The hypothetical impact accidents are evaluated as short duration Level D conditions. The stress criteria are taken from Section III, Appendix F of ASME(1) Code. For elastic quasistatic analysis, the primary membrane stress is limited to the smaller of 2.4S_m or 0.7S_u and membrane plus bending stress intensities are limited to the smaller of 3.6S_m or S_u. The average primary shear stress across a section is limited to 0.42 S_u. The fusion weld shear stress allowable is the smaller of 0.42 S_u or (2 *0.6S_m).

The fuel compartment walls, when subjected to compressive loadings, are also evaluated against ASME Code rules for component supports to ensure that buckling will not occur. The acceptance criteria (allowable buckling loads) are taken from ASME Code, Section III, Appendix F, paragraph F-1341.4, Plastic Instability Load. The allowable buckling load is equal to 70% of the calculated plastic instability load. The buckling analyses of the aluminum rails are considered separately. See Appendix 3B.5.4 for complete details of criteria for these conditions.

3.1.2.4 Trunnions

The design criteria for the trunnions are both unique and specific. They are specified in Section 3.4.3.1.

3.2 Weights and Centers of Gravity

The weight of the TN-68 cask and contents is 115 tons. The weights of the major individual subassemblies are listed in Table 3.2-1. The center of gravity of the cask is located on the axial centerline 97.16 inches from the base of the cask.

In most of the structural analyses, a conservatively high weight is used. However, in certain cases, such as the G load calculation and the stability analysis of the cask, a conservatively low weight and higher c.g. are used.

3.3 Mechanical Properties of Materials

3.3.1 Cask Material Properties

This section provides the mechanical properties of materials used in the structural evaluation of the TN-68 storage cask. Table 3.3-1 lists the materials selected, the applicable components, and the minimum yield, ultimate, and design stress values specified by the ASME Code. All values reported in Table 3.3-1 are for metal temperatures up to 100°F. For higher temperatures, the temperature dependency of the material properties is reported in Table 3.3-2.

Table 3.3-3 summarizes the thermal analysis results from Chapter 4. These results support the selection of cask body component design temperatures for structural analysis purposes.

3.3.2 Basket Material Properties

The material properties of the 304 stainless steel plates are taken from the ASME(1)Code, Section II, Part D. The material properties of the aluminum alloy (6061-T6) are also taken from the ASME Code. These properties are listed with specific references in Tables 3.3-4 and 3.3-5.

3.3.3 Material Properties Summary

Table 3.3-6 provides a table which summarizes the components of the TN-68 cask, their primary function and an overview of the general conditions (stresses,temperatures, pressures, coatings, etc) during storage. This table is intended to summarize the information provided elsewhere in the SAR.

3.3.4 Material Durability

Materials must maintain the ability to perform their safety-related functions over at least the cask's 40 year lifetime under the cask's thermal, radiological, corrosion, and stress environment.

Metallic components:

Gamma radiation has no significant effect on metals. The effect of fast neutron irradiation of metals is a function of the integrated fast neutron flux, which is on the order of 10^{14} n/cm^2 inside the TN-68 after 40 years. Studies on fast neutron damage in aluminum, stainless steel, and low alloy steels rarely evaluate damage below 10^{17} n/cm^2 because it is not significant. Extrapolation of the data available down to the 10^{14} range confirms that there will be virtually no neutron damage to any of the TN-68 metallic components.

The effect of the TN-68 temperature environment on the required structural properties is evaluated in the SAR. There is no long term degradation of metals in the TN-68 temperature environment. The effect of creep at temperature is the basis for establishing the seal temperature limits. Additional information on the seals, including construction, corrosion evaluation and long term test data, is provided in Sections 2.3.2.1 and 7.1.3.

The cask exterior carbon steel components is protected from corrosion by the paint (epoxy, acrylic urethane or equivalent). The interior is protected by the helium environment inside the cask. The aluminum, carbon steel, and stainless steel components are not subject to significant corrosion as discussed in Section 3.4.1.

Studies have been conducted to show that neither of the neutron absorber materials used in the basket will degrade significantly as both have excellent resistance to thermal and radiation alteration in the service environments of interest to this application.

Non-metallic components:

The radial neutron shield resin is a proprietary reinforced polymer. Appendix 9A provides information on the composition and the radiation and temperature resistance of the resin. Polyester is inert with respect to water, and the fire retardant mineral fill makes it self-extinguishing. Furthermore, the resin is contained in aluminum tubes inside a steel shell, so that the material is retained in place, and isolated from both water and from sources of ignition.

Elastomer o-rings or gaskets in the weather cover, quick disconnects, drain tube, and pressure relief valve are not important to safety. The quick disconnects are not part of the confinement boundary.

Stem tips on overpressure system valves are Kel-F or similar material, and are not important to safety; at the valve locations, the radiation level and temperatures are low.

Paint is subject to routine maintenance and touch-up. Radiation levels and temperature on the cask exterior are not high enough to damage the paint. This is confirmed by dry cask experience.

The top neutron shield (polypropylene) is Not Important to Safety. Polypropylene is slow burning to non-burning according to Table 24, Section 1 of the Handbook of Plastics and Elastomers(23). Polypropylene is inert with respect to water. Furthermore, the weather protective cover isolates the top neutron shield material from sources of ignition and from water.

3.4 General Standards for Casks

3.4.1 Chemical and Galvanic Reactions

The materials of the TN-68 cask have been reviewed to determine whether chemical, galvanic or other reactions among the materials, contents and environment might occur during any phase of loading, unloading, handling or storage. This review is summarized below:

The TN-68 cask components are exposed to the following environments:

- During loading and unloading, the casks are submerged in pool water. For BWR plants the pool water is deionized. This affects the interior and exterior surfaces of the cask body, lid and the basket. The protective cover, the top neutron shield, and the overpressure system are not submerged in the spent fuel pool. The casks are only kept in the spent fuel pool for a short period of time, typically about 6 hours to load or unload fuel, 1 - 2 hours to drain, and another 8 - 10 hours to completely dry, evacuate and backfill the cask with helium.

- During handling and storage, the exterior of the cask is exposed to normal environmental conditions of temperature, rain, snow, etc. All of the exterior surfaces with the exception of stainless steel components are protected from environmental exposure by a polyamide enamel epoxy coating. The paint is touched up periodically if there are any areas which peel or otherwise deteriorate. Therefore, the cask exterior is protected from chemical, galvanic or other reactions during storage.

- During storage, the interior of the cask is exposed to an inert helium environment. The helium environment does not support the occurrence of chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur. The cask is thoroughly dried before storage by a vacuum drying process. It is then sealed and backfilled with helium, thus stopping corrosion. Since the cask is vacuum dried, galvanic corrosion is also precluded since there is no water present at the point of contact between dissimilar metals.

- The radial neutron shielding materials and the aluminum resin boxes are sealed during all normal operations. The amount of oxygen in the sealed region is very small. The resin material is inert after it has cured and does not affect the aluminum boxes or the carbon steel housing.

3.4.1.1 Cask Interior

The TN-68 cask materials are shown in the Parts List on Drawing 972-70-2. The confinement vessel is made from SA-203 Grade E and SA-350 LF3. This low-alloy carbon steel is uncoated.

All sealing surfaces are stainless steel clad by weld overlay.

Within the cask cavity, there are basket rails made from 6061-T6 aluminum. The cask basket is assembled from SA-240, Type 304 stainless steel boxes which are joined together by a proprietary fusion welding process and separated by neutron poison and stainless steel plates which form a sandwich panel. The neutron poison is not welded or bolted to the stainless steel, but is held in place by the geometry of the boxes and stainless steel plates.

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, aluminum-based neutron poison and stainless steel within the basket itself, and the interaction of the aluminum basket rails with the carbon steel cask cavity wall and the pool water.

Typical water chemistry in a BWR Spent Fuel pool is as follows:

pH	5.6 - 7.1
Chloride	1 - 10 ppb
Conductivity	0.7 - 1.8 μmho
Silica	2.5 - 2.7 ppm
Pool Temperature	70 - 115°F

Behavior of Aluminum in Deionized Water

Aluminum is used for many applications in spent fuel pools. In order to understand the corrosion resistance of aluminum within the normal operating conditions of spent fuel storage pools, a discussion of each of the types of corrosion is addressed separately. None of these corrosion mechanisms are expected to occur in the short time period that the cask is submerged in the spent fuel pool.

General Corrosion

General corrosion is a uniform attack of the metal over the entire surfaces exposed to the corrosive media. The severity of general corrosion of aluminum depends upon the chemical nature and temperature of the electrolyte and can range from superficial etching and staining to dissolution of the metal. Figure 3.4-5 shows a potential -pH diagram for aluminum in high purity water at 77°F. The potential for aluminum coupled with stainless steel and the limits of pH for BWR pools are shown in the diagram to be well within the passivation domain. The passivated surface of aluminum (hydrated oxide of aluminum) affords protection against corrosion in the domain shown because the coating is insoluble, non-porous and adherent to the surface of the aluminum. The protective surface formed on the aluminum is known to be stable up to 275°F and in a pH range of 4.5 to 8.5(13).

Galvanic Corrosion

Galvanic corrosion is a type of corrosion which could cause degradation of dissimilar metals exposed to a corrosive environment for a long period of time.

Galvanic corrosion is associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte. The two dissimilar conductors of interest in this discussion are aluminum and stainless steel or aluminum and carbon steel in deionized water. There is little galvanic corrosion in deionized water since the water conductivity is very low. There is also less galvanic current flow between the aluminum-stainless steel couple than the potential difference on stainless steel which is known as polarization. It is because of this polarization characteristic that stainless steel is compatible with aluminum in all but severe marine, or high chloride, environmental conditions[15].

At points of contact between the aluminum basket rails and the carbon steel shell, some galvanic reaction may occur, with the aluminum acting as a sacrificial anode. The carbon steel shell will be protected from corrosion as a result of this reaction. The corrosion of the aluminum rails will not be sufficient to affect their thermal or mechanical performance given the water purity and short immersion time.

Pitting Corrosion

Pitting corrosion is the forming of small sharp cavities in a metal surface. The first step in the development of corrosion pits is a local destruction of the protective oxide film. Pitting will not occur on commercially pure aluminum when the water is kept sufficiently pure, even when the aluminum is in electrical contact with stainless steel. Pitting and other forms of localized corrosion occur under conditions like those that cause stress corrosion, and are subject to an induction time which is similarly affected by temperature and the concentration of oxygen and chlorides. As with stress corrosion, at the low temperatures and low chloride concentrations of a spent fuel pool, the induction time for initiation of localized corrosion will be greater than the time that the cask internal components are exposed to the aqueous environment.

Crevice Corrosion

Crevice corrosion is the corrosion of a metal that is caused by the concentration of dissolved salts, metal ions, oxygen or other gases in crevices or pockets remote from the principal fluid stream, with a resultant build-up of differential galvanic cells that ultimately cause pitting. Crevice corrosion could occur in the basket plates, around the stainless steel welds. However, due to the short time in the spent fuel pool, this type of corrosion is not expected to be significant.

Intergranular Corrosion

Intergranular corrosion is corrosion occuring preferentially at grain boundaries or closely adjacent regions without appreciable attack of the grains or crystals of the metal itself. Intergranular corrosion does not occur with commercially pure aluminum and other common work hardened aluminum alloys.

Stress Corrosion

Stress corrosion is failure of the metal by cracking under the combined action of corrosion and high stresses approaching the yield stress of the metal. During normal operations, the cask is upright and there is negligible load on the basket. The stresses on the basket plates are very small, well below the yield stress of the basket materials.

Behavior of Carbon Steel in Deionized Water

The corrosion rate of iron in aerated soft water with the range $4 \leq pH \leq 10$ is 0.01 inch/year. For 48 hour submersion during fuel loading, the total corrosion would be $5x10^{-5}$ inch, which is negligible. Hydrogen evolution from iron corrosion does not occur in near neutral water[16]. See Figure 3.4-6. Low alloy carbon steel is slightly more resistant to corrosion than iron under these conditions.

Behavior of Austenitic Stainless Steel in Deionized Water

The fuel compartments and the structural plates which support the fuel compartments are made from Type 304 stainless steel. In addition, the gasket sealing surfaces are stainless steel clad. Stainless steel does not exhibit general corrosion when immersed in deionized water. Galvanic attack can occur between the aluminum in contact with the stainless steel in the water. However, the attack is mitigated by the passivity of the aluminum and the stainless steel in the short time the pool water is in the cask. Also the low conductivity of the pool water tends to minimize galvanic reactions.

Stress corrosion cracking in the Type 304 stainless steel welds of the basket to the structural stainless steel plates is also not expected to occur, since the baskets are not highly stressed during normal operations. There may be some residual fabrication stresses as a result of welding of the stainless steel boxes and fusion welds between the boxes and stainless steel plates. Of the corrosive agents that could initiate stress corrosion cracking in the 304 stainless steel basket welds, only the combination of chloride ions with dissolved oxygen occurs in spent fuel pool water. Although stress corrosion cracking can take place at very low chloride concentrations and temperatures such as those in spent fuel pools (less than 10 ppb and 160°F, respectively), the effect of low chloride concentration and low temperature is to greatly increase the induction time, that is, the period during which the corrodent is breaking down the passive oxide film on the stainless steel surface. Below 60°C (140°F), stress corrosion cracking of austenitic stainless steel does not occur at all. At 100 °C (212 °F), chloride concentration on the order of 15% is required to initiate stress corrosion cracking[18]. At 288 °C (550 °F), with tensile stress at 100%

of yield in BWR water containing 100 ppm O_2, time to crack is about 40 days in sensitized 304 stainless steel [19]. Thus, the combination of low chlorides, low temperature and short time of exposure to the corrosive environment eliminates the possibility of stress corrosion cracking in the basket welds.

The chloride content of all expendable materials which come in contact with the basket materials are restricted and water used for cleaning the baskets is restricted to 1.0 ppm chloride.

Behavior of Aluminum Based Neutron Poison in Deionized Water

The aluminum component of the borated aluminum is a ductile metal having a high resistance to corrosion. Its corrosion resistance is provided by the buildup of a protective oxide film on the metal surface when exposed to a corrosive environment. As stated above for aluminum, once a stable film develops, the corrosion process is arrested at the surface of the metal. The film remains stable over a pH range of 4.5 to 8.5.

Tests were performed by Eagle Picher[14] which concluded that borated aluminum exhibits a strong corrosion resistance at room temperature in deionized water. Satisfactory long-term usage in these environments is expected. At high temperature, the borated aluminum still exhibits high corrosion resistance in the pure water environment.

From tests on pure aluminum, it was found that borated aluminum was more resistant to uniform corrosion attack than pure aluminum.

The alternate neutron poison material is a boron carbide / aluminum composite. The billet is produced by blending of aluminum and boron carbide powders, cold isostatic compacting, and vacuum sintering. The plates are formed from the billet by rolling or extrusion. The result is a matrix of full-density aluminum with a fine dispersion of boron carbide particles throughout. The corrosion behavior is similar to that of the base aluminum alloy.

There are no chemical, galvanic or other reactions that could reduce the areal density of boron in the TN-68's neutron poison plates with either of the poison plate materials.

3.4.1.2 Cask Exterior

The exterior of the cask is carbon steel. The exterior of the cask, with the exception of the trunnion bearing surfaces is painted using an epoxy, acrylic urethane, or equivalent enamel coating with the appropriate primer. The paint should be compatible with the pool water and easy to decontaminate.

The paint is visually inspected prior to installation of the cask in the spent fuel pool and periodically during storage. Touch up painting is performed if the paint deteriorates.

3.4.1.3 Lubricants and Cleaning Agents

The following lubricants and cleaning agents may be used on the TN-68 cask:

- Never-seez or Neolube (or equivalent) is used to coat the threads and bolt shoulders of the closure bolts. Never-seez is also used to coat the contact areas of the top and bottom trunnions during transport and lifting operations to prevent impregnation of contamination.

The lubricant should be selected for compatibility with the spent fuel pool water and the cask materials, and for its ability to maintain lubricity under long term storage conditions.

- During fabrication, expendable materials are restricted to limit exposure to water leachable chlorides, halogenated compounds and sulfur and its compounds. As the cask is lowered into the spent fuel pool, the cask is sprayed with demineralized water to provide a film of clean water on the cask surfaces. The time in the pool is minimized in order to minimize cask contamination levels.

The cask body is cleaned in accordance with approved procedures to remove cleaning residues prior to shipment to the Power Station. The basket is also cleaned prior to installation in the cask. The cleaning agents and lubricants have no significant affect on the cask materials and their safety related functions.

3.4.1.4 Hydrogen Generation

During the initial passivation state, small amounts of hydrogen gas may be generated in the TN-68 cask. The passivation stage may occur prior to submersion of the cask into the spent fuel pool. Any amounts of hydrogen generated in the cask will be insignificant and will not result in a flammable gas mixture within the cask.

The small amount of hydrogen which may be generated during cask operations does not result in a safety hazard. In order for concentrations of hydrogen in the cask to reach levels that could ignite or explode, most of the cask would have to be filled with water for the hydrogen generation to occur, and the lid would have to be in place with both the vent and drain ports closed. This does not occur during TN-68 loading or unloading operations.

After loading fuel into the TN-68, the lid, with the vent port quick-disconnect coupling removed, is placed on the cask and the cask is raised to the pool surface. At this time the cask is completely filled with water. Any hydrogen generated inside the cask will be released at the vent port. Once the process of pumping out the water is begun, it is carried through to completion without interruption, a process which takes 1 to 2 hours. The vent port remains open during this process, allowing air into the vent. The rate of hydrogen generation is too low and the time period too short to generate an ignitable or explosive mixture. After a short period of passivating the surfaces of the aluminum and aluminum-based neutron poison, there is no source for further generating H_2 gas.

An estimate of the maximum hydrogen concentration can be made, ignoring the effects of radiolysis, recombination, and solution of hydrogen in water. Testing was conducted by Transnuclear(12) to determine the rate of hydrogen generation for aluminum metal matrix composite in intermittent contact with 304 stainless steel and for aluminum 6061 in intermittent contact with SA203 low alloy steel. The samples represent the basket rails paired with the cask cavity wall, and the neutron poison plates paired with the basket compartment tubes. The test specimens were submerged in deionized water for 12 hours at 70 °F to represent the period of initial submersion and fuel loading, followed by 12 hours at 150 °F to represent the period after the fuel is loaded, until the water is drained. The hydrogen generated during each period was removed from the water and the test vessel and measured.

The test results were

	12 hour @ 70 °F		12 hour @ 150 °F	
	$cm^2hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$	$cm^2hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$
aluminum MMC/SS304	0.517	1.696E-4	0.489	1.604E-4
low alloy steel/ Al plate	0.476	1.562E-4	0.644	2.113E-4

The total surface area of the aluminum/steel interface at the basket perimeter is 186.3 ft^2 and the total area of neutron absorber/compartment wall interface is 1976.4 ft^2. If paired aluminum and neutron absorber plates are used, this surface area would double to 3953 ft^2. These surface areas, combined with the data at 150 °F above result in a hydrogen generation rate of

$$[(2.1x10^{-4}\ ft^3/ft^2hr)(186.3\ ft^2)]+[(1.6x10^{-4}\ ft^3/ft^2hr)(3953\ ft^2)] = 0.67\ ft^3/hr$$

in the TN-68. The total free volume in the cask, with fuel in place, and without water, is 211.6 ft^3. The following assumptions are made to arrive at a conservative estimate of hydrogen concentration:

- The hydrogen generation rate is constant, that is, no credit is taken for the fact that less surface area is submerged as draining proceeds
- The draining rate is constant
- All generated hydrogen is released instantly to the plenum between the water and the lid, that is, no dissolved hydrogen is pumped out with the water, and no released hydrogen escapes through the open vent port.

Under these assumptions, the hydrogen concentration in the space between the water and the lid is constant during draining, and is a function of the total drain time only. For a typical drain time of 2 hours, the hydrogen concentration is 0.67 ft^3 H_2/hr (2 hr)/211.6 ft^3 = 0.6 %. For a drain time of 10 hours, much longer than expected, the concentration would be 3.2 %, still well below the lower flammable limit of 4%.

Unlike welded canisters, the TN-68 cask has a bolted closure. There is no source of ignition to result in an explosion or fire.

3.4.1.5 Effect of Galvanic Reactions on the Performance of the Cask

There are no significant reactions that could reduce the overall integrity of the cask or its contents during storage. The cask and fuel cladding thermal properties are provided in Chapter 4. The emissivity of the fuel compartment is 0.3, which is typical for non-polished stainless steel surfaces. If the stainless steel is oxidized, this value would increase, improving heat transfer. The fuel rod emissivity value used is 0.8, which is a typical value for oxidized Zircaloy. Therefore, the passivation reactions would not reduce the thermal properties of the component cask materials or the fuel cladding.

There are no reactions that would cause binding of the mechanical surfaces or the fuel to basket compartment boxes due to galvanic or chemical reactions.

There is no significant degradation of any safety components caused directly by the effects of the reactions or by the effects of the reactions combined with the effects of long term exposure of the materials to neutron or gamma radiation, high temperatures, or other possible conditions.

3.4.2 Positive Closure

Positive fastening of all access openings through the confinement boundary is accomplished by bolted closures which preclude unintentional opening. All of the openings in the TN-68 cask are through the lid of the cask. A protective cover is installed around the lid during storage. Security seals are installed in two of the protective cover bolts to ensure that no unauthorized entry into the cask has been attempted.

3.4.3 Lifting Devices

Section 3.4.3.1 provides the analysis of the trunnions, which are the only components which are used to lift the cask. Section 3.4.3.2 provides an analysis of the local stresses in the cask wall due to the effect of a 6G lifting load on the trunnions. The resulting local stresses in the cask wall are conservatively added to the normal condition stresses resulting from other load combinations. Section 3.4.3.3 provides the stress analysis of the upper trunnion flange bolts.

3.4.3.1 Trunnion Analysis

This section provides the structural analysis of the TN-68 storage cask trunnions. The upper and lower trunnion geometry is shown in Figure 3.4-1. The upper trunnions are SA-182 Gr F6NM alloy forgings and are attached to the cask body with bolted flange connections. The lower trunnions are SA-105 carbon steel forgings, and are welded to the cask body. A flat surface is machined on the cask body outer surface at each trunnion location for this purpose.

The two upper trunnions are used for lifting the cask and are designed to the requirements of ANSI N14.6(2). They can support a loading equal to 6 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also lift 10 times the weight of the cask without exceeding the ultimate tensile strength of the material. A dynamic load factor of 1.15 is used in evaluating the trunnion stresses.

The lower trunnions are used to rotate the cask from a horizontal orientation to the vertical orientation. If the cask were lifted in a horizontal orientation, all four trunnions would be used and the loading on each trunnion would be only half of the load due to the vertical lift.

Figure 3.4-1 shows the basic dimensions of the upper and lower trunnions. A cask weight of 240,000 lbs. is used in this calculation. Table 3.4-1 shows the cross sectional area and moment of inertia at shoulder cross section A-A of the upper trunnions. In addition the loads applied to this section (for 6 W and 10 W loading) to evaluate the yield and ultimate limits are also listed.

Table 3.4-2 presents a summary of the stresses at the same location to compare against the trunnion yield and ultimate strengths. Also listed at the bottom of the table are the allowable stresses (yield and ultimate strengths). All of the calculated stresses in the trunnions are acceptable. Both upper and lower trunnions are designed such that the minimum margin of safety occurs at the trunnions' shoulders.

3.4.3.2 Local Stresses in Cask Body at Upper Trunnion Locations

This section describes the analysis performed to calculate the local stresses in the cask body at the trunnion locations due to the loadings applied through the trunnions. These local effects are not included in the ANSYS stress result tables reported in Section 3.4.4. These local stresses are superimposed on the ANSYS stress results for the cases where the inertial lifting loads are reacted at the trunnions. The local stresses are calculated in accordance with the methodology of WRC Bulletin 107(5) which is based on the Bijlaard analysis for local stresses in cylindrical shells due to external loadings. A summary of the trunnion loads is provided in Table 3.4-3.

The neutron shield and thin outer shell are not considered to strengthen either the trunnions or the gamma shield shell. The trunnion is approximated by an equivalent attachment so that the curves of Reference 5 can be used to obtain the necessary coefficients. These resulting coefficients are read from the reference 5 curves and inserted into blanks in a standard computation form, a sample of which is shown on Table 3.4-4. The stresses are calculated by performing the indicated multiplications and the resulting stress is inserted into the stress table at the eight stress locations, i.e., AU, AL, BU, BL, etc. Note that the sign convention for this table is defined on the figure for the load directions as shown. The membrane plus bending stresses are calculated by completing Table 3.4-4.

The cylindrical body is assumed to be a hollow cylinder of infinite length. This is conservative since end restraints reduce the local cylinder bending effects.

The trunnion and cylinder dimensions are taken from Section 1.5 drawings. The dimensions and Bijlaard parameters used are as follows:

List Of Bijlaard Parameters at Upper Trunnion Locations

Parameter	Parameter Description	Parameter Value
R_m	Mean radius of shell	37.88 in.
T	Wall thickness of shell	6.27 in.
$\alpha=R_m/T$	Shell Parameter	6.0
r_o	Outside radius of attachment	6.875 in.
$\beta=0.875r_o/R_m$	Attachment Parameter	0.16

The maximum primary plus bending stress intensity due to a 6 G vertical lift is 19.8 ksi. The membrane stress intensity due to this load is 7.3 ksi. These are well below the yield stress of the gamma shield cylinder material. The stress intensity due to the local trunnion loading are combined with the finite element results at the top trunnion attachment locations and presented in Section 3A.2.

3.4.3.3 Trunnion Bolt Stresses

The trunnion flange is attached to the gamma shield vessel by twelve 1.5-8UN-2A bolts of SA-320 Gr. L43 material. The bolted flange is tightly fitted into the recess in the cask body. This recess provides a bearing area between the outside perimeter of the trunnion flange and the cask body. The radial clearance between the bolt shank and trunnion flange bolt holes is large enough so that shear loads are carried by the trunnion flange-to-cask body recess interface and not the bolts. The bolts develop only the tensile load due to trunnion moment.

The bending moment at the flange interface due to 10G is equal to 1,380,000 x 7.51 = 10,363,800 in-lbs. From Reference 11, Case 3, (for bolt patterns symmetrical about the vertical axis and flange rotating about the bottom bolt) the maximum bolt force due to bending moment M is:

$F_{max} = (4/(3RN))M$

where

R = Bolt circle radius = 6.875 in.
N = No. of bolts = 12

$F_{max} = 4(10,363,800)/(3 \times 6.875 \times 12) = 167,496$ lbs.

The bolt stress area = 1.492 in^2

Max. tensile stress = 167,496/1.492 = 112.3 ksi

Bolt allowable tensile stress = S_u (at 300°F) = 125 ksi

For yield load (6G), the maximum tensile stress = (6/10)(112,263) = 67.4 ksi

The bolt allowable yield stress = S_y (at 300°F) = 95.7 ksi

Therefore the bolt stresses are acceptable for both 10G(ultimate) and 6G (yield) trunnion loads.

3.4.4 Heat

3.4.4.1 Summary of Pressures and Temperatures

Stress allowables for the cask components are a function of component temperature. The temperatures used to perform the structural analysis are based on actual maximum calculated temperatures or conservatively selected higher temperatures. Chapter Four summarizes significant temperatures calculated for the TN-68 cask. The design temperatures used for stress analysis acceptance criteria for the cask are provided in Table 3.3-3. These temperatures are used to establish the allowables for every normal and accident load combination evaluated in this report.

The maximum internal pressure in the cask under normal and hypothetical accident conditions is calculated in Section 7.2.2. The structural analysis of the cask is conservatively performed using 100 psi as internal pressure.

3.4.4.2 Differential Thermal Expansion

A thermal evaluation of the cask was performed in Chapter 4 to determine the maximum temperature of the cask components under normal conditions. The analysis considers maximum decay heat and maximum solar heat loading. Analyses of the thermal effects which resulted from heating the cask from an ambient temperature (70° F) to the steady state maximum temperature are presented in Appendix 3A for the cask and Appendix 3B for the basket. The results of these calculations are presented in Tables 3A.2.3-9 and 3A.2.3-10 for the cask and Section 3B.3.4 for the basket.

The basket plates are free to expand in the axial direction, since sufficient clearance is provided between the lid and the top of the basket. As described in Section 3B.3.4, adequate clearance also exists in the aluminum and stainless steel plates, and between the basket outer diameter and cask cavity inside diameter for free thermal expansion.

3.4.4.3 Stress Calculations

The stress calculations performed on the cask and basket are presented in Appendices 3A and 3B, respectively. Finite element models of the cask body and basket have been developed, and detailed computer analyses have been performed using the ANSYS computer program(3). The stress analysis of the lid bolts is based on the methodology of NUREG/CR-6007(4). Other components such as trunnions are analyzed using conventional textbook methods. Table 3.1-1 lists the specific individual load cases analyzed for each major cask component. The SAR sections where these analyses are described and the tables listing the stress results, where applicable, are also indicated.

Section 2.2 categorizes the loads for the cask body as indicated in Tables 2.2-8 and 2.2-9 into Normal (Level A) and Hypothetical Accident (Level D) Service Loadings and lists the load combinations to be evaluated. Each combination is a set of loads that are assumed to occur simultaneously.

The cask body key dimensions are shown in Figure 3.4-2. The Standard Reporting Locations for the cask body stresses are shown in Figure 3.4-3.

3.4.4.3.1 Confinement Vessel

Table 3.4-5 lists the highest confinement shell, flange, and lid stress intensities for each service condition and identifies the load combinations and locations where these maxima occur. Also listed in the tables are the stress limits for the service conditions based on the Section 3.1.2 structural design criteria.

3.4.4.3.2 Gamma Shielding

The load combinations, for the gamma shielding cask weld locations indicated in Figure 3.4-4, are presented in Appendix 3A. Table 3.4-6 lists the highest stress intensities in cylinder, bottom and weld for each service condition and identifies the load combinations and locations where those maxima occur. The allowable stress intensity limits are also listed. It is seen that the stresses in the gamma shielding are acceptable. A 1 inch thick carbon steel shield ring may be added to the cask. The shield ring is 19 inches high and rests on the outer shell, extending up to the body flange. The weight of the shield ring is included in the weight and CG calculations as shown in Table 3.2-1 for cask stability and lifting analyses. The shield ring does not strengthen the gamma shield cylinder, and therefore it is not included in the structural analysis of that cylinder. The cask is evaluated for a safe shutdown earthquake (SSE) of 0.26g horizontal and 0.17g vertical. Since the maximum up load is 0.17g, this is much less than the shield ring gravity weight (1g), and therefore, the shield ring will not slide up during the seismic event.

3.4.4.3.3 Lid Bolts

The stress intensities in the lid bolts as calculated in Appendix 3A.3 are summarized in Table 3.4-7. These values are well below the allowables stresses.

3.4.4.3.4 Basket

Tables 3.4-8 and 3.4-9 summarize the maximum stresses in the basket. As shown in Tables 3.4-8 and 3.4-9, the stresses in the basket are below the allowable stresses. It is shown in Chapter 2 that the cask will not tipover. It is further shown in Appendix 3D that if the cask were to tip, the maximum expected g loading on the basket including dynamic load factor would be approximately 77 g's. The analysis presented in Appendix 3B indicates that even in this extremely unlikely hypothetical accident, there is sufficient margin to ensure that the basket maintains fuel assembly geometry subcritical and allows removal of the fuel.

3.4.4.3.5 Outer Shell

The neutron shield outer shell stresses are summarized in Table 3.4-10. The shell stresses are the highest when the cask is vertical and subjected to 3G inertia load and 25 psi internal pressure (e.g. before the cask is loaded). Stresses in the shell will be much lower during normal storage of the TN-68 cask on the ISFSI pad. The shell is not analyzed under tornado missile loading, but it could be damaged by either Missile A or Missile B, as defined in Section 2.2.1. The effect of any damage to the neutron shielding is bounded by the evaluation of completely removing the neutron shield, which is evaluated in Table 5.1-2.

3.4.4.4 Comparison with Allowable Stresses

The stresses in each of the major components of the cask are compared to their allowables in Tables 3.4-5 through 3.4-10.

3.4.5 Cold

The cask has been designed for operation to ambient temperatures as low as -20^{o}F. The confinement seals are all metallic o-rings which are not affected by temperature. The shielding materials are all solids, so there is no concern for over freezing.

The confinement vessel is made from materials selected for their low temperature fracture toughness properties. The confinement boundary materials satisfy the brittle fracture criteria of ASME B & PV code, NB-2000 and Regulatory Guides 7.11(21) and 7.12(22).

The pressure switch/ transducer used for the overpressure system, which is not a safety related component, is selected to operate at temperatures of -20°F and above.

An evaluation has also been performed to evaluate thermal stresses due to cold rain on a hot cask. The analysis is provided below.

The cold rain is assumed at 32° F. The maximum cask temperature in unprotected flange-lid region is 212° F (see Chapter 4, table 4.3-1). It is conservatively assumed that the outer flange surface is at 32° F while the inner surface is at 212° F. Thermal stress calculation is based on a temperature differential of 212°-32°= 180° F. The maximum flange thermal stress of 1,150 psi is calculated for 9° F temperature differential in Appendix 3A, Table 3A.2.3-10. Therefore,

Maximum thermal stresses for cold rain on hot cask = (180/9) 1,150 = 23,000 psi.

This stress is well below the flange material (SA 350, Grade LF3) thermal stress allowable ($3S_m = 3 \times 22{,}200 = 66{,}600$ psi at 300° F - see Table 3.3-2).

3.4.6 Fire Accident

The lid and lid bolts reach about 470°F (see Table 4.4-1). Since the lid and lid bolts have the same thermal expansion coefficients, no bolt preload will be lost and a positive (compressive) seal load is maintained during the fire accident conditions.

The maximum temperature in seal region is 470°F (SeeTable 4.4-1) which is lower than the maximum allowable operating temperature of 536°F for the Helicoflex seal.

The basket temperature does not change appreciably (from 595°F to 717°F, see Tables 4.3-1 and 4.4-1) while the cask temperature rises during the fire accident (from 255°F to 842°F). The gap between the outside diameter of the basket and inside diameter of the cask will increase slightly based on thermal expansion evaluation results from normal and vacuum drying conditions (Section 3B.3.4); therefore, no thermal stress will be induced in the basket.

3.5 Fuel Rods

The handling of spent fuel within the Nuclear Generating Plant will be conducted in accordance with existing fuel handling procedures. Fuel with gross cladding defects will not be considered for storage at the ISFSI.

3.5.1 Fuel Rod Temperature Limits

Fuel cladding temperature limits are 400 °C (752 °F) for normal conditions including loading operations, and 570 °C (1058 °F) for off-normal and accident conditions, based on NRC Interim Staff Guidance memorandum ISG-11 rev 3(6).

That guidance also limits thermal cycling during loading operations to a maximum of 10 cycles with amplitude of 65 °C (117 °F). The TN-68 vacuum drying procedures only include one-half thermal cycle with amplitude of about 60 °F, that is, the reduction in cladding temperature at the time that helium is introduced, as shown in Figure 4.5-1(b).

3.5.2 Thermal Stress of Fuel Cladding due to Unloading Operations

To evaluate the effects of the thermal loads on the fuel cladding during unloading operations, the following assumptions are made:

- A conservatively high maximum fuel rod temperature of 622°F (see Table 4.3-1) and quench water temperature of 50°F are used (normally water will be taken from the spent fuel pool, average water temperature is 90°F; using 50°F for thermal stress analysis is conservative).
- Fuel rod is assumed simply supported at both ends.
- The outer surface temperatures of the fuel rod are conservatively assumed as shown in Fig. 3.5-2. 50° F, 212° F, and 622° F temperatures occur at three equal heights.

Analysis

Steady state thermal analyses are performed using the ANSYS(3) computer program. The finite element model is shown in Figure 3.5-1. ANSYS finite elements Plane 55 and Plane 42 (Axisymmetric) are used. The model is based on the maximum fuel rod outer diameter of 0.563 inches and a maximum clad thickness of 0.034 in. to bound all GE type fuel rods. A tube length of two inches was selected for the finite element model so that it is a long cylinder (minimum length = $3.0/\lambda = 0.22$ inches) and the maximum stresses are not affected by the assumed boundary conditions. The maximum thickness of the cylinder was selected so as to result in higher ΔT and higher thermal stresses.

Material Properties

The following material properties are used for the analysis:

Material Properties of Zircaloy

Temp ^oF	Conductivity$^{(8)}$ Btu/hr-in-^oF	$\alpha^{(9)}$ in/in/^oF	$E^{(10)}$ (psi)	$S_y^{(10)}$ (ksi)
200	.574	3.73×10^{-6}	12.8×10^6	
248	.579	3.73×10^{-6}	12.7×10^6	94.9
284	.583	3.73×10^{-6}	12.5×10^6	93.9
334	.588	3.73×10^{-6}	12.3×10^6	92.4
415	.593	3.73×10^{-6}	12.0×10^6	90.1
615	.614	3.73×10^{-6}	11.1×10^6	84.4
622	.615	3.73×10^{-6}	11.1×10^6	84.17

Thermal Analysis

The steady state thermal analysis was conducted using the surface nodal temperatures as shown on Figure 3.5-2. The inside surface nodal temperatures are all assumed to be 622^{o}F, and the outside surface nodal temperatures to conservatively represent the quench water temperature. The temperature distribution resulting from this analysis is shown on Figure 3.5-3.

Thermal Stress Analysis and Results

A thermal stress analysis using the same model was conducted using the nodal temperatures obtained from the thermal analysis. The resulting nodal stress intensity distribution is shown on Figure 3.5-4. The maximum nodal stress intensity in the fuel cladding is 18.54 ksi. This stress in less than the yield strength of zircaloy of 84.17 ksi at 622°F.

3.6 Supplemental Information

[Sections 3.6.1, 3.6.2, and 3.6.3 (pages 3.6-1 through 3.6-17)
are unchanged from TN-68 FSAR rev 2]

3.7 References

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21. Regulatory Guide 7.11,"Fracture Toughness criteria of Base Material for ferritic steel shipping Cask Confinement Vessels With a Maximum Wall thickness of 4 Inches (0.1m).

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<u>TABLE 3.1-1</u>

INDIVIDUAL LOAD CASES ANALYZED

COMPONENT/ ANALYSIS	LOADING	SAR SECTION	INDIVIDUAL STRESS RESULT TABLES
CASK BODY			
Bolt Preload	Preload	3A.2.3.1	3A.2.3-1 3A.2.3-2
Gravity	1G down	3A.2.3.1	3A.2.3-3 3A.2.3-4
Internal Pressure (1)	100 PSI	3A.2.3.1	3A.2.3-5 3A.2.3-6
External Pressure (1)	25 PSI	3A.2.3.1	3A.2.3-7 3A.2.3-8
Thermal Stress	Short Term Temperatures	3A.2.3.1	3A.2.3-9 3A.2.3-10
Lifting	6G on Upper Trunnions	3A.2.3.1 3.4.3	3A.2.3-11 3A.2.3-12 Section 3.4-3
Seismic Load (1)	2G Down + 1G lateral	3A.2.3.1 2.2.3	3A.2.3-17 3A.2.3-18
Tipover	1G Side Drop	3A.2.3.2	3A.2.3-13 3A.2.3-14 3A.2.3-15 3A.2.3-16
LID BOLTS			
Preload	Preload Tension	3A.3	---
Thermal Effects	Differential Expansion	3A.3	---
Torquing	Preload Torsion	3A.3	---
Pressure	100 psi	3A.3	---
Impact	Tip Over - 65 G	3A.3	---

TABLE 3.1-1(Continued)(3)

INDIVIDUAL LOAD CASES ANALYZED

COMPONENT/ ANALYSIS	LOADING	SAR SECTION	INDIVIDUAL STRESS RESULTS TABLES
BASKET			
Bounding Side Load (2)	1 G Lateral	3B.3.2	3B.3-1 through 3B.3-4
Bounding Down Load (2)	3 G Down	3B.3.3	---
Hypothetical Accident	End Drop	3B.4.1	---
Hypothetical Accident	Tipover	3B.4.2	3B.4-1 through 3B.4-4
TRUNNIONS			
Lifting	6 g and 10 g	3.4.3	3.4-2

NOTES:

1. The above pressures and bounding loads conservatively envelope all possible pressure effects as well as tornado wind load, flood water load and seismic load.

2. The bounding loads selected for basket evaluation are extremely conservative. These loads are more severe than any loads that will actually be applied to the basket.

3. Local loads and stresses due to tornado driven missiles are evaluated in Chapter 2, Section 2.2.1.3

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TABLE 3.1-2

CONFINEMENT VESSEL STRESS LIMITS (3)

CLASSIFICATION	STRESS INTENSITY LIMIT(3)
Normal (Level A) Conditions(1)	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m \text{ or } P_l) + P_b$	$1.5\ S_m$
Shear Stress	$0.6\ S_m$
Bearing Stress	S_y
$(P_m \text{ or } P_l) + P_b + Q$	$3\ S_m$
$(P_m \text{ or } P_l) + P_b + Q + F$	S_a
Hypothetical Accident (Level D)(2)	
P_m	Smaller of $2.4\ S_m$ or $0.7\ S_u$
P_l	Smaller of $3.6\ S_m$ or S_u
$(P_m \text{ or } P_l) + P_b$	Smaller of $3.6\ S_m$ or S_u
Shear Stress	$0.42\ S_u$

NOTES:

1. Classifications and Stress Intensity Limits are as defined in ASME B&PV Code, Section III, Subsection NB.

2. Stress intensity limits are in accordance with ASME B&PV Code, Section III, Appendix F.

3. When using materials data from ASME B&PV Code Section II, Part D Tables other than 2A, S values may be substituted for S_m values in these expressions.

TABLE 3.1-3

CONFINEMENT BOLT STRESS LIMITS (1)(5)

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions (2)	
Average Tensile Stress	$2\ S_m$
Maximum Combined Stress	$3\ S_m$
Bearing Stress	S_y
Hypothetical Accident (Level D)(3)	
Average Tensile Stress	Smaller of S_y or $0.7\ S_u$
Average Shear Stress	Smaller of $0.4\ S_u$ or $0.6\ S_y$
Maximum Combined Stress	S_u
Combined Shear & Tension	$R_t^2 + R_s^2 < 1$(4)

NOTES

1. The stress analysis of the lid bolt is performed in accordance with NUREG/CR-6007(4) described in Appendix 3A.3. The stress limits for the lid bolt are listed separately in Tables 3A.3-3 and -4.

2. Classification and stress limits are as defined in ASME B&PV Code, Section III, Subsection NB.

3. Stress limits are in accordance with ASME B&PV Code, Section III, Appendix F.

4. R_t : Ratio of average tensile stress to allowable average tensile stress
   R_s : Ratio of average shear stress to allowable average shear stress

5. All stresses include the effect of tensile and torsional loads due to bolt preloading.

TABLE 3.1-4

NON CONFINEMENT STRUCTURE STRESS LIMITS

CLASSIFICATION	STRESS INTENSITY LIMIT (3)
Normal (Level A) Conditions (1)	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m + P_l) + P_b$	$1.5\ S_m$
$(P_m + P_l) + P_b + Q$	$3\ S_m$
Shear Stress	$0.60\ S_m$
Bearing Stress	S_y
Hypothetical Accident (Level D)(2)	
P_m	Smaller of $2.4\ S_m$ or $0.7\ S_u$
P_l	Smaller of $3.6\ S_m$ or S_u
$(P_m + P_l) + P_b$	Smaller of $3.6\ S_m$ or S_u
Shear Stress	$0.42\ S_u$

NOTES:

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NB.

2. Stress intensity limits are in accordance with ASME B&PV Code, Section III, Appendix F.

3. When using materials data from ASME B&PV Code, Section II, Part D Tables other than 2A, S values may be substituted for S_m values in these expressions.

TABLE 3.1-5[4]

BASKET STRESS LIMITS

CLASSIFICATION	**STRESS INTENSITY LIMIT (3)**
Normal (Level A) Conditions (1)	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m + P_l) + P_b$	$1.5\ S_m$
$(P_m + P_l) + P_b + Q$	$3\ S_m$
$(P_m + P_l) + P_b + Q + F$	S_a
Shear Stress	$0.6\ S_m$
Hypothetical Accident (Level D)(2)	
P_m	Smaller of $2.4\ S_m$ or $0.7\ S_u$
P_l	Smaller of $3.6\ S_m$ or S_u
$(P_m + P_l) + P_b$	Smaller of $3.6\ S_m$ or S_u
Shear Stress	Smaller of $0.42\ S_u$ or $2(0.6S_m)$

NOTES

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NG.

2. Limits are in accordance with ASME B&PV Code, Section III, Appendix F.

3. When using materials data from ASME B&PV Code, Section II, Part D Tables other than 2A, S values may be substituted for S_m values in these expressions.

4. Stability is also evaluated under compressive loading. See Section 3B.5.

TABLE 3.2-1

CASK WEIGHT AND CENTER OF GRAVITY

COMPONENT	**NOMINAL WEIGHT** (lbs. x 1000)	**CENTER OF GRAVITY** (Inches)*
Body	94.4	101.1
Bottom	15.6	4.875
Lid and Lid Bolts	12.3	192.25
Neutron Shield Aluminum Boxes	2.5	93.25
Resin	13.9	93.25
Outer Shell	11.2	93.25
Resin Disk	0.9	199.25
Trunnions - Upper	0.8	173.25
- Lower	0.9	27.41
Protective Cover	0.8	203.7
Basket, Fuel Compartment Extension, End Caps, and Rails	26.1	91.75
Shield Ring	1.4	182.75
Basket Hold Down Ring	1.2	180.5
Fuel Assemblies	47.9	91.75
Overpressure Tank, Drain Tube	0.1	205.6
Cask Weight w/o Protective Cover and Resin Disk	228.3	96.38
Weight on Storage Pad	230.0	97.16 **

* Center of Gravity is measured along the axial centerline from the base of the cask.
** Center of Gravity of 97.26 is conservatively used for stability analysis.
Summary of weight used for Analysis:

1.	Stability of Cask	227,000 lbs.
2.	Accident G Load Calculations	229,600 lbs.
3.	Trunnion and Local Stress Analysis	240,000 lbs.
4.	Cask Body Analysis	240,000 lbs.

TABLE 3.3-1

MECHANICAL PROPERTIES OF BODY MATERIALS (NOTE 1)

Material Specification (Nominal Composition)	Application	Minimum Yield Strength S_y, psi	Minimum Ultimate Strength S_u, psi	Design Stress Value,Psi (Note 2)	Data Source (Note 3)
ASME SA-350, Grade LF3 (3 ½ Ni)	Flange Confinement Lid	37,500	70,000	S_m=23,300	Table 2A
ASME SA-203, Grade E (3-1/2 Ni)	Confinement Lid Confinement Shell	40,000	70,000	S_m=23,300	Table 2A
ASME SA-266, Class 2 (C-Si)	Gamma Shielding	36,000	70,000	S= 20,000	Table 1A
ASME SA-516, Gr. 70 (C-Mn-Si)	Outer Shell Lid Shield Plate, Protective Cover	38,000	70,000	S= 20,000	Table 1A
ASME SA-105, (C-Si)	Lower Trunnion	36,000	70,000	S= 17,500	Table 1A
ASME SA-182 Gr. F6 NM (13 Cr – 4 Ni)	Upper Trunnion	90,000	115,000	S_m= 32,900	Table 2A
ASME SA-540 Gr. B24 Cl. 1 (2Ni-3/4 Cr-1/3 Mo)	Lid Bolts	150,000	165,000	S_m= 50,000	Table 4
ASME SA-320, Grade L43 (1 ¾ Ni-3/4 Cr - ¼ Mo)	Upper Trunnion Bolts	105,000	125,000	S_m= 35,000	Table 4

TABLE 3.3-1(continued)

MECHANICAL PROPERTIES OF BODY MATERIALS (NOTE 1)

NOTES:

1. Mechanical properties listed are for metal temperatures up to 100°F to provide a baseline comparison of all structural materials.
   Temperature dependent properties required for structural analysis are provided in Table 3.3-2.
2. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
   S refers to the ASME allowable stress for Class 2 or Class 3 components,

   S_m refers to the ASME design stress intensity for Class 1 components, and S_y

   refers to minimum yield strength.
3. Data are taken from tables in ASME Section II, Part D, 1998 including 2000 Addenda, unless otherwise noted.

TABLE 3.3-2

TEMPERATURE DEPENDENT BODY MATERIAL PROPERTIES (SHEET 1 OF 4)

COEFFICIENTS OF THERMAL EXPANSION (NOTE 1)

Material/Temp., ^{o}F	100	150	200	250	300	350	400	450	500	550	600
SA350,SA320, SA540, SA203 (Note 2)	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.3	7.4
SA105,SA266 and SA516 (Note 2)	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.3	7.4
SA182 Gr F6NM (Note 2)	6.0	6.1	6.2	6.2	6.3	6.4	6.4	6.4	6.5	6.5	6.5

NOTES:

1. Values listed are the mean coefficients of thermal expansion x 10^{-6} (in./in.°F) from 70°F to the indicated temperature.
2. Source of data is ASME Section II, Part D, 1998 including 2000 Addenda, Table TE-1.

TABLE 3.3-2

TEMPERATURE DEPENDENT BODY MATERIAL PROPERTIES (SHEET 2 OF 4)

MODULUS OF ELASTICITY, E (NOTE 1)

MATERIAL/ TEMPERATURE ^{O}F	70	200	300	400	500	600
SA-203, SA-320, SA-540 and SA-350 (Note 2)	27.8	27.1	26.7	26.1	25.7	25.2
SA-105, SA-266 And SA-516 (Note 2)	29.5	28.8	28.3	27.7	27.3	26.7
SA-182 Gr F6 NM (Note 2)	29.2	28.5	27.9	27.3	26.7	26.1

NOTES:

1. Values listed are the modulus of elasticity x 10^6 psi for the indicated temperature.
2. Source of data is ASME SECTION II, Part D, 1998 including 2000 addenda, Table TM-1.

TABLE 3.3-2

TEMPERATURE DEPENDENT BODY MATERIAL PROPERTIES (SHEET 3 OF 4)

MATERIAL	**STRESS PARAMETER** (NOTE 1)	100°F	200°F	300°F	400°F	500°F	600°F	**DATA SOURCE** (NOTE 2)
SA-350, Gr. LF3	S_m	23.3	22.8	22.2	21.5	20.2	(Note 4)	Table 2A
	S_y	37.5	34.3	33.2	32.0	30.4	28.2	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-203, Grade E	S_m	23.3	23.3	23.3	22.9	21.6	(Note 4)	Table 2A
	S_y	40.0	36.6	35.4	34.2	32.5	30.0	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-266 Class 2	S	20.0	20.0	20.0	20.0	19.6	18.4	Table 1A
	S_y	35.0	32.1	31.0	29.9	28.5	26.8	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-516 Grade 70	S	20.0	20.0	20.0	20.0	20.0	19.4	Table 1A
	S_y	38.0	34.8	33.6	32.5	31.0	29.1	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-105	S	20.0	20.0	20.0	20.0	19.6	18.4	Table 1A
	S_y	36.0	33.0	31.8	30.8	29.3	27.6	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-182 Gr. F6 NM	S_m	38.3	38.3	38.3	37.9	36.6	35.0	Table 2A
	S_y	90.0	86.5	84.6	82.8	80.8	78.5	Table Y-1
	S_u	115.0	115.0	115.0	113.6	109.7	105.1	Table U
SA-540 Gr. B24, CL.1 (Bolt)(Note3)	S_m	50.0	47.8	46.2	44.8	43.4	41.4	Table 4
	S_y	150.0	143.4	138.6	134.4	130.2	124.2	$3S_m$
	S_u	165.0	165.0	165.0	165.0	165.0	165.0	Table 3
SA-320, Gr. L43 (Bolt)(Note3)	S_m	35.0	33.0	31.9	30.6	29.5	28.1	Table 4
	S_y	105.0	99.0	95.7	91.8	88.5	84.3	$3S_m$
	S_u	125.0	125.0	125.0	125.0	125.0	125.0	Table 3

TABLE 3.3-2

TEMPERATURE DEPENDENT BODY MATERIAL PROPERTIES (SHEET 4 OF 4)

NOTES FOR SHEET 3 OF 4:

1. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
   S refers to the ASME allowable stress for Class 2 or Class 3 components, or Section VIII, Division 1
   S_m refers to the ASME design stress intensity for Class 1 components, and
   S_y refers to minimum yield strength.
2. Data is taken from ASME Section II, Part D, 1998 including 2000 addenda.
3. For bolting materials, $S_y \geq 3 S_m$.
4. Properties are not available at 600F in ASME Section II, Part D.

TABLE 3.3-3

REFERENCE TEMPERATURES FOR STRESS ANALYSIS ACCEPTANCE CRITERIA*

Component	**Max. Calculated Temperature, °F**	**Selected Design** Temperature, °F**
Cask Body	314	400
Cask Lid	212	400
Lid Bolts	212	300
Trunnions	227	300
Upper Trunnion Bolts	227	300

* For thermal stress due to fire accident, see Section 3.4.6.

** Temperatures specified are used to determine allowable stresses. They are not a maximum use temperature for the material.

TABLE 3.3-4

MECHANICAL PROPERTIES OF BASKET MATERIALS (NOTE 1)

Material Specification (Nominal Composition)	Minimum Yield Strength S_y, psi	Minimum Ultimate Strength S_u, psi	Design Stress Value, psi (Note 2)	Data Source (Note 3)
ASME SA-240, Type 304 (Basket Plates)	30,000	75,000	S_m = 20,000	Table 2A
ASME SB 221, 6061-T6 Aluminum (Aluminum Rails)	35,000	38,000	S = 10,900	Table 1B

NOTES

1. Mechanical properties listed are for metal temperatures up to 100°F to provide a baseline comparison of all structural materials.

   Temperature dependent properties required for structural analysis are provided in Table 3.3-5.

2. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.

   S refers to the ASME allowable stress for Class 2 or Class 3 components,
   S_m refers to the ASME design stress intensity for Class 1 components, and S_y refers to minimum yield strength.

3. Data is taken from tables in ASME Section II, Part D, 1998 including 2000 addenda unless otherwise noted.

TABLE 3.3-5

TEMPERATURE DEPENDENT BASKET MATERIAL PROPERTIES (SHEET 1 OF 3)

COEFFICIENTS OF THERMAL EXPANSION (Note 1)

	TEMPERATURE, °F										
MATERIAL	100	150	200	250	300	350	400	450	500	550	600
SA 240, TYPE 304	8.6	8.8	8.9	9.1	9.2	9.3	9.5	9.6	9.7	9.8	9.8
SB-221, 6061-T6 ALUMINUM	12.4	12.7	13.0	13.1	13.3	13.4	13.6	13.8	13.9	14.1	14.2

1. Values listed are the mean coefficients of thermal expansion x 10^{-6} (in./in.°F from 70°F to the indicated temperature).
2. Source of data is ASME Section II, Part D, 1998 including 2000 addenda.

TABLE 3.3-5

TEMPERATURE DEPENDENT BASKET MATERIAL PROPERTIES (SHEET 2 OF 3)

MODULI OF ELASTICITY, E (Note 1)

	TEMPERATURE, ^{O}F					
MATERIAL	70	200	300	400	500	600
SA-240, TYPE 304 STAINLESS STEEL	28.3	27.6	27.0	26.5	25.8	25.3
SB-221, 6061-T6 ALUMINUM	10.0	9.6	9.2	8.7	8.1	

NOTES:

1. Values listed are the moduli of elasticity x 10^6 psi for the indicated temperature.
2. Source of data is ASME Section II, Part D, 1998 including 2000 addenda.

TABLE 3.3-5

TEMPERATURE DEPENDENT BASKET MATERIAL PROPERTIES (SHEET 3 OF 3)

DESIGN STRESS PARAMETERS

TEMPERATURE,°F								
MATERIAL	STRESS PARAMETER (KSI) (NOTE 1)	100	200	300	350	400	500	DATA SOURCE
ASME SA-240 Type 304	S_y	30.0	25.0	22.4	21.6	20.7	19.4	Table Y-1 (NOTE 2)
	S_u	75.0	71.0	66.2	65.1	64.0	63.4	Table U
	S_m	20.0	20.0	20.0	19.4	18.7	17.5	TABLE 2A
ASME SB-221 Alloy 6061-T6 (Aluminum)	S_y	35.0	33.7	27.4	20.0	13.3		TABLE Y-1
	S_u	38.0	35.5	28.7	22.4	16.0		NOTE 3
	S	10.9	10.9	7.9	6.3	4.5		TABLE 1B

NOTES:

1. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
2. S_m refers to the ASME design stress intensity for Class 1 components, and
   S_y refers to minimum yield strength.
   S_u refers to minimum ultimate strength.
3. S_u is available in ASME Section II, Part D only at room temperature. For elevated temperatures, S_u was obtained by ratioing S_u data in Aluminum Association "Aluminum Standards and Data" 1990. (Reference 20)

Table 3.3-6 Sheet 1 of 3
TN-68 Cask Components and Materials

Materials and Components of TN-68 Cask					
Primary Function	**Component**	**Drawing**	**Safety Class.**	**Codes/Standards**	**Material**
Containment	Lid	972-70-2 It.2	A	ASME Subsection NB	SA-350, LF3 or SA-203 Gr. E
	Inner Containment	972-70-2 It.3	A	ASME Subsection NB	SA-203 Gr. E
	Bottom Containment	972-70-2 It.5	A	ASME Subsection NB	SA-203 Gr. E
	Flange	972-70-2 It.35	A	ASME Subsection NB	SA-350, LF3
	Lid Bolt (48)	972-70-2 It.14	A	ASME Subsection NB	SA-540 Gr. B24 Cl. 1
	Lid Seal	972-70-2 It.16	A		Double Metallic O-Ring
	Drain Port Cover	972-70-2 It.22	A	ASME Subsection NB	SA-240, Type 304
	Vent Port Cover	972-70-2 It.23	A	ASME Subsection NB	SA-240, Type 304
	Threaded Insert	972-70-2 It. 45	A		304 SST
	Vent & Drain Port Cover Seal	972-70-2 It.24	A		Double Metallic O-Ring
	Vent & Drain Port Cover Bolts	972-70-2 It.25	A	ASME Subsection NB	SA-193 Gr. B7
Criticality Control	Poison Plates	972-70-2 It.33	A		Borated Aluminum or Boron Carbide /Aluminum Metal Matrix Composite
	Basket Rail Type 1	972-70-2 It.28	A		B221, 6061-T6 Aluminum
	Basket Rail Type 2	972-70-2 It.29	A		B221, 6061-T6 Aluminum
	Basket Shim	972-70-2 It.30	A		SA-240 Type 304, SA-336 Type 304, or SA-351 CF-3
	Fuel Compartment	972-70-2 It.32	A	ASME Subsection NG	SA-240 Type 304
	Structural Plates	972-70-2 It.34	A	ASME Subsection NG	SA-240 Type 304
	Basket Holddown	972-70-2 It.39	A	ASME Subsection NF	SA-240 Type 304
Shielding	Gamma Shield	972-70-2 It.1	A	ASME Subsection NF	SA-266 Class 2
	Shield Plate	972-70-2 It.8	B	ASME Subsection NF	SA-105 or SA-516, Gr. 70
	Bottom	972-70-2 It.4	A	ASME Subsection NF	SA-516 Gr. 70 or SA-266 Cl. 2
	Radial Neutron Shield	972-70-2 It. 9	B		Borated Polyester Resin
	Outer Shell	972-70-2 It. 10	B		SA-516 Gr. 70
	Soc. Head Cap Screw	972-70-2 It. 47	B		304 SST
	Shim	972-70-2 It. 36	A		SA-516 Gr. 70
	Top Neutron Shield	972-70-2 It. 12	B		Polypropylene
Heat Transfer	Radial Neutron Shield Box	972-70-2 It. 13	B		6063-T5 Aluminum
	Poison Plates	972-70-2 It. 33	A		Borated Aluminum or Boron Carbide /Aluminum Metal Matrix Composite
	Basket Rail Shim	972-70-2 It. 31	B		6061-T6 Aluminum
	Basket Rail Type 1	972-70-2 It.28	A		B221, 6061-T6 Aluminum
	Basket Rail Type 2	972-70-2 It.29	A		B221, 6061-T6 Aluminum
	Basket Shim	972-70-2 It.30	A		SA-240 Type 304, SA-336 Type 304, or SA-351 CF-3
Structural Integrity	Gamma Shield	972-70-2 It.1	A	ASME Subsection NF	SA-266 Class 2
	Bottom	972-70-2 It.4	A	ASME Subsection NF	SA-516 Gr. 70 or SA-266 Cl. 2
Operations Support	Upper Trunnion	972-70-2 It. 6	A	ANSI N14.6	SA-182 Gr. F6NM
	Lower Trunnion	972-70-2 It. 7	B		SA-105
	Protective Cover	972-70-2 It. 11	C		SA-516 Gr. 70
	Protective Cover Bolt	972-70-2 It. 15	C		SA-193 Gr. B7
	Protective Cover Seal	972-70-2 It.17	C		Elastomer
	Top Neutron Shield Bolt	972-70-2 It.20	C		SA-193 Gr. B7
	Trunnion Bolt	972-70-2 It. 37	A		SA-320 L43
	Fuel Spacer	972-70-2 It. 38	C		Aluminum
	Shear Key	972-70-2 It. 40	A		SA-203 Gr. E
	Pressure Relief Valve	972-70-2 It. 41	C		SST
	Security Wire	972-70-2 It. 42	C		304 SST
	Security Wire Seal	972-70-2 It. 43	C		Lead
	Flat Washer	972-70-2 It. 46	C		SST
	Threaded Insert	972-70-2 It. 44	C		304 SST
	Quick Disconnect Couplings	972-70-3	C		SST
	Lid Alignment Pin	972-70-2 It 27	C		A479, Type 316
Leakage Monitoring Secondary Seal	Overpressure Port Cover	972-70-2 It. 18	C		SA-240 Type 304
	Overpressure Port Cover Seal	972-70-2 It. 19	C		Single Metallic O-ring
	Pressure Monitoring System	972-70-2 It. 21	C		Carbon Steel/Stainless Steel
	Overpressure Port Cover Bolts	972-70-2 It. 26	C		SA-193 Gr. B7

Table 3.3-6 Sheet 2 of 3

Materials and Components of TN-68 Cask (cont.)				
Primary Function	**Component**	**Strength (ksi)**	**Coating**	**Welding/Weld Filler Metal**
Containment	Lid	70	SST Cladding on Sealing Surfaces; Epoxy Paint on External Surfaces	Per Section III, NB and Section IX
	Inner Containment	70	None	Per Section III, NB and Section IX
	Bottom Containment	70	None	Per Section III, NB and Section IX
	Flange	70	SST Cladding on Sealing Surfaces; Epoxy Paint on External Surfaces	Per Section III, NB and Section IX
	Lid Bolt (48)	165	Nuclear Grade Neolube or equiv.	N/A
	Lid Seal		None	N/A
	Drain Port Cover	75	None	N/A
	Vent Port Cover	75	None	N/A
	Threaded Insert	300	None	N/A
	Vent & Drain Port Cover Seal		None	N/A
	Vent & Drain Port Cover Bolts		Nuclear Grade Neolube or equiv.	N/A
Criticality Control	Poison Plates		None	N/A
			None	N/A
	Basket Rail Type 1	38	None	N/A
	Basket Rail Type 2	38	None	N/A
	Basket Shim	75	None	Per Section III, NG and Section IX
	Fuel Compartment	75	None	Per Section III, NG and Section IX
	Structural Plates	75	None	Per Section III, NG and Section IX
	Basket Holddown	75	None	Per Section III, NG and Section IX
Shielding	Gamma Shield	70	Epoxy Paint on Exterior	Per Section IX
	Shield Plate	70	None	Per Section IX
	Bottom	70	Epoxy Paint on Exterior	Per Section IX
	Radial Neutron Shield		None	
	Outer Shell	70	Epoxy Paint on Exterior	
	Soc. Head Cap Screw	70	None	
	Shim	70	None	
	Top Neutron Shield		None	
Heat Transfer	Radial Neutron Shield Box		None	
	Poison Plates		None	
			None	
	Basket Rail Shim	38	None	
	Basket Rail Type 1	38	None	
	Basket Rail Type 2	38	None	
	Basket Shim	75	None	
Structural Integrity	Gamma Shield	70	Epoxy Paint on Exterior	
	Bottom	70	Epoxy Paint on Exterior	
Operations Support	Upper Trunnion	115	Nuclear Grade Neolube or equiv.	
	Lower Trunnion	70	Epoxy Paint on Exterior	
	Protective Cover	70	Epoxy Paint on Exterior	
	Protective Cover Bolt		Nuclear Grade Neolube or equiv.	
	Protective Cover Seal		None	
	Top Neutron Shield Bolt		None	
	Trunnion Bolt	125	Nuclear Grade Neolube or equiv.	
	Fuel Spacer		None	
	Shear Key	70	None	
	Pressure Relief Valve		None	
	Security Wire		None	
	Security Wire Seal		None	
	Flat Washer		None	
	Threaded Insert		None	
	Quick Disconnect Couplings		None	
	Lid Alignment Pin		None	
Leakage Monitoring Secondary Seal	Overpressure Port Cover	75	None	
	Overpressure Port Cover Seal		None	
	Pressure Monitoring System		Epoxy Paint on Exterior	
	Overpressure Port Cover Bolts		Nuclear Grade Neolube or equiv.	

Table 3.3-6, Sheet 3 of 3

Materials and Components of TN-68 Cask (cont.)

Primary Function	Component	Stress		Normal Temp (deg F)**			Pressure		
		Normal Cond.	Accident Cond.	Min	Max	20 yr ***	Min (psig)	Max (psig)	Gas (type)
Containment	Lid	4.5	5.5	-20	212	204	0	100	Helium
	Inner Containment	25.8	53.3	-20	319	223	0	100	Helium
	Bottom Containment			-20	309	218	0	100	Helium
	Flange	3.1	29.6	-20	212	204	0	100	Helium
	Lid Bolt (48)	40.7	25	-20	212	204	0	100	Helium
	Lid Seal			-20	212	204	0	100	Helium
	Drain Port Cover			-20	212	204	0	100	Helium
	Vent Port Cover			-20	212	204	0	100	Helium
	Threaded Insert			-20	212	204	0	100	Helium
	Vent & Drain Port Cover Seal			-20	212	204	0	100	Helium
	Vent & Drain Port Cover Bolts	26	47.4	-20	212	204	0	100	Helium
Criticality Control	Poison Plates*			-20	595	359			
	Basket Rail Type 1	0.15	1	-20	382	258			
	Basket Rail Type 2	0.15	1	-20	382	258			
	Basket Shim	0.15	1	-20	350	258			
	Fuel Compartment*			-20	595	359			
	Structural Plates*	0.58	6.03	-20	595	359			
	Basket Holddown*			-20	595	359			
Shielding	Gamma Shield	25.3	55.3	-20	314	211			
	Shield Plate	2.8	5.4	-20	212	204			
	Bottom			-20	248	218	3	5	Air
	Radial Neutron Shield			-20	295	211			
	Outer Shell	4.5	9.1	-20	255	185	3	5	Air
	Soc. Head Cap Screw			-20	255	185			
	Shim			-20	211	204			
	Top Neutron Shield			-20	211	204			
Heat Transfer	Radial Neutron Shield Box			-20	295	211			
	Poison Plates			-20	595	359			
	Basket Rail Shim			-20	350	258			
	Basket Rail Type 1	0.15	1	-20	350	258			
	Basket Rail Type 2	0.15	1	-20	350	258			
	Basket Shim	0.15	1	-20	350	258			
Structural Integrity	Gamma Shield			-20	314	211			
	Bottom			-20	248	218	3	5	Air
Operations Support	Upper Trunnion	10.65		-20	227	223	3	5	Air
	Lower Trunnion			-20	284	223	3	5	Air
	Protective Cover			-20	176	185	3	5	Air
	Protective Cover Bolt	17		-20	176	204	3	5	Air
	Protective Cover Seal			-20	176	204			
	Top Neutron Shield Bolt			-20	211	204			
	Trunnion Bolt			-20	227	223			
	Fuel Spacer			-20	330	258			
	Shear Key			-20	362	258			
	Pressure Relief Valve			-20	225	211			
	Security Wire			-20	212	204			
	Security Wire Seal			-20	212	204			
	Flat Washer			-20	212	204			
	Threaded Insert			-20	212	204			
	Quick Disconnect Couplings			-20	212	204			
	Lid Alignment Pin			-20	212	204			
Leakage Monitoring Secondary Seal	Overpressure Port Cover			-20	211	204			
	Overpressure Port Cover Seal			-20	211	204			
	Pressure Monitoring System			-20	212	185	3	5	Air
	Overpressure Port Cover Bolts			-20	212	204			

* A value of 565 deg F is obtained during short-term drying.

** See SAR Tables 4.3-1, 4.3-2, and 4.4-1 for Additional Temperature Information

*** based on initial 21.2 kW thermal load

TABLE 3.4-1

UPPER TRUNNION SECTION PROPERTIES AND LOADS

ITEM	SECTION A-A
Cross Section Area, In^2	29.3
Area Moment Of Inertia, In^4	279.83
Yield Condition* Shear Force, Lbs	828,000
Yield Condition* Bending Moment, In- Lbs	1,705,680
Ultimate Condition ** Shear Force, Lbs.	1,380,000
Ultimate Condition ** Bending Moment, In-Lbs	2,842,800

* Trunnion Loads to Support (6 * 1.15) times Cask Weight

** Trunnion Loads to Support (10 * 1.15) times Cask Weight

TABLE 3.4-2

UPPER TRUNNION STRESSES WHEN LOADED BY 6 AND 10 TIMES CASK WEIGHT

STRESS	YIELD LIMIT (ksi)
	SECTION A-A
Shear Stress	28.3
Bending Stress	29.8
Stress Intensity	63.9
Allowable Stress, S_y	84.6
	ULTIMATE LIMIT (ksi)
Shear Stress	47.1
Bending Stress	49.6
Stress Intensity	106.5
Allowable Stress	115.0

NOTE:

1. Sections A-A is shown on Figure 3.4-1.

TABLE 3.4-3

UPPER TRUNNION LOADINGS ON TN-68 FOR USE IN CASK BODY EVALUATION

Loading Description	Inertial Load	Max. Trunnion Load / Trunnion (Load Shared by 2 Top Trunnions)
Lifting Cask Vertical	(6 * 1.15) G	V_L = 828,00 lbs. M_L = 6,218 in-kips

TABLE 3.4-4

BIJLAARD COMPUTATION SHEET

* 1. APPLIED LOADS

RADIAL LOAD P = ________ LB.

CIRC. MOMENT M_c = ________ IN-LB.

LONG. MOMENT M_L = ________ IN-LB.

TORSION MOMENT M_T = ________ IN-LB.

SHEAR LOAD V_c = ________ LB.

SHEAR LOAD V_L = ________ LB.

* NOTE: ENTER ALL FORCE VALUES IN ACCORDANCE WITH SIGN CONVENTION

2. GEOMETRY

VESSEL THICKNESS T = ________ IN.

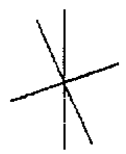
ATTACHMENT RADIUS r_o = ________ IN.

VESSEL RADIUS R_m = ________ IN.

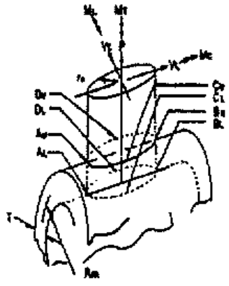
3. GEOMETRIC PARAMETERS

$\gamma = \frac{R_m}{T}$ = ________

$\beta = (0.875)\frac{r_o}{R_m}$ = ________



PIPING LOAD COORDINATE SYSTEM



FROM FIG.	READ CURVES FOR	COMPUTE ABSOLUTE VALUES OF STRESS AND ENTER RESULT	STRESSES - IF LOAD IS OPPOSITE THAT SHOWN, REVERSE SIGNS SHOWN A_U	A_L	B_U	B_L	C_U	C_L	D_U	D_L
3C AND 4C	$\frac{N_\phi}{P/R_m}$ =	$\left(\frac{N_\phi}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C AND 2C-1	$\frac{M_\phi}{P}$ =	$\left(\frac{M_\phi}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
3A	$\frac{N_\phi}{M_c/R_m^2\beta}$ =	$\left(\frac{N_\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =	▨	▨	▨	▨	−	−	+	+
1A	$\frac{M_\phi}{M_c/R_m\beta}$ =	$\left(\frac{M_\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =	▨	▨	▨	▨	−	+	+	−
3B	$\frac{N_\phi}{M_L/R_m^2\beta}$ =	$\left(\frac{N_\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+	▨	▨	▨	▨
1B OR 1B-1	$\frac{M_\phi}{M_L/R_m\beta}$ =	$\left(\frac{M_\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−	▨	▨	▨	▨
ADD ALGEBRAICALLY FOR SUMMATION OF ϕ STRESSES σ_ϕ =										
3C AND 4C	$\frac{N_x}{P/R_m}$ =	$\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C-1 AND 2C	$\frac{M_x}{P}$ =	$\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
4A	$\frac{N_x}{M_c/R_m^2\beta}$ =	$\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =	▨	▨	▨	▨	−	−	+	+
2A	$\frac{M_x}{M_c/R_m\beta}$ =	$\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =	▨	▨	▨	▨	−	+	+	−
4B	$\frac{N_x}{M_L/R_m^2\beta}$ =	$\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+	▨	▨	▨	▨
2B OR 2B-1	$\frac{M_x}{M_L/R_m\beta}$ =	$\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−	▨	▨	▨	▨
ADD ALGEBRAICALLY FOR SUMMATION OF x STRESSES σ_x =										
SHEAR STRESS DUE TO TORSION M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
SHEAR STRESS DUE TO LOAD V_c		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$	+	+	−	−	▨	▨	▨	▨
SHEAR STRESS DUE TO LOAD V_L		$\tau_{\phi x} = \frac{V_L}{\pi r_o T}$	▨	▨	▨	▨	+	+	−	−
ADD ALGEBRAICALLY FOR SUMMATION OF SHEAR STRESSES τ =										

LONGITUDINAL σ_x

PRESSURE STRESS $\frac{PR-0.4PT}{2ET}$ = ________

LONGITUDINAL BENDING STRESS = ________

TOTAL MEMBRANE STRESS = ________ ≤ ________

TOTAL SURFACE STRESS = ________ ≤ ________

CIRCUMFERENTIAL σ_ϕ

$\frac{PR+0.6PT}{ET}$ = ________

= ________ ≤ ________

= ________ ≤ ________

NOZZLE NO. ________

PIPING LOAD CODE ________

ANALYSIS POINT ________

COMPUTATION SHEET FOR LOCAL STRESSES IN CYLINDRICAL SHELLS

TABLE 3.4-5

COMPARISON OF ACTUAL WITH ALLOWABLE STRESS INTENSITY CONFINEMENT VESSEL

Service Condition	**Component**	**Stress Category**	**Stress Resultant Table**	**Maximum Stress Intensity (ksi)**	**Allowable Stress Intensity (ksi)**
Normal Condition	Shell	P_m	3A.2.5-12 Location 16	-	22.9 (S_m)
		$P_m + P_b$	3A.2.5-12 Location 16	20.0	34.35 ($1.5S_m$)
	Flange	P_m			21.5 (S_m)
		$P_m + P_b$	3A.2.5-7 Location 20	1.0	32.25 ($1.5S_m$)
	Lid	P_m			21.5 (S_m)
		$P_m + P_b$	3A.2.5-7 Location 22	2.0	32.25 ($1.5S_m$)
Accident Condition	Shell	P_m	3A.2.5-21 Location 11	37.0	49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-21 Location 11	53.0	70.0 (S_u)
	Flange	P_m			49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-26 Location 19	30.0	70.0 (Su)
	Lid	P_m			49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-18 Location 22	5.0	70.0 (Su)

Note: If the primary plus bending stress for a particular component meets the primary membrane stress allowable, only the Normal Condition primary plus bending stress is reported

TABLE 3.4-6

COMPARISON OF ACTUAL WITH ALLOWABLE STRESS INTENSITY GAMMA SHIELDING

Service Condition	Component	Stress Category	Stress Resultant Table	Maximum Stress Intensity (ksi)	Allowable Stress Intensity (ksi)
Normal Condition	Cylinder	P_m	3A.2.5-7 Location 36	-	20.0 (S)
		$P_m + P_b$	3A.2.5-7 Location 36	20.0[**]	30.0 (1.5S)
	Bottom	P_m			20.0 (S)
		$P_m + P_b$	3A.2.5-7 Location 23	16.0	30.0 (1.5S)
	Welds	P_m			17.5 (S)
		$P_m + P_b$	3A.2.5-7 Location 38	2.0	30.0 (1.5S)
Accident Condition	Cylinder	P_m	3A.2.5-26 Location 32	11.0	49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-26 Location 32	54.0	70.0 (S_u)
	Bottom	P_m	3A.2.5-26 Location 25	11.0	49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-26 Location 25	60.0	70 ($3.6S_u$)
	Welds	P_m			49.0 ($0.7S_u$)
		$P_m + P_b$	3A.2.5-26 Location 37	21.0	70.0 ($3.6S_u$)

Note: If the primary plus bending stress for a particular component meets the primary membrane stress allowable, only the Normal Condition primary plus bending stress is reported. Local loads and stresses due to tornado driven missiles are evaluated in chapter two, section 2.2.1.3.

[**] For this maximum combined stress including secondary stress (thermal), the maximum allowable stress is $3S_m$. It is conservative to use allowable stress of $1.5S_m$. Gamma shielding is SA-266 Class 2 or SA-516 Gr. 70 or SA-105. The lowest value of allowable stress is used in these evaluations.

TABLE 3.4-7

SUMMARY OF MAXIMUM STRESS INTENSITY AND ALLOWABLE STRESS LIMITS FOR LID BOLTS

STRESS CATEGORY	SERVICE CONDITION	CALCULATED STRESS (ksi)	ALLOWABLE STRESS (ksi)
Tensile	Level A	25.0	92.4 (2/3 S_Y)
	Level D	25.0	115.5 (0.7 S_u)
Shear	Level A	10.7	55.4 (0.4S_y)
	Level D	10.7	69.3 (0.4S_u)
Combined S.I.	Level A	40.7	124.7 (0.9S_y)
	Level D	(not required)	(not required)
Interaction Equation: $R_t^2 + R_S^2 \leq 1$	Level A Level D	0.11 0.07	

TABLE 3.4-8

COMPARISON OF ACTUAL WITH ALLOWABLE STRESS INTENSITY IN BASKET (NORMAL CONDITIONS)

Loading	Stress Category	Max.Stress (ksi)	Allowable Stress (ksi)	Reference Section/ Table
304 Stainless Steel Plate				
1G Lateral	P_m	0.36	14.76 ($S_m \times 0.9$)	Table 3B.3-1 (0^o Drop)
	$P_m + P_b$	0.63	22.14 ($1.5\ S_m \times 0.9$)	Table 3B.3-1 (0^o Drop)
3G Vertical	P_m	0.30	14.76 ($S_m \times 0.9$)	Sect. 3B.3.3
Stainless Steel Fusion Weld				
1G Lateral	τ	0.055	2.95 ($0.6\ S_m \times 0.3$)	Table 3B.3-1 (45^o Drop)
3G Vertical	τ	0.05	2.95 ($0.6\ S_m \times 0.3$)	Sect. 3B.3.3
6061-T6 Aluminum Rail				
1G Lateral	P_m	0.11	4.5 (S_m)	Table 3B.3-2 (Location 1)
	$P_m + P_b$	0.15	6.75 ($1.5\ S_m$)	Table 3B.3-2 (Location 1)
3G Vertical	P_m	0.05	4.5 (S_m)	Sect. 3B.3.3

TABLE 3.4-9

COMPARISON OF ACTUAL WITH ALLOWABLE STRESS INTENSITY IN BASKET (ACCIDENT CONDITIONS)

Loading	Stress Category	Max. Stress (ksi)	Allowable Stress (ksi)	Max. Allowable G load	Max. Calculated G Load	Reference Section/Table
304 Stainless Steel Plate / Box						
60 G End Drop	P_m	6.03 (60G)	39.36 (2.4 S_m)	392	60	Sect. 3B.4.1
Side drop Stress Analysis	P_m	0.36 (1G)	39.36 (2.4 S_m)	109	77	Table 3B.4-1 (0^o Drop)
	$P_m + P_b$	0.63 (1G)	59.04 (S_u)	94	77	Table 3B.4-1 (0^o Drop)
Side drop Buckling Analysis				92	77	Sect. 3B.5.2
Stainless Steel Fusion weld						
60 G End Drop	τ	0.92 (60G)	19.68 (0.6 $S_m \times$ 2)	1283	60	Sect. 3B.4.1
Side Drop Stress Analysis	τ	0.055 (1G)	19.68 (0.6 $S_m \times$ 2)	358	77	Table 3B.4-1 (45^o Drop)
6061-T6 Aluminum Rail						
60 G End Drop	P_m	1.0 (60G)	10.8 (2.4 S_m)	648	60	Sect. 3B.4.1
Side Drop Stress analysis	P_m	0.10 (1G)	10.8 (2.4 S_m)	98	77	Table 3B.4-2 (Location 1)
	$P_m + P_b$	0.15 (1G)	16.0 (S_u)157	107	77	Table 3B.4-2 (Location 1)
Side Impact Buckling Analysis				100	77	Sect. 3B.5.4

TABLE 3.4-10

COMPARISON OF MAXIMUM STRESS INTENSITY WITH ALLOWABLES IN OUTER SHELL

LOAD	Maximum Stress Intensity (ksi)	Allowable Stress (ksi)
25 psi Internal Pressure	4.5	S_y = 33.6
25 psi + 3G Down Cask Vertical	9.1	S_y = 33.6
25 psi + 3G Down Cask Horizontal	7.0	S_y = 33.6

Figure 3.4-1
Trunnion Geometry

Figure Withheld Under 10 CFR 2.390

Figure 3.4-2
Cask Body Key Dimensions

Figure Withheld Under 10 CFR 2.390

Figure 3.4-3
Standard Reporting Locations for Cask Body

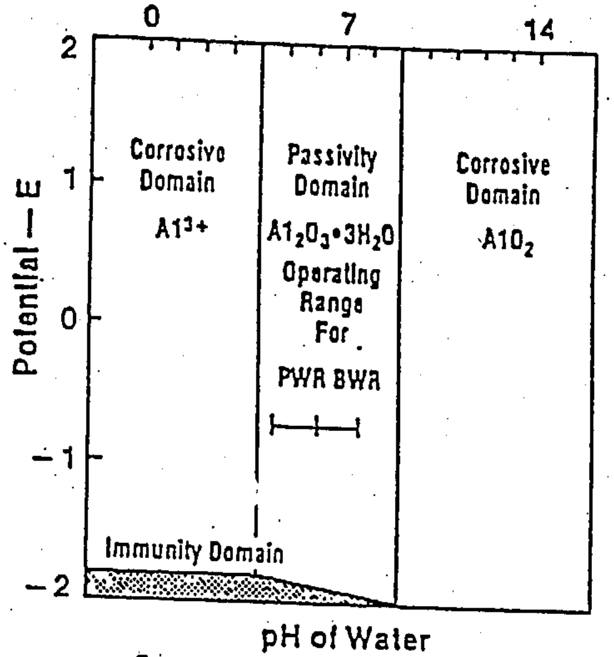
Figure Withheld Under 10 CFR 2.390

Figure 3.4-4
Weld Stress Locations

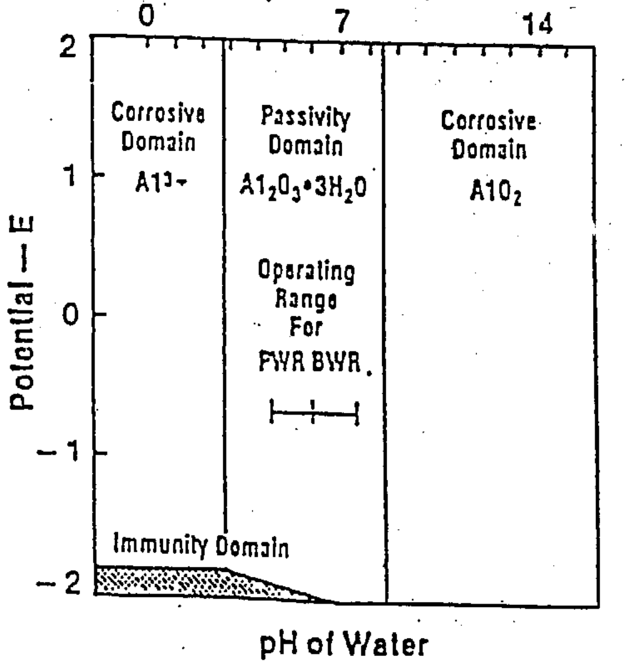
Figure Withheld Under 10 CFR 2.390

Figure 3.4-5
Potential Versus pH Diagram for Aluminum-Water System

At 25°C (77°F):

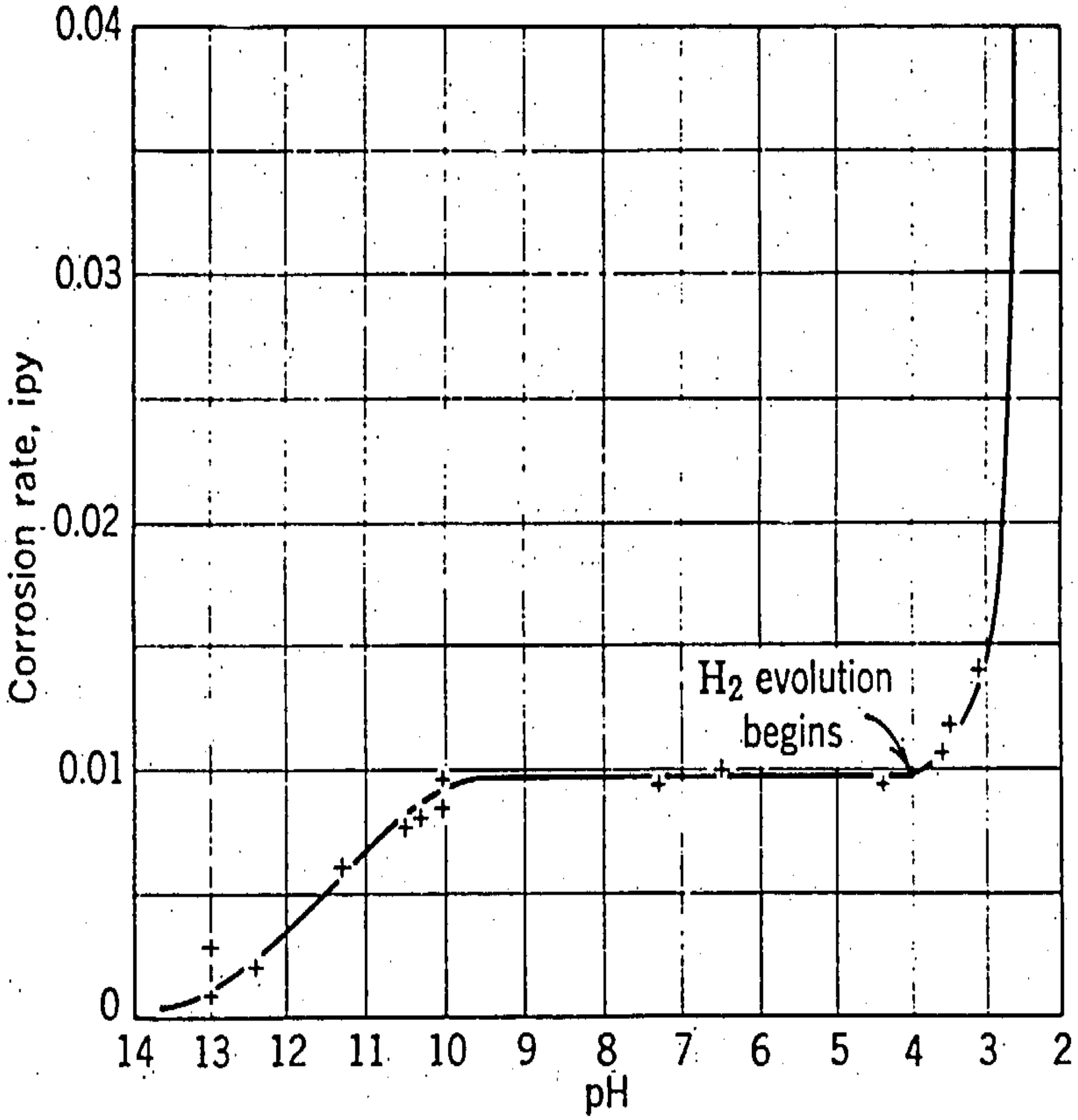


At 60°C (140°F):



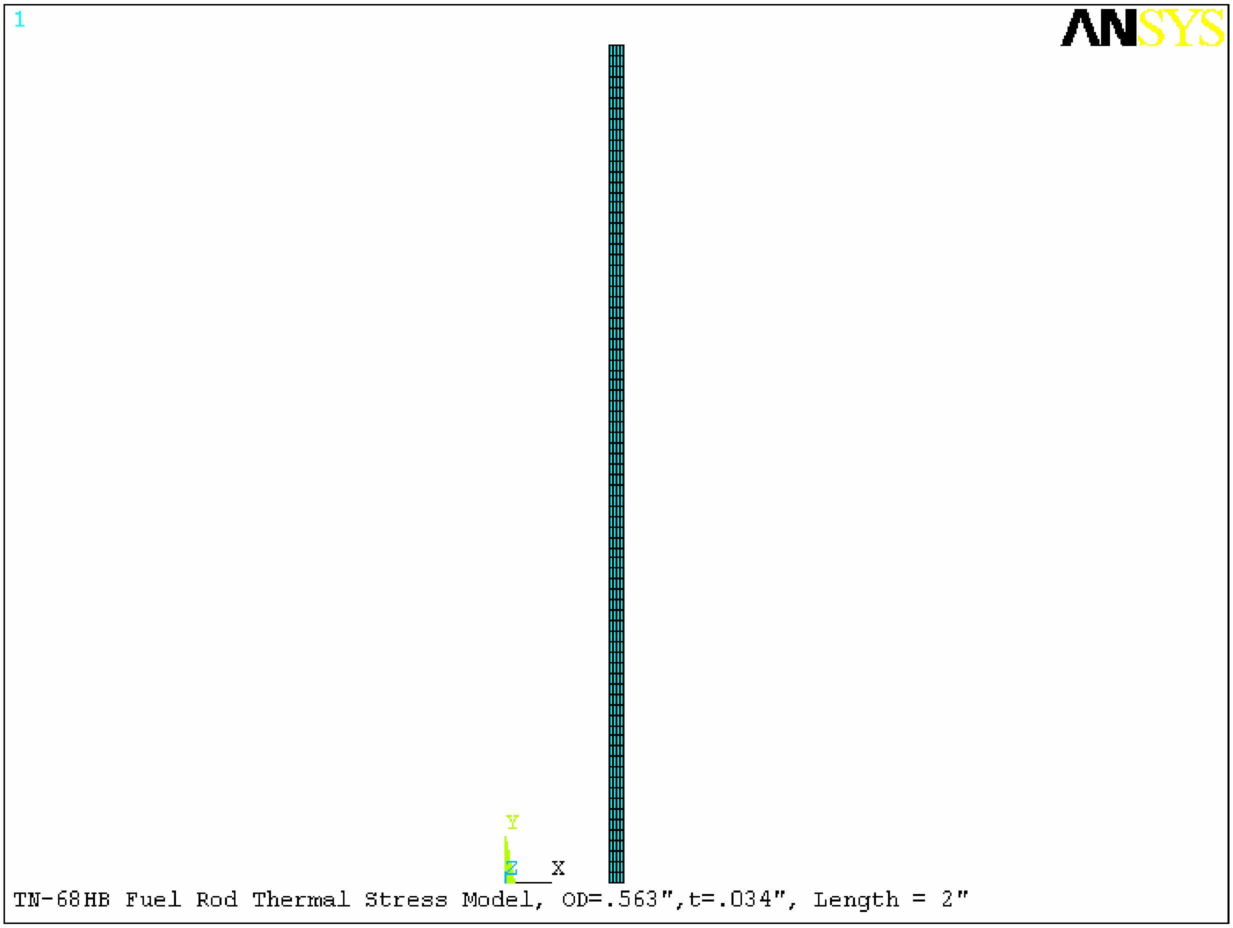
Source: Reference 13

Figure 3.4-6
Effect of pH on Corrosion of Iron in Aerated Soft Water Room Temperature



Source: Reference 16

Figure 3.5-1
Finite Element Model



TN-68HB Fuel Rod Thermal Stress Model, OD=.563",t=.034", Length = 2"

Figure 3.5-2
Nodal Temperature Used for Thermal Analysis

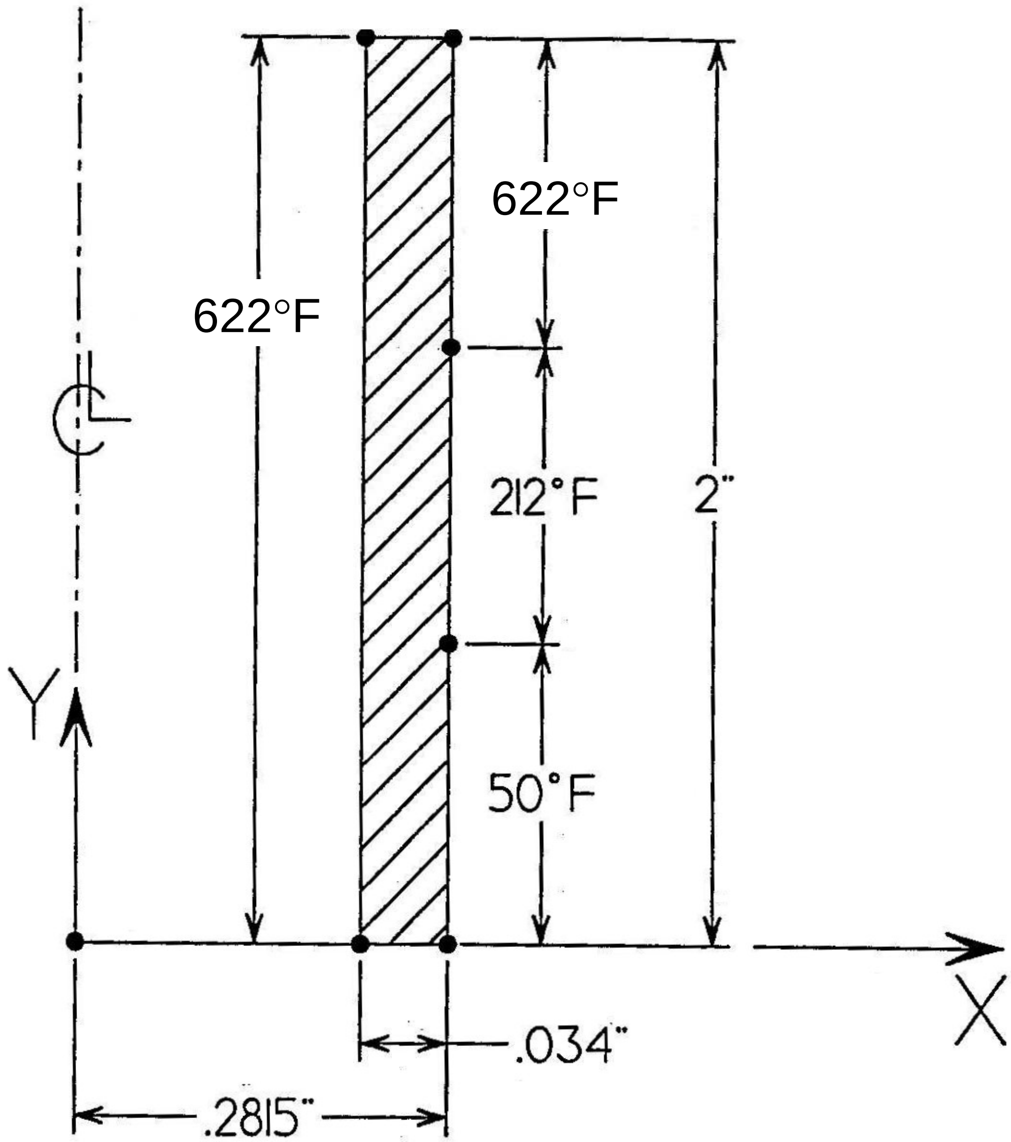


Figure 3.5-3
Temperature Distribution Resulting From Thermal Analysis

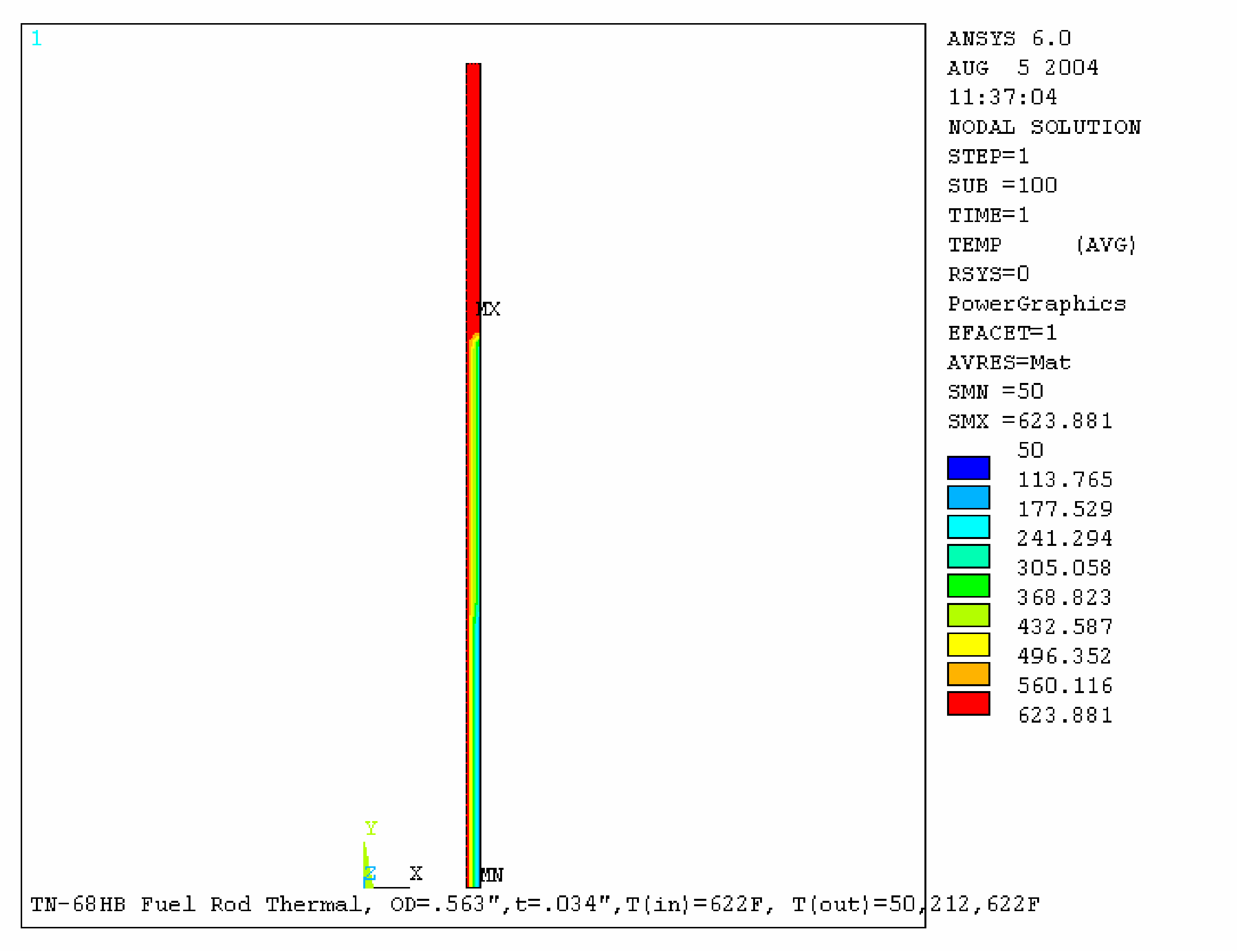


Figure 3.5-4
Nodal Stress Intensity