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7.0 CONFINEMENT

The NAC-MPC transportable storage canister (canister) provides confinement for its radioactive contents in long-term storage. The confinement boundary is closed by welding that presents a leaktight barrier to the release of contents in all of the evaluated normal, off-normal and accident conditions.

The NAC-MPC canister contains an inert gas (helium). The confinement boundary retains the helium and also prevents the entry of outside air into the NAC-MPC. The exclusion of air precludes degradation of the fuel rod cladding over time, due to cladding oxidation failures.

The NAC-MPC canister confinement system meets the requirements of 10 CFR 72.24 for protection of the public from release of radioactive material, and 10 CFR 72.122 for protection of the spent fuel contents in long-term storage such that future handling of the contents would not pose an operational safety concern.

The NAC-MPC canister overpack is designed to serve as the confinement boundary, when an NAC-MPC canister is loaded into it. The canister overpack contains an inert gas (helium) and satisfies the same leaktight requirement as the canister, and it incorporates a welded shield lid (inner lid) and welded structural lid (outer lid) arrangement similar to that used in the canister.

The canister overpack confinement boundary is formed by welding the stainless steel inner lid and outer lid to the canister shell. The welds are visually inspected and nondestructively examined to confirm integrity. The canister overpack confinement boundary is leaktight in all of the evaluated normal and accident conditions.

Alternately, the NAC-STC cask could provide a confinement boundary for the transportable storage canister during transport to a facility where the canister confinement boundary could be restored or the canister contents could be placed into a new canister.

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7.1 Confinement Boundary

Confinement of the contents in long-term storage is provided by the transportable storage canister or canister overpack. The welded canister or welded canister overpack forms the confinement vessel.

The primary confinement boundary of the canister consists of the canister shell, bottom closure plate, shield lid, the two (2) port covers, and the welds that join these components. There are no bolted closures or mechanical seals in the primary confinement boundary. The confinement boundary welds are described in Table 7.1-1.

The primary confinement boundary of the canister overpack consists of the canister overpack shell, bottom closure plate, inner lid, one (1) port cover, and the welds that join these components. There are no bolted closures or mechanical seals in the primary canister overpack confinement boundary. The confinement boundary welds described in Table 7.1-1 also apply to the canister overpack.

7.1.1 Confinement Vessel

The NAC-MPC transportable storage canister provides the confinement vessel for the radioactive contents. In the hypothetical situation where the canister confinement boundary is compromised the canister may be placed in a canister overpack. The canister overpack is then the primary confinement vessel.

7.1.1.1 Confinement Vessel - Canister

The canister consists of three (3) principal components: the canister shell; the shield lid; and the structural lid. The canister shell is a right circular cylinder constructed of 5/8-inch thick rolled Type 304L stainless steel plate. The edges of the rolled plate are joined using full penetration welds. It is closed at the bottom end by a 1-inch thick circular plate joined to the shell by a full penetration weld. The inside and outside diameter of the canister are 69.39 inches and 70.64 inches, respectively. The inside length is 121.5 inches. The overall external length of the canister is 122.5 inches. The canister is fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, except for the top end weld closures and their nondestructive ultrasonic or progressive dye penetrant examinations.

After loading, the canister is closed at the top by a shield lid and a structural lid. The shield lid is a 5-inch-thick Type 304 stainless steel plate. It is joined to the canister shell using a field installed bevel weld. The shield lid contains the drain and fill penetrations and provides gamma radiation protection to the operators during the draining, drying and inerting operations. After the shield lid is welded in place, the canister is pressure tested and leak tested to ensure leaktightness. Following draining, drying and inerting operations, the penetrations are closed with Type 304 stainless steel port covers that are welded in place with bevel welds. The operating procedures, describing the handling steps to close the canister are presented in Chapter 8. The pressure and leak test procedures are described in Chapter 9.

A secondary, or redundant, confinement boundary is formed at the top of the canister by a structural lid, which is placed over the shield lid. The structural lid is a 3-inch thick Type 304L stainless steel plate. The structural lid provides the attachment points for lifting the loaded canister. The structural lid is welded to the shell using a field installed bevel weld. The weld specifications and weld inspection and acceptance criteria are presented in Sections 7.1.3.5 and 7.1.3.4, respectively.

The confinement boundaries are shown in Figures 7.1-1 and 7.1-2. As illustrated in Figure 7.1-2, the secondary confinement boundary includes the structural lid, the upper 3.5 inches of the canister shell and the joining weld. This boundary provides additional assurance of the leaktightness of the canister during its service life.

7.1.1.2 Confinement Vessel - Canister Overpack

The canister overpack consists of three (3) principal components: the canister overpack shell; the inner lid; and the outer lid. The canister overpack shell is a right circular cylinder constructed of 0.5-inch thick rolled Type 304L stainless steel plate. The edges of the rolled plate are joined using full penetration welds. It is closed at the bottom end by a 1-3/8-inch thick circular plate joined to the shell by a full penetration weld. The inside and outside diameter of the canister overpack are nominally 71.64-inches and 72.64-inches, respectively. The inside length is 128-inches. The overall external length of the overpack is 133-inches. The canister overpack is fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, except for the top end weld closure designs and their nondestructive ultrasonic or dye penetrant examinations.

After loading, the canister overpack is closed at the top by an inner lid and outer lid. The inner lid is a 3-inch-thick Type 304 stainless steel plate. It is joined to the canister overpack shell using a field installed weld. The inner lid contains the vacuum and fill penetration. After the inner lid is welded in place, the canister overpack is pressure tested and leak tested to ensure leaktightness. Following inerting operations, the penetration is closed with a Type 304 stainless steel port cover that is welded in place on the inner lid. The operating procedures, describing the handling steps to close the canister overpack, are presented in Chapter 8. The pressure and leak test procedures are described in Chapter 9.

A secondary, or redundant, confinement boundary is formed at the top of the canister overpack by an outer lid, which is placed over the inner lid. The outer lid is a 2-inch thick Type 304L stainless steel plate. The outer lid is welded to the shell using a field installed bevel weld. The weld specifications and weld inspection and acceptance criteria are presented in Sections 7.1.3.2 and 7.1.3.3, respectively.

The confinement boundaries are similar to those shown in Figures 7.1-1 and 7.1-2 for the canister, with the inner lid replacing the shield lid and the outer lid replacing the structural lid. For the canister overpack, the secondary confinement boundary includes the outer lid, the upper 2 inches of the canister overpack shell and the joining weld. This boundary provides additional assurance of the leaktightness of the canister overpack during its service life.

7.1.1.3 Design Documents, Codes, and Standards

The canister and canister overpack are constructed in accordance with the license drawings presented in Section 1.5. The principal Codes and Standards that apply to the design, fabrication and assembly are described in Sections 7.1.1 and 7.1.3, and are shown on the licensing drawings. Other Codes and Standards are applied as appropriate in the design or specification of the canister.

7.1.1.4 Technical Requirements for Canister and Canister Overpack

The canister confines up to 36 intact or reconfigured Yankee Class fuel assemblies. The total number of rods in reconfigured assemblies is limited to 64. Over its 50-year design life, the canister precludes the release of radioactive contents and precludes the entry of air that could potentially damage the cladding of the stored spent fuel. The design of the canister to the

requirements of ASME Section III, Subsection NB ensures that the canister maintains confinement in all of the evaluated normal, off-normal, and accident conditions.

The design of the canister allows the recovery of stored spent fuel should that become necessary.

The canister has no exposed penetrations, no mechanical closures, and does not employ seals to maintain confinement. There is no requirement for continuous monitoring.

The design basis parameters for the Yankee Class fuel are presented in Section 1.2.3. The design criteria that apply to the canister, as an element of the NAC-MPC dry storage system, are presented in Table 1.2-1.

The canister overpack meets all design requirements of the NAC-MPC transportable storage canister.

7.1.1.5 Release Rate

The primary confinement boundary is formed by a stainless steel plate joined by welding. The welds are visually inspected, nondestructively examined, and pressure tested to confirm integrity. Consequently, the confinement boundary is leaktight. There is no maximum allowable leak rate specified for the NAC-MPC canister, as leakage to any degree up to the level of sensitivity of the leak test, is not acceptable. However, to demonstrate leaktightness of the shield lid, a measurement of helium leakage is made based on the leaktight condition of $1x10^{-7}$ ref cm^3/sec, as defined by the American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials, ANSI N14.5-1997, issued by the American National Standards Institute in December, 1997.

Based on a leaktight configuration, the calculation of radionuclide inventories is not required.

7.1.2 Confinement Penetrations

Two penetrations (with quick disconnect fittings) are provided in the canister shield lid for operator use. One penetration is used for draining residual water from the canister. It connects to a drain tube that extends to the bottom of the canister. The other penetration extends only to the underside of the shield lid. It is used to introduce air, or inert gas, into the top of the canister. Once draining is completed, either penetration may be used for vacuum drying and backfilling with helium. Following backfilling, both penetrations are closed with port covers that are welded to the shield lid. When the port covers are in place, the penetrations are not accessible. These port covers are subsequently enclosed and covered by the structural lid, which is also welded in place. The structural lid and the remainder of the canister have no penetrations.

One penetration (with quick disconnect fitting) is provided in the canister overpack inner lid to introduce inert gas into the overpack. Following backfilling, the penetration is closed with a port cover that is welded to the inner lid. When the port cover is in place, the penetration is not accessible. The port cover is subsequently enclosed and covered by the canister overpack outer lid, which is also welded in place. The outer lid and the remainder of the canister overpack have no penetrations.

7.1.3 Seals and Welds

This section describes the process used to properly assembly the confinement vessel (canister or canister overpack). Weld processes and inspection and acceptance criteria are described in Sections 7.1.3.2 and 7.1.3.3.

There are no elastomer or metallic seals used in the confinement boundary of the canister or canister overpack.

7.1.3.1 Fabrication

All cutting, machining, welding, and forming is in accordance with Section III, Article NB-4000 of the ASME Code, unless otherwise specified in the approved fabrication drawings and specifications consistent with the exception to the code described in Section 7.1.1. License drawings are provided in Section 1.5. ASME code stamping of the canister is not required.

7.1.3.2 Welding Specifications

The canister and canister overpack bodies are assembled using longitudinal welded joints in the shell and circumferential welded joints at the bottom plate/ shell juncture.

These welds are in accordance with ASME Code Section IX. The full penetration seam weld joining the canister shell is radiographed in accordance with ASME Section V, Article 2. The weld joining the bottom plate to the canister shell is ultrasonically inspected in accordance with ASME Section V, Article 5. The acceptance criteria for these welds is as specified in ASME Code Section III, NB-5320 and NB-5330, respectively. The finished surface of these welds is liquid penetrant inspected in accordance with ASME Code, Section V, Article 6, and accepted in accordance with Section III, NB-5350.

After loading, the canister is closed by a shield lid and a structural lid using field installed bevel welds.

After the shield lid is welded in place, the canister is pressure tested. Following draining, drying and inerting operations, the penetrations are closed with port covers that are welded in place with bevel welds. The shield lid and port cover welds are liquid penetrant inspected in accordance with ASME Section V, Article 6, and acceptance is in accordance with ASME Code Section III, NB-5350. The shield lid to canister shell weld is liquid penetrant inspected on root and final passes in accordance with ASME Code Section V, Article 6, and is pressure and leak tested to ensure leaktightness. The operating procedures, describing the handling steps to seal the canister are presented in Chapter 8.0. The pressure and leak test procedures are described in Chapter 9.0.

A secondary, or redundant, confinement boundary is provided at the top end of the canister by a structural lid, which is placed over the shield lid. The structural lid is welded to the shell using a field-installed bevel weld. The weld is liquid penetrant inspected on root and final passes in accordance with ASME Section V, Article 6. Acceptance is in accordance with ASME Code Section III, NB-5350.

All welding procedures are written and qualified in accordance with Section IX of the ASME Code. Each welder and welding operator must be qualified in accordance with Section IX of the ASME Code.

The specification for welding the lids of the canister overpack is identical to that of the canister with the exception that only one penetration exists in the overpack inner lid, compared to two penetrations in the canister shield lid.

7.1.3.3 Testing, Inspection, and Examination

The following tests are performed to ensure satisfactory performance of the confinement vessel:

1. All components are visually examined for conformance with the fabrication drawings.

2. All welds that are directly visible are visually examined in accordance with the requirements of ASME Code Section V, Article 9.

3. The acceptance standards for visual examination of canister and canister overpack welded joints are as specified in ASME Code, Section III, Paragraphs NB-4424 and NB-4427. Unacceptable weld defects are repaired in accordance with ASME Code Section III, Subarticle NB-4450 and visually re-examined.

4. Canister and canister overpack welds designated to be examined by radiographic examination are examined in accordance with the requirements of Section V, Article 2 of the ASME Code. The minimum acceptance standards for radiographic examination are as specified in ASME Code Section III, NB-5320. Welds designated for ultrasonic examination are examined in accordance with the requirements of Section V, Article 5 of the ASME Code. The minimum acceptance standards for ultrasonic examination are as specified in ASME Code Section III, NB-5330. Unacceptable defects in the welds are repaired in accordance with ASME Code Section III, NB-4450 and re-examined.

5. A written report of each weld examined by radiography or ultrasonics is prepared. At a minimum, the written report includes: identification of part, material, name and level of examiner, NDE procedure used and the findings or dispositions, if any.

6. All personnel performing nondestructive testing are qualified in accordance with American Society of Nondestructive Testing Recommended Practice No. SNT-TC-1A.

7. Individuals qualified for NDT Level I, NDT Level II, or NDT level III may perform nondestructive testing. Only Level II or Level III personnel may interpret the results of examination or make determination of the acceptability of examined parts.

8. The vendor completely assembles the canister or canister overpack prior to shipping. The purpose of assembling the canister is to ensure that all items specified have been supplied and to test the fit of the shield lid assembly including drain tube and the structural lid. The purpose of assembling the canister overpack is to ensure that all items specified have been supplied and to test the fit of the inner and outer lid.

9. A helium leak test is used to verify that the weld joining the shield lid to the canister wall, or the inner lid to the canister overpack wall, is leaktight. The containment vessel is pressurized to 22 psia through the either the drain port (canister) or fill port (canister overpack) to leak test the shield lid to canister shell weld or inner lid to overpack shell weld. The sensitivity of the helium leak test shall be at least 4.0×10^{-8} cm^3/sec (helium) so as to demonstrate a leakage rate not greater than 8.0×10^{-8} cm^3/sec (helium). Any indication of a leak is an unacceptable condition and must be repaired.

7.1.4 Closure

The primary closure of the transportable storage canister consists of the welded shield lid and the two (2) welded port covers. There are no bolted closures or mechanical seals in the primary closure. A secondary closure is provided at the top end of the canister by the structural lid. The structural lid, when welded to the canister shell, fully encloses the shield lid and the penetration port covers. The closures of the canister overpack are identical to those of the canister with the exception that only one penetration/port cover exists in the overpack lid.

Figure 7.1-1 Transportable Storage Canister Primary and Secondary Confinement Boundaries

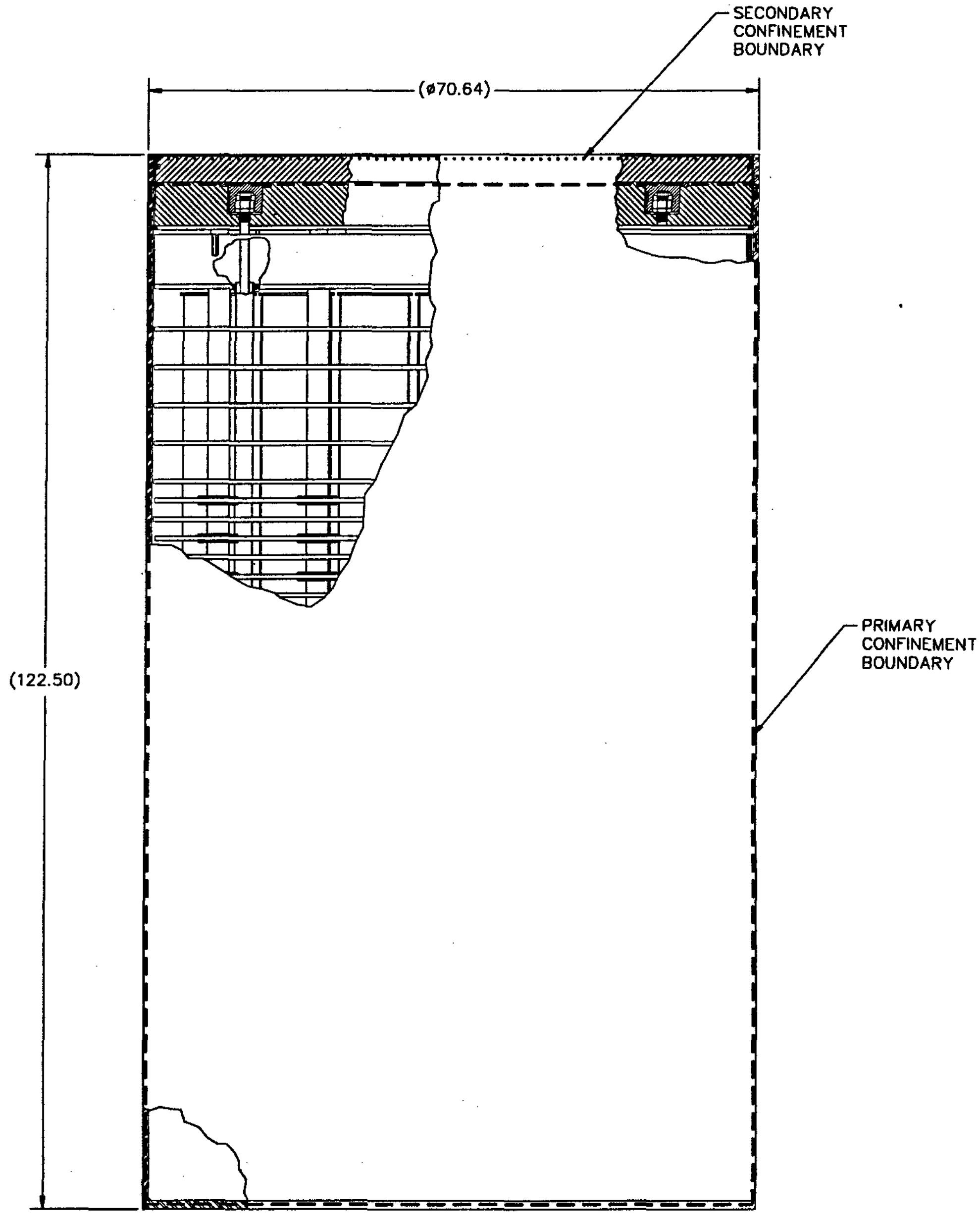

Figure 7.1-2 Confinement Boundary Detail at Shield Lid Penetration

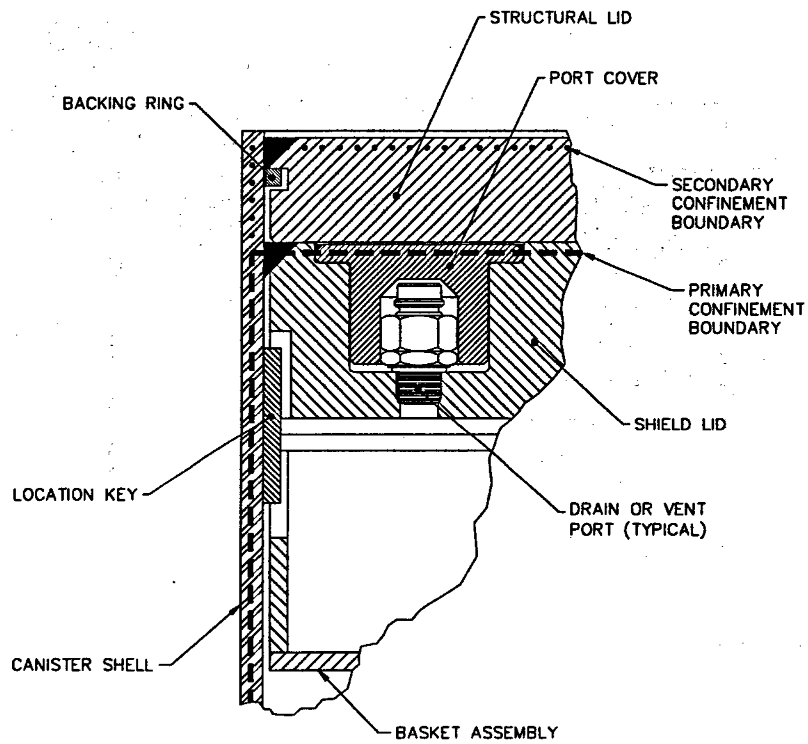

Table 7.1-1 Canister Confinement Boundary Welds

Confinement Boundary Welds		
MPC Weld Location	Weld Type	ASME Code Category (Section III, Subsection NB)
Shell longitudinal seam	Full penetration groove (shop weld)	A
Shell circumferential seam (if used)	Full penetration groove (shop weld)	B
Baseplate to shell	Full penetration groove (shop weld)	C
Shield lid to shell	Bevel (field weld)	C
Structural lid to shell	Bevel (field weld)	C
Vent and drain port covers to shield lid	Bevel (field weld)	C

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7.2 Requirements for Normal Conditions of Storage

The canister is transferred to a vertical concrete storage cask using a transfer cask. During this transfer, the canister is subject to handling loads. The evaluation of the canister for normal handling loads is provided in Chapter 3.0. The principal design criteria for the NAC-MPC system are provided in Chapter 2.0.

Once the canister, with or without the canister overpack, is placed inside of the vertical concrete storage cask, it is effectively protected from direct loading due to natural phenomena, such as wind, snow and ice loading. The principal direct loading for normal operating conditions arises from increased internal pressure caused by decay heat, solar insolation, and ambient temperature. The normal operating internal pressure is evaluated in Chapter 3.0, as described in Section 7.2.2

7.2.1 Release of Radioactive Material

The structural analysis of the canister for normal conditions of storage that is presented in Section 3.4.4 shows that the canister is not breached in any of the normal operating events. Consequently, there is no release of radioactive material during normal conditions of storage.

The structural analysis of the canister overpack presented in Section 11.4 shows that the canister overpack is not breached in any of the normal operating events. Consequently, there is no release of radioactive material from the canister overpack during normal conditions of storage.

7.2.2 Pressurization of the Confinement Vessel

The canister is vacuum dried and backfilled with helium at one (1) atmosphere absolute prior to installing and welding the penetration port covers. In service, the internal pressure increases due to an increase in temperature of the helium and due to the postulated failure of fuel rod cladding of 3% of the fuel rods, which releases 30% of the available fission gases in those rods.

The temperature of the helium increases due to the fuel decay heat, high ambient temperature, and the effect of full solar insolation on the concrete cask surface. Fuel cladding failure is assumed to release a fraction of the available fission gas and other radionuclides that are assumed to be releasable, and all of the charge gas installed in the fuel rods at the time of manufacture of the rod. The evaluation conservatively adds the releasable inventory of the reconfigured fuel rods classified as failed to the inventory of the intact fuel that is assumed to fail in normal conditions.

The canister, shield lid, fittings, and the canister basket are fabricated from materials that do not react with ordinary or borated spent fuel pool water to generate gases. The aluminum heat transfer disks, fuel tubes, and BORAL plates used for criticality control are protected by an oxide film that forms shortly after fabrication. This oxide layer effectively precludes further oxidation of the aluminum components or other reaction with water in the canister at temperatures less than 200°F, which is higher than the typical spent fuel pool water temperature. No steels requiring protective coatings or paints are used in the canister, shield lid, fittings, or basket. Therefore, there are no protective coatings or paints present that could interact with water to release gases.

The calculation of the canister pressure based on normal storage conditions is presented in Section 3.4.4.1.3, and is 11.5 psig. This pressure is well within the design basis internal pressure value of 50 psig. There are no adverse consequences due to the internal pressure resulting from normal storage conditions.

Since the canister is vacuum dried and backfilled with helium prior to sealing, there are no significant moisture or gases, such as air, that remain in the canister. Consequently, there is no potential that radiolytic decomposition could cause an increase in canister internal pressure or result in a build up of explosive gases in the canister.

The canister overpack pressure is not explicitly calculated but is bound by the pressure evaluation of the canister. The overpack is backfilled with helium to one atmosphere (0 psig). The overpack pressure may increase due to temperature increases and the postulated failure of fuel rod cladding within the canister. The canister overpack provides additional free volume for the canister gases, resulting in a lower overall system pressure.

7.3 Confinement Requirements for Hypothetical Accident Conditions

The evaluation of the canister for off-normal and accident condition loading is provided in Sections 3.5, 11.1 and 11.2, respectively.

Once the canister is placed inside the vertical concrete storage cask, it is effectively protected from direct loading due to natural phenomena, such as seismic events, flooding and tornado (wind driven) missiles. Accident conditions assume the cladding failure of all the fuel rods stored in the canister. Consequently, there is an increase in canister internal pressure due to the release of a fraction of the fission product and charge gases. The accident conditions internal pressure is 33 psig as calculated in Section 11.2.1.

For evaluation purposes, a class of accidents identified as off-normal is also considered in Section 11.1. This class of accidents is not considered here since off-normal conditions are bounded by the hypothetical accident conditions.

The structural analysis of the canister for off-normal and accident conditions of storage that is presented in Chapter 11 shows that the canister is not breached in any of the evaluated events. Consequently, based on a leaktight configuration, there is no release of radioactive material during off-normal or accident conditions of storage.

The structural analysis of the canister overpack, Section 11.5, similarly shows that there is no breach of confinement in any evaluated accident condition. Consequently, there is no release of radioactive material from the canister overpack in any evaluated off-normal or accident condition.

The resulting site boundary dose due to a hypothetical accident is therefore less than the 5 rem whole body or organ (including skin) dose at a 100 meter minimum boundary required by 10CFR72.106 (b) for accident exposures.

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8.0 OPERATING PROCEDURES

This chapter provides general guidance for using the NAC-MPC for storage operations. Five operating conditions are addressed. The first is loading the transportable storage canister (canister), installing it in the vertical concrete cask (concrete cask), and transferring it to the storage (ISFSI) pad. The second is the removal of the loaded canister from the concrete cask. The third is opening the canister to remove spent fuel in the unlikely event that this should be necessary. The fourth is loading a canister into a canister overpack. The fifth is removal of the canister from the canister overpack in preparation for transport in the NAC-STC transport cask.

The operating procedure for transferring a loaded canister from a concrete cask to the NAC-STC transport cask is described in Section 7.2.2 of the NAC-STC SAR.

Users are expected to develop site-specific procedures that incorporate the requirements presented here, consistent with the Operating Controls and Limits presented in Chapter 12. In addition, supplemental shielding may be employed to reduce radiation exposure for certain of the tasks specified by these procedures. Use of supplemental shielding is at the discretion of the user.

Operation of the NAC-MPC system requires the use of ancillary equipment items. The ancillary equipment supplied with the system is shown in Table 8.1-1. The system does not rely on the use of bolted closures, but bolts are used to secure retaining rings and lids. The hoist rings used for lifting the shield lid and canister have threaded fittings. Table 8.1-2 provides the torque values for installed bolts and hoist rings.

The design of the NAC-MPC is such that the potential for spread of contamination during handling and future transport of the canister is minimized. The concrete cask is constructed of new materials. The canister is loaded in the spent fuel pool but is protected from gross contact with pool water by a jacket of clean water while it is in the transfer cask. Only the top of the open canister is exposed to contaminated pool water. The top of the canister is closed by the structural lid, which is not contaminated when it is installed. Consequently, the canister external surface is expected to be essentially clean.

When used in accordance with these procedures, the user dose is ALARA.

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8.1 Loading the NAC-MPC Storage System

The NAC-MPC storage system consists of three principal components: the transportable storage canister (canister), the transfer cask, and the vertical concrete cask (concrete cask). The transfer cask is used to hold the canister during loading and while the canister is being closed and sealed. The transfer cask is also used to transfer the canister to the concrete cask and to load the canister into the transport cask. The principal handling operations involve closing and sealing the canister by welding and loading it into the concrete cask. The vent and drain port locations are shown in Figure 8.1-1.

This procedure assumes that the canister with an empty basket is installed in the transfer cask, that the transfer cask is positioned in the decontamination area or other suitable work station, and that the concrete cask is positioned on a heavy-haul transporter in the cask receiving area or other suitable staging area. The staging area should be within the handling "footprint" of the cask handling crane.

The operator must ensure that the fuel assemblies selected for loading into the canister conform to the requirements of Table 2.1-1 and the Certificate of Compliance or Site Specific Approval.

8.1.1 Loading and Closing the Transportable Storage Canister

1. Visually inspect the basket fuel tubes to ensure they are unobstructed and free of debris. Ensure that the welding zones on the canister, shield and structural lids, and the port covers are prepared for welding. Ensure transfer cask door lock bolts are installed and secure.
2. Flood the canister with clean water until the water is about 4 inches from the top of the canister.

   Note: Do not fill the canister completely in order to avoid spilling water during the transfer to the spent fuel pool.
3. Attach a clean water line to the transfer cask.
4. If it is not already attached, attach the transfer cask lifting yoke to the cask handling crane, and engage the transfer cask lifting trunnions.

   Note: The minimum temperature of the transfer cask must be verified to be 0°F or higher prior to lifting.
5. Raise the transfer cask and move it over the pool, following the prescribed travel path.
6. Lower the transfer cask to the pool surface and turn on the clean water line to flood the annulus between the transfer cask and canister.

7. Lower the transfer cask as the annulus fills with clean water until the trunnions are at the surface, and hold that position until clean water fills the remainder of the canister and overflows the sides of the transfer cask. Then lower the transfer cask to the bottom of the pool cask loading area.

   Note: If an intermediate shelf is used to avoid wetting the cask handling crane hook, follow the plant procedure for use of the extension piece.

8. Disengage the transfer cask lifting yoke to provide clear access to the canister.
9. Load the previously designated fuel assemblies into the canister.
10. Attach a three-legged sling to the shield lid using the swivel hoist rings.
11. Using the cask handling crane, or auxiliary hook, lower the shield lid until it rests in the top of the canister. Note the time that the shield lid is installed.

    Note: Ensure that the shield lid key slot aligns with the key welded to the canister shell.

    Caution: The operations from this point through step 26 must be completed within 20 hours.

12. Raise the transfer cask until its top just clears the pool surface. Hold at that position, and using a suction pump, drain the pool water from above the shield lid. After the water is removed, continue to raise the cask.
13. As the cask is raised, spray the transfer cask outer surface with clean water to wash off any gross contamination.
14. When the cask is clear of the pool surface, but still over the pool, turn off the clean water flow to the annulus and allow the annulus water to drain to the pool. Move the cask to the decontamination area or other suitable work station.

    Note: Access to the top of the transfer cask is required. A suitable work platform may need to be erected.

15. Verify that the shield lid is level. Decontaminate the top of the transfer cask and shield lid as required to allow welding and inspection activities.

    Note: Supplemental shielding may be used for activities around the shield lid.

16. Insert the drain tube through the drain port of the shield lid into the basket drain tube sleeve. Install a mating quick-disconnect fitting in the vent line to open the vent. Remove the hoist rings.
17. Connect the suction pump to the drain port. Verify that the vent port is open. Remove approximately 50 gallons of water from the canister. Disconnect and remove the pump.
18. Install the semiautomated welding equipment.

19. Attach the hydrogen gas detector to the vent port. Verify that the concentration of any detectable hydrogen gas is below 2.4%.

    Note: If the concentration exceeds 2.4%, operate the vacuum system to remove gases from the under side of the shield lid, and re-verify hydrogen gas concentration.

20. Operate the welding equipment to complete the root weld joining the shield lid to the canister shell, following approved procedures to minimize canister shell and weld stress.

    Note: Stop welding if the hydrogen detector indicates a hydrogen concentration above 2.4% and clear hydrogen gas buildup.

21. Prepare the weld and perform a liquid penetrant weld examination of the root pass.

    Note: The hydrogen detector may be removed from the vent port if necessary.

22. Complete welding of the shield lid to the canister wall and remove the weld equipment.
23. Prepare the weld and perform a liquid penetrant weld examination of the final pass.
24. Remove any lines attached to the drain port. Attach an air pressure line to the vent port. Pressurize the canister to 22 psia (approximately 7.5 psig) and hold the pressure. There must be no loss of pressure for 10 minutes.
25. Release the pressure and visually inspect the shield lid to canister shell weld for indications of defects.
26. Attach the suction pump to the drain line. Ensure that the vent line is open. Using the pump, remove the remaining free water from the canister cavity.

    Note: Steps 26 through 35 must be completed within 10 hours.

27. Remove any free water in the drain port cavity. Install the drain port coverplate.

    Note: If previously removed, reinstall the hydrogen gas detector to the vent port. Operate the detector to verify that the concentration of hydrogen gas is below 2.4%. If not, use the vacuum system to clear hydrogen gas from the cavity and the drain line.

28. Weld the drain port cover to the shield lid.
29. Prepare the weld and perform a liquid penetrant examination of the drain port cover weld.
30. Attach the vacuum equipment to the vent port line.
31. Operate the vacuum equipment until a vacuum of 3 to 5 mm of mercury exists in the canister.
32. Verify that no water remains in the canister by holding the vacuum for 20 minutes. If water is present in the cavity, the pressure will rise as the water vaporizes. Continue the vacuum/hold cycle until there is no indicated rise in pressure after 20 minutes.
33. Backfill the canister cavity with helium having a minimum purity of 99.9%.
34. Restart the vacuum equipment and evacuate the canister to 3 to 5 mm of mercury.
35. Backfill the canister cavity with helium, pressurizing it to 22 psia (approximately 7.5 psig).

36. Using a helium leak detector, verify that there is no leak at the shield lid weld in excess of 1×10^{-7} ref. cm^3/sec.

    Note: Steps 36 through Step 12 of the concrete cask loading procedure (Section 8.1.2) must be completed within 36 hours.
37. Vent the canister helium pressure to one (1) atmosphere absolute (0 psig).
38. Remove any attachments to the vent port fitting. Dry any residual water that may be present in the vent port cavity.
39. Install the vent port cover.
40. Weld the vent port cover to the shield lid.
41. Prepare the weld and perform a liquid penetrant examination of the vent port cover weld.
42. Remove any supplemental shielding used during shield lid closure activities.
43. Attach a three-legged sling to the structural lid using the swivel hoist rings.

    Note: Verify that the structural lid is stamped, or otherwise marked, to provide traceability of the canister contents. Verify that the structural lid weld backing ring is in place on the structural lid.
44. Using the cask handling, or the auxiliary, crane, install the structural lid in the top of the canister. Verify that the structural lid does not protrude above the canister shell and is approximately centered in the canister shell. Verify that the gap in the backing ring is not aligned with the shield lid alignment key. Remove the hoist rings.
45. Install the automated welding equipment on the structural lid.
46. Complete the root weld pass joining the structural lid to the canister shell.
47. Prepare the weld and perform a liquid penetrant examination of the weld root pass.
48. Complete the remainder of the weld, performing progressive liquid penetrant examination if required.
49. Remove the welding equipment.
50. Prepare the weld and perform an ultrasonic inspection of the weld, if required, then perform a liquid penetrant examination of the final weld pass.
51. Perform a smear survey of the accessible area at the top of the canister to ensure that the surface contamination is less than the limits established for the site. (Typically less than 190 dpm/100 cm^2 alpha, and less than 22,900 dpm/ 100 cm^2 beta-gamma.)
52. Install the transfer cask retaining ring.
53. Decontaminate the external surface of the transfer cask.

8.1.2 Loading the Vertical Concrete Cask

This section of the loading procedure assumes that the vertical concrete cask (concrete cask) is located on the bed of a heavy-haul transporter under the cask handling crane, and that the concrete cask shield plug and lid are not in place.

1. Using a suitable crane, place the transfer adapter on the top of the concrete cask.
2. Using the transfer adapter bolt hole pattern, align the adapter to the concrete cask. Bolt the adapter to the cask using four (4) socket head cap screws.
3. Verify that the bottom door connectors on the adapter plate are in the fully extended position.
4. If not already done, attach the transfer cask lifting yoke to the cask handling crane. Verify that the transfer cask retaining ring is installed.
5. Install six (6) swivel hoist rings in the structural lid of the canister. Verify that the hoist ring threads are fully engaged, and attach two (2) three-legged slings. Stack the slings on the top of the canister so they are available for use in lowering the canister into the concrete cask.
6. Engage the transfer cask trunnions with the transfer cask lifting yoke. Ensure that all lines are disconnected from the transfer cask.
7. Raise the transfer cask and move it over the concrete cask. Lower the transfer cask, ensuring that the transfer cask bottom door rails and connector tees align with the adapter plate rails and door connectors. Prior to final set down, remove transfer cask door lock bolts.

   Note: The minimum temperature of the transfer cask must be verified to be 0°F or higher prior to lifting.
8. Ensure that the bottom door connector tees are engaged with the adapter plate door connectors.
9. Disengage the transfer cask yoke from the transfer cask and from the cask handling crane hook.
10. Return the cask handling crane hook to the top of the transfer cask and engage the two (2) three-legged slings attached to the canister by attaching the master links to the crane hook. Lift the canister slightly (about ½ inch) to take the canister weight off of the transfer cask bottom doors.

    Note: A load cell may be used to determine when the canister is supported by the crane. Avoid raising the canister to the point that the structural lid engages the transfer cask retaining ring, as this could result in lifting the transfer cask.

    Caution: The three-legged sling master links must be at least 67 inches above the canister lid.
11. Using the hydraulic system, open the bottom doors to access the concrete cask cavity.

12. Lower the canister into the concrete cask, using a slow crane speed as the canister nears the bottom of the concrete cask.
13. Disconnect the slings from the canister, and close the transfer cask bottom doors.
14. Retrieve the transfer cask lifting yoke and attach the yoke to the transfer cask.
15. Lift the transfer cask off the concrete cask and return it to the decontamination area or designated work station.
16. Using the auxiliary crane, remove the adapter plate from the top of the concrete cask.
17. Remove the swivel hoist rings from the structural lid and replace them with bolts.
18. Using the auxiliary crane, retrieve the shield plug and install the shield plug in the top of the concrete cask.
19. Using the auxiliary crane, retrieve the concrete cask lid and install the lid in the top of the concrete cask using six stainless steel bolts.
20. Ensure that there is no foreign material left at the top of the concrete cask. Install the tamper-indicating seal.

8.1.3 Transporting the Vertical Concrete Cask

This section of the procedure assumes that the loaded concrete cask is positioned on a heavy-haul transporter.

1. Using a suitable towing vehicle, tow the heavy-haul transporter to the dry storage pad (ISFSI). Verify that the bed of the transporter is approximately at the same height as the pad surface.
2. Install four (4) hydraulic jacks at the four (4) designated jacking points at the bottom cooling air vents.
3. Raise the concrete cask approximately 3 inches.

   Caution: Do not exceed a maximum lift height of 6 inches.
4. Move the air-bearing rig set under the cask.

   Note: A hydraulic skid may also be used to move the concrete cask. The height the concrete cask is raised depends upon the height of the skid or air pad set used, but may not exceed 6 inches.
5. Inflate the air-bearing rig set. Remove the four (4) hydraulic jacks.
6. Using a suitable towing vehicle, move the concrete cask from the bed of the transporter to the designated location on the storage pad.
7. Turn off the air-bearing rig set, allowing it to deflate.

6. Using a suitable towing vehicle, move the concrete cask from the bed of the transporter to the designated location on the storage pad.
7. Turn off the air-bearing rig set, allowing it to deflate.
8. Reinstall the four (4) hydraulic jacks and raise the concrete cask approximately 3 inches.

   Caution: Do not exceed a maximum lift height of 6 inches.
9. Remove the air-bearing rig set pads. Ensure that the surface of the dry storage pad under the cask is free of foreign objects.
10. Lower the concrete cask to the surface.

    Note: Ensure that the spacing between concrete casks is not less than 15 feet.
11. Remove the four (4) hydraulic jacks.
12. Install screens in the inlet and outlet vents.
13. Install/connect the temperature monitoring equipment.
14. Scribe/stamp the concrete cask name plate to indicate loading.
15. Verify that concrete cask surface dose rates are less than those established by the site. (The average surface dose rate should not exceed 50 mrem per hour on the sides and 35 mrem per hour on the top. The peak dose rate should be less than 70 mrem per hour. The dose rates measured at the inlet and outlet vents should be less than 100 mrem per hour measured at a point that is the extension of the external surface.)

Figure 8.1-1 Vent and Drain Port Locations

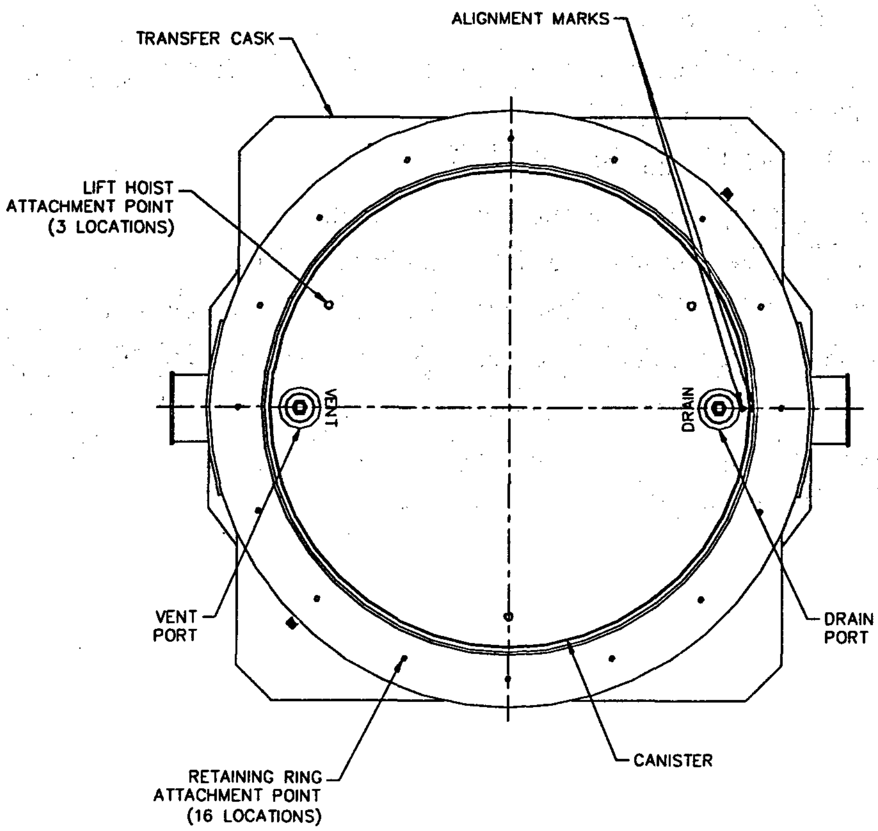

Table 8.1-1 List of Ancillary Equipment

Item	Description
Transfer Cask Lifting Yoke	Required for lifting and moving the transfer cask.
Transport Trailer (Optional)	Heavy-haul (double drop frame) trailer required for moving the loaded and empty concrete cask to and from the ISFSI pad.
Helium Supply System	Supplies helium to the canister for helium backfill and purging operations.
Vacuum Drying System	Used for evacuating the canister. Used to remove residual water, air and initial helium backfill.
Automated Welding System	Used for welding the shield lid and structural lid to the canister shell.
Self-Priming Pump	Used to remove water from the canister.
Shield Lid Sling	A three-legged sling used for lifting the shield lid. It is also used to lift the concrete cask shield plug and lid.
Canister Sling	A set of 2 three-legged slings joined by a master link, used for lifting the structural lid by itself, or for lifting the canister when the structural lid is welded to it. The master link allows the slings to be loaded simultaneously during the lift.
Canister Overpack Shell Sling	A four-legged sling used for lifting the canister overpack shell.
Transfer Adapter	Used to align the transfer cask to the concrete cask or transport cask. Provides the platform for the operation of the transfer cask bottom doors.
Hydraulic Unit	Operates the bottom doors of the transfer cask.
Lift Pump Unit	Jacking system for raising and lowering the concrete cask.
Air Pad Rig Set	Air cushion system used for moving the concrete cask.

Table 8.1-2 Torque Values

Fastener	Torque Value (ft-lbs)	Torque Pattern
Transfer Adapter Bolts	40 ± 5	None
Transfer Cask Retaining Ring	100 ±10	None
Concrete Cask Lid	40 ± 5	None
Lifting Hoist Rings*		
Canister Shield Lid	800 + 80, - 0	None
Canister Structural Lid	800 + 80, - 0	None
Concrete Cask Lid	800 + 80, - 0	None
Canister Overpack Inner Lid	800 + 80, - 0	None
Canister Overpack Outer Lid	800 + 80, - 0	None
* Threads must be fully engaged		
Canister and Lid Plug Bolts	Hand Tight	None
Transfer Cask Door Lock Bolts	Hand Tight	None
Canister Drain Line	Hand Tight	None

8.2 Removal of the Transportable Storage Canister from the Vertical Concrete Cask

Removal of the loaded canister from the concrete cask is expected to occur at the time of shipment of the canistered fuel off site. Alternately, removal could be required in the unlikely event of an accident condition that rendered the concrete cask or canister unsuitable for continued long-term storage or for transport. This procedure identifies the general steps to return the loaded canister to the transfer cask and return the transfer cask to the decontamination station, or other designated work area. Since these steps are the reverse of those undertaken to place the canister in the concrete cask, as described in Section 8.1.2, they are summarized here.

At the option of the user, the canister may be removed from the concrete cask and transferred to another concrete cask or to the NAC-STC transport cask at the ISFSI site. This transfer is done using the transfer cask, which provides shielding for the canister contents during the transfer.

1. Using the hydraulic jacking system and the air pad set, move the concrete cask from the ISFSI pad to the heavy-haul transporter. The bed of the transporter must be approximately level with the surface of the pad.

   Caution: Do not exceed a maximum lift height of 6 inches when raising the concrete cask to install the air pad set.
2. Tow the transporter to the cask receiving area or other designated work station.
3. Remove the concrete cask shield plug and lid. Install the hoist rings in the canister structural lid. Verify that the hoist ring threads are fully engaged and attach the lift slings. Install the transfer adapter.
4. Retrieve the transfer cask and position it on the transfer adapter on the top of the concrete cask.

   Note: The minimum temperature of the transfer cask must be verified to be 0°F or higher prior to lifting.
5. Open the shield doors. Attach the canister lift slings to the cask handling crane hook.

   Caution: The three-legged sling master links must be at least 67 inches above the canister lid.
6. Raise the canister into the transfer cask. Use caution to avoid contacting the transfer cask retaining ring with the canister.

7. Close the shield doors. Lower the canister to rest on the bottom doors. Disconnect the canister slings from the crane hook.
8. Retrieve the transfer cask lifting yoke. Engage the transfer cask trunnions and move the transfer cask to the decontamination area or designated work station.

   Note: Prior to moving transfer cask, install and secure door lock bolts.

After the transfer cask containing the canister is in the decontamination area or other suitable work station, additional operations may be performed on the canister. It may be opened, transferred to another concrete cask, or placed in the NAC-STC transport cask.

8.3 Unloading the Transportable Storage Canister

Circumstances could arise that dictate the opening of a previously loaded canister and the removal of the stored spent fuel. This section describes the basic operations needed to open the sealed canister. It is assumed that the canister is positioned in the transfer cask and that the transfer cask is in the decontamination station or other suitable work station. The principal mechanical operations are the cutting of the closure welds, filling with water, and the removal of the spent fuel. Supplemental shielding is used as required.

1. Remove the transfer cask retaining ring.
2. Survey the top of the canister to establish the radiation level and contamination level at the structural lid.
3. Set up the weld cutting equipment to cut the structural lid weld. (Abrasive grinding, hydrolaser, or similar cutting equipment.)
4. Tent the top of the transfer cask as required.
5. Operate the cutting equipment to cut the structural lid weld.
   Note: Monitor for any out-gassing. Wear respiratory protection as required.
6. Remove the cutting equipment and attach a three-legged sling to the structural lid.
7. Using the auxiliary crane, lift the structural lid off of the canister and out of the transfer cask.
8. Survey the top of the shield lid to determine radiation and contamination levels. Use supplemental shielding as necessary. Decontaminate the top of the shield lid if necessary.
9. Tent the top of the transfer cask, if required. Using an abrasive grinder, and wearing suitable respiratory protection, cut the welds joining the vent and drain port covers to the shield lid.
10. Remove the port covers. Monitor for any out-gassing and survey the radiation level at the quick-disconnect fittings. Attach a manually valved line with a vacuum bottle to the vent port quick-disconnect. Open the valve to the vacuum bottle to obtain a gas sample from the vent line. Analyze the gas sample to determine the make up of the canister atmosphere.
    Caution: The canister could be pressurized.
11. Attach a nitrogen gas line to the drain port quick-disconnect and a discharge line from the vent port quick-disconnect to an off-gas handling system. Monitor the vent line so that the radiation level of the discharge gas and the temperature of the discharge gas are indicated. (Note: Any significant radiation level in the discharge gas indicates the presence of fission gas products. The temperature of the gas indicates the thermal conditions in the canister.
    Caution: Discharge gas temperature could initially be above 400°F.

12. Continue to flow nitrogen through the line until there is no evidence of fission gas activity in the discharge line. Continue to monitor the gas discharge temperature. When there is no additional evidence of fission gas, stop the nitrogen flow and disconnect the drain and vent port line connections.

    Caution: the discharge line and fittings may be very hot.

13. Attach a source of clean water with a minimum temperature of 70°F to the drain port quick-disconnect. Attach a discharge line to the vent port quick-disconnect. Start the flow of clean water and maintain the flow rate of 5 (+ 3, - 0) gpm. The discharge line will initially discharge hot gas, but after the canister fills, it will discharge hot water. The canister filling is expected to take less than 8 hours. (Caution: Relatively cool water may flash to steam as it encounters hot surfaces within the canister. Caution: If there are grossly failed or ruptured fuel rods within the canister, very high levels of radiation could rapidly appear at the discharge line. The radiation level of the discharge gas or water should be continuously monitored.)
14. Continue to flow water through the canister until the exit water temperature stabilizes, then stop the flow of water.
15. Connect a suction pump to the drain port and remove approximately 50 gallons of water. Disconnect and remove the pump.
16. Attach a hydrogen gas detector to the vent port. Verify that the concentration of hydrogen gas is less than 2.4%.
17. Set up the weld cutting equipment to cut the shield lid weld. (Abrasive grinding, hydrolaser, or similar cutting equipment.) Route the vent line to avoid interference with the weld cutting operation.
18. Operate the cutting equipment to cut the shield lid weld.

Note: Stop the cutting operation if the hydrogen gas detector indicates a concentration of hydrogen gas above 2.4%. Clear the gas before proceeding with the cutting operation.

19. Remove the cutting equipment. Install the shield lid lifting hoist rings and attach a three-legged sling. Attach a line to the sling master link to aid in attaching the sling to the crane hook.
20. Attach the clean water line to the transfer cask.
21. Retrieve the transfer cask lifting yoke and engage the transfer cask lifting trunnions.

    Note: The minimum temperature of the transfer cask must be verified to be 0°F or higher prior to lifting.

22. Move the transfer cask over the pool and lower the bottom of the transfer cask to the surface. Start the flow of clean water to the transfer cask annulus. Continue to lower the transfer cask, as the annulus fills with clean water, until the top of the transfer cask is about 4 inches above the pool surface. Hold this position until clean water fills the top of the transfer cask.
23. Lower the transfer cask to the bottom of the cask loading area and remove the lifting yoke.
24. Attach the shield lid lifting sling to the crane hook.
25. Slowly lift the shield lid. Move the shield lid to one side after it is raised clear of the transfer cask. (Caution: The drain line tube is suspended from the under side of the shield lid. The lid should be raised as straight as possible until the tube clears the canister basket. Use caution if the shield lid is removed from the pool. The under side of the shield lid, and the attached drain line, could be highly contaminated.)
26. Visually inspect the fuel for damage.

At this point, the spent fuel could be transferred from the canister to the fuel racks. If the fuel is damaged, special rigging could be required to remove the fuel. In addition, the bottom of the canister could be highly contaminated. Care must be exercised in the handling of the transfer cask when it is removed from the pool. Highly radioactive particles could rest on flat surfaces of the transfer cask resulting in high dose rates.

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8.4 Loading the Canister Overpack

The canister overpack is an additional component of the NAC-MPC storage system sized to accommodate a transportable storage canister. When welded closed, it establishes a confinement boundary for the canister it holds. The canister overpack is shown in Figure 1.2-4. The transfer cask is used to hold the canister during the loading of the canister overpack shell into the concrete cask. The transfer cask is then used to load the canister into the canister overpack. The remaining handling operations, which involve the closing and sealing of the canister overpack by welding, take place in the concrete cask. Consequently, scaffolding or other structure is needed to establish a work station at the top of the concrete cask.

The transportable storage canister is removed from the concrete cask using the transfer cask. The steps necessary to remove the canister from the concrete cask are listed in Section 8.2.1, beginning with Step 3. Additional steps may be necessary, depending on the condition of the canister, to ensure that the canister can be safely lifted into the transfer cask.

This procedure assumes that the loaded canister is in storage within the concrete cask, the necessary handling equipment for the transfer cask, canister and canister overpack is available, and that the area surrounding the concrete cask is staged with the necessary equipment, including the canister overpack and its inner and outer lids.

8.4.1 Loading the Canister Overpack Shell into the Vertical Concrete Cask

1. Open the concrete cask and remove the transportable storage canister using the procedure described in Section 8.2.
2. Remove the transfer cask adapter plate.
3. Decontaminate accessible surfaces as required for canister overpack installation.
4. Visually inspect the interior of the concrete cask for foreign debris and remove as necessary.
5. Install four (4) swivel hoist rings in the lift lugs of the canister overpack shell. Verify that the hoist rings are fully engaged, and attach the canister overpack lift sling.
6. Raise the canister overpack shell and move it over the concrete cask. Lower the shell into the concrete cask, ensuring that it is properly centered within the concrete cask.
7. Remove the lift sling and the hoist rings from the canister overpack shell.

8.4.2 Loading the Transportable Storage Canister into the Canister Overpack

The steps necessary to load the canister into the canister overpack are essentially the same as those listed in Section 8.1.2. Additional inspections are required after installation of the transfer adapter in Step 2 to ensure that the canister overpack shell is properly aligned with the transfer adapter.

In the event that the overpack shell interferes with the lowering of the canister, the canister shall be returned to the transfer cask, and the alignment of the overpack shell adjusted as appropriate.

1. Load the transportable storage canister into the canister overpack using the procedure provided in Section 8.1.2.
   Caution: Ensure that the canister is straight, level and centered when lowering it into the overpack to preclude binding contact with the sides of the overpack. Use a slow crane speed for lowering the canister and very slow speed for lowering in the final 5 or 6 inches.
   Note: The minimum temperature of the transfer cask must be verified to be 0°F or higher prior to lifting.
2. Remove the transfer cask and transfer adapter from the concrete cask.
   Caution: The following steps, through Step 35, require operations within the confines of the concrete cask. Ensure adequate ventilation within this work area.
3. Install the lid support ring into the overpack shell, ensuring that the ring is level and at the proper depth inside the shell.
4. Apply the weld joining the support ring to the overpack shell, following approved procedure to minimize overpack shell and weld stresses.
5. Inspect the weld, and grind as necessary, to ensure a level seating surface for the overpack inner lid.
6. Install the hoist rings in the canister overpack inner lid and attach the shield lid lift sling.
7. Lift the overpack inner lid and raise above the concrete cask. Lower the inner lid into the canister overpack until it rests on the lid support ring.
8. Remove the lift sling and hoist rings from the inner lid.
9. Install the semiautomated welding equipment.
10. Operate the welding equipment to complete the root weld joining the inner lid to the canister overpack shell, following approved procedures to minimize shell and weld stress.
11. Prepare the weld and perform a liquid penetrant weld examination of the root pass.

12. Complete welding of the inner lid to the overpack shell wall and remove the weld equipment.
13. Prepare the weld and perform a liquid penetrant weld examination of the final pass.
14. Attach an air pressure line to the vent port. Pressurize the canister to 22 psia and hold the pressure. There must be no loss of pressure for 10 minutes.
15. Release the pressure and visually inspect the inner lid to overpack shell weld for indications of defects.
16. Attach the vacuum equipment to the vent port line.
17. Operate the vacuum equipment until a vacuum of 3 to 5 mm of mercury exists.
18. Verify that no water remains in the canister by holding the vacuum for 20 minutes. If water exists in the cavity, the pressure will rise as the water vaporizes. Continue the vacuum/hold cycle until there is no indicated rise in pressure after 20 minutes.
19. Backfill the overpack with helium.
20. Restart the vacuum equipment and evacuate the canister to 3 to 5 mm of mercury
21. Backfill the overpack with helium, pressurizing it to 22 psia (approximately 7.5 psig).
22. Using a helium leak detector, check for leaks at the inner lid to canister overpack shell welds to 8×10^{-8} cm^3/sec (helium).
23. Vent the overpack helium pressure to one (1) atmosphere (0 psig).
24. Remove the attachment to the vent port fitting. Dry any residual water that may be present in the vent port cavity.
25. Install the vent port cover.
26. Weld the vent port cover to the inner lid.
27. Prepare the weld and perform a liquid penetrant examination of the vent port cover weld.
28. Install the hoist rings in the canister overpack outer lid and attach the shield lid lift sling.
    Note: Verify that the outer lid is stamped, or otherwise marked, to provide traceability of the canister contents. Verify that the outer lid weld backing ring is in place on the outer lid.
29. Install the outer lid in the top of the canister overpack and remove the hoist rings.
30. Install the automated welding equipment.
31. Complete the root weld pass joining the outer lid to the overpack shell.
32. Prepare the weld and perform a liquid penetrant examination of the weld root pass.
33. Complete the remainder of the weld.
34. Remove the welding equipment.

36. Close the concrete cask using the procedure provided in Section 8.1.2, beginning at Step 17.

37. Verify that concrete cask surface dose rates are less than those established by the site. (The average surface dose rate should not exceed 50 mrem per hour on the sides and 35 mrem per hour on the top. The peak dose rate should be less than 70 mrem per hour. The dose rates measured at the inlet and outlet vents should be less than 100 mrem per hour measured at a point that is the extension of the external surface.)

8.5 Removal of the Transportable Storage Canister from the Canister Overpack

When shipment of a canister stored within a canister overpack is desired, the canister overpack must first be unloaded. This procedure involves opening the concrete cask, removing the canister overpack lids, and removal of the canister from the canister overpack using the transfer cask. The canister overpack is shown in Figure 1.2-4.

This procedure assumes that the necessary handling equipment for the transfer cask, canister and canister overpack is available. In addition, scaffolding, or other structure, to form a work station at the top of the concrete cask is required.

1. Remove the concrete cask shield plug and lid.
2. Set up the weld cutting equipment to cut the canister overpack outer lid weld. (Abrasive grinding, hydrolaser, or similar cutting equipment.)
3. Tent the top of the canister overpack as required.
4. Operate the cutting equipment to cut the outer lid weld.

   Caution: Monitor for any out-gassing. Wear respiratory protection as required.
5. Remove the cutting equipment and attach the hoist rings and shield lid sling to the outer lid.
6. Lift the outer lid off of the canister overpack.
7. Tent the top of the canister overpack, and use respiratory protection for the remaining steps, as required.
8. Use an abrasive grinder to cut the vent port cover from the overpack inner lid.
9. Remove the vent port cover. Monitor for any out-gassing and survey the radiation level at the quick-disconnect fittings. Attach a manually valved line with a vacuum bottle to the vent port quick-disconnect. Open the valve to the vacuum bottle to obtain a gas sample from the vent line. Analyze the gas sample to determine the makeup of the canister atmosphere. The presence of fission gases indicates failed fuel that may require special handling.

   Caution: The canister overpack could be pressurized.
10. Set up the weld cutting equipment to cut the overpack inner lid weld. (Abrasive grinding, hydrolaser, or similar cutting equipment.) Route the vent line to avoid interference with the weld cutting equipment.
11. Tent the top of the canister overpack as required.
12. Operate the cutting equipment to cut the inner lid weld.
13. Remove the cutting equipment and attach the hoist rings and shield lid sling to the inner lid.
14. Lift the inner lid off of the canister overpack.

15. Install the hoist rings in the canister structural lid.
16. Using the procedure provided in Section 8.2, beginning at Step 4, remove the loaded canister from the canister overpack.

The steps necessary to remove the canister from the canister overpack are the same steps as those presented in Section 8.2.1, beginning with Step 4, for removing the loaded canister from the concrete cask.

Additional precautions should be taken during lifting to ensure that there is no interference between the canister overpack and canister which could cause binding. Caution should be used to ensure that the canister is lifted straight and level from the overpack.

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9.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter specifies the acceptance criteria and the maintenance program for the NAC-MPC storage system primary components: vertical concrete cask (storage cask), transportable storage canister (canister) and canister overpack. The design of the NAC-MPC system requires shop fabrication of the canister shell with the bottom plate, the canister overpack shell with the bottom plate, the shield and structural lids for the canister, the inner and outer lids of the canister overpack, and the basket that holds the spent fuel. The storage cask consists of reinforced concrete placed around steel components that are integral to the performance of the storage cask. These steel components include a liner that forms the central cavity of the storage cask, a set of air outlet passage-ways that allow cooling to the stored canister, a shield plug, a steel closure lid, and a steel base. The base includes the air inlets and associated pathways, provides a pedestal upon which the canister or canister overpack rests, and provides a structural support for raising the storage cask. The steel components are shop fabricated. The reinforcing steel will be bent in the shop and delivered to the storage cask construction site. The storage cask construction will include the erection of the cask liner onto the steel base. The concrete is placed around the liner after the reinforcing steel has been properly erected.

As described in Chapter 8, the storage cask is intended to be lifted by hydraulic jacks and moved using air pads under the base. It does not have lifting trunnions.

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9.1 Acceptance Tests

The acceptance tests ensure that the storage cask, canister, and canister overpack are fabricated, assembled, inspected and tested in accordance with the requirements of this SAR and the license drawings.

9.1.1 Visual and Nondestructive Examination Inspections

The acceptance test program establishes a set of visual inspections and nondestructive examination or test requirements for the fabrication and assembly of the storage cask, canister, and canister overpack. Satisfactory results for these inspections, examinations and tests demonstrate that the components comply with the requirements of the SAR and the license drawings, and that initial operation of the storage system complies with regulatory requirements.

A fit-up test of the canister and its components is performed during the acceptance inspection. The fit-up test demonstrates that the canister, basket, shield lid and structural lid can be properly assembled during fuel loading and canister closure operations.

Fit-up tests of the canister overpack and its components are performed during the acceptance inspection. The fit-up test demonstrates that the canister overpack, inner lid and outer lid can be properly assembled if use of the canister overpack is required.

A visual inspection is performed on all materials and welds used for storage cask, canister, canister overpack and basket fabrication. The visual inspection applies to finished surfaces of the components. All welds (shop and field installed) are visually inspected for defects prior to the nondestructive examinations that may also be specified. The welding of the canister and canister overpack is performed in accordance with ASME Code, Section III, Subsection NB-4000, except as allowed by this safety analysis report. (See Chapter 7.0)

The visual inspections of the canister and canister overpack welds are performed in accordance with the ASME Code, Section V, Article 9. Acceptance criteria for the visual examinations of the canister and canister overpack welds are in accordance with ASME Code, Section VIII, Division 1, UW-35 and UW-36. Required weld repairs on the canister or canister overpack are

performed in accordance with ASME Code, Section III, Subarticle NB-4450 and are reexamined in accordance with the original acceptance criteria.

Welding of the storage cask's steel components, including field installed welds, is performed in accordance with ANSI/AWS D1.1-96 and is inspected in accordance with ANSI/AWS D1.1, Section 8.15.1. Weld procedures and welder qualifications shall be in accordance with ANSI/AWS D1.1, Section 5, or ASME Code, Section IX.

Welding of the basket assembly for spent fuel is performed in accordance with ASME Code, Section III, Article NG-4000. Visual examination of the welds is performed per the requirements of ASME Code, Section V, Article 9. Acceptance criteria for the visual examination of the basket assembly welds are that of ASME Code, Section VIII, Division 1, UW-35 and UW-36. Any required weld repairs are performed in accordance with ASME Code, Section III, Subarticle NG-4450 and are reexamined in accordance with the original acceptance criteria.

All visual inspections are performed according to written and approved procedures by qualified personnel.

9.1.1.1 Nondestructive Weld Examination

All of the welds of the canister and canister overpack assembly are nondestructively examined in addition to the visual examination previously discussed. In accordance with the ASME Code, Section III, Subsection NB requirements for confinement vessels, the canister and canister overpack shell welds are volumetrically examined by radiography (RT) in accordance with the ASME Code, Section V, Article 2, with acceptance criteria in accordance with ASME Code, Section III, NB-5320. The weld that joins the bottom plate to the canister or canister overpack shell is ultrasonically (UT) examined per ASME Code, Section V, Article 5, with acceptance criteria in accordance with ASME Code, Section III, NB-5330. The finished surface of the canister and canister overpack shell and bottom plate welds are liquid penetrant inspected in accordance with ASME Code, Section V, Article 6. Weld acceptance is in accordance with ASME Code, Section III, NB-5350. The shield lid to canister shell weld and the structural lid to shell weld, as well as the vent and drain port cover to shield lid welds, are field welds that are performed after the canister is loaded. The inner lid to overpack shell weld and the outer lid weld, as well as the canister overpack vent port cover to inner lid welds, are field welds that are performed after the canister overpack is loaded. The root and final passes of the shield

lid to canister shell weld and the inner lid to overpack shell weld are liquid penetrant (PT) examined per ASME Code, Section V, Article 6. The acceptance criteria are in accordance with ASME Code, Section III, NB-5350. The canister vent port and drain port coverplate to shield lid welds and the overpack vent port to inner lid weld are progressively liquid penetrant examined, i.e. root, each 1/4-inch layer, and final surfaces, in accordance with ASME Code Section V, Article 6. Acceptance criteria are specified in ASME Code Section III, NB-5350. The canister structural lid to shell weld and the overpack outer lid to shell weld are either: 1) ultrasonically (UT) examined in accordance with the ASME Code, Section V, Article 5 with the final weld surface liquid penetrant examined in accordance with ASME Code, Section V, Article 6; or 2) progressively liquid penetrant examined in accordance with the ASME Code, Section V, Article 6. Acceptance criteria are specified in ASME Code Section III, Subarticle NB-5330 (ultrasonic) and NB-5350 (liquid penetrant). The other welds in the canister and canister overpack assembly are PT examined and accepted to the criteria previously defined in this paragraph for liquid pentrant examination.

The basket assembly welds are PT examined in accordance with the ASME Code, Section V, Article 6. The acceptance criteria is in accordance with ASME Code, Section III, Subarticle NG-5350.

All welding of NAC-MPC components is performed using procedures and welders qualified in accordance with the ASME Code, Section IX.

9.1.1.2 Fabrication Inspections

Materials used in the fabrication of the NAC-MPC storage cask, canister, and canister overpack are procured with certifications and supporting documentation as necessary to assure compliance with procurement specifications. All materials are receipt inspected for appropriate acceptance requirements and for traceability to required material certification.

The canister and canister overpack assemblies are fabricated to the requirements of ASME Code, Section III, Subsection NB. Specific exceptions to the ASME Code are described in Chapter 2.0 and 7.0. The basket assembly is fabricated to ASME Code, Section III, Subsection NG. Shop fabricated components of the storage cask are fabricated in accordance with ANSI/AWS D1.1-96.

A complete dimensional inspection of all critical components and a components fit-up test is performed on the canister and canister overpack assembly to ensure proper assembly in the field. Acceptance criteria for dimensions shall conform to the fabrication drawings.

Concrete strength and density shall be field verified to American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM) standards to ensure adequacy. Reinforcing steel is installed per specification requirements based on ACI-318.

On completion of fabrication, the canister, canister overpack, basket, and other shop fabricated components shall be inspected for cleanliness. All components shall be free of any foreign material, oil, grease and solvents. Carbon steel components assembled for the storage cask shall be coated with a corrosion-resistant paint .

9.1.2 Structural and Pressure Test

The canister is pressure tested at the time of use. After loading of the canister basket with spent fuel , the shield lid is welded in place after approximately 50 gallons of water are removed from the canister. Prior to removing the remaining spent fuel pool water from the canister, the canister is pressure tested at 22 psia. This pressure is held for 10 minutes. Any loss of pressure during the test period is unacceptable and the leak must be located and repaired. The pressure test is described in Section 8.1.

The canister overpack is pressure tested at the time of use. After loading the canister into the overpack, the inner lid is welded in place. The canister overpack is pressure tested at 22 psia. This pressure is held for 10 minutes. Any loss of pressure during the test period is unacceptable and the leak must be located and repaired. The pressure test is described in Section 8.1.

9.1.3 Leak Tests

The canister and canister overpack are leak tested at the time of use. After the pressure test described in Section 9.1.2, the canister is drained of residual water, vacuum dried and backfilled with helium. The canister or canister overpack is pressurized with helium to 22 psia. The shield lid or inner lid to canister shell weld is helium leak tested. The leak test is performed at a sensitivity of at least 4.0×10^{-8} cm^3/sec (helium). Any indication of a leak is unacceptable and repair of the leak is required.

9.1.4 Component Tests

The components of the NAC-MPC do not require any special tests in addition to the material receipt, dimensional, and form and fit tests described above, or as described below.

9.1.4.1 Valves, Rupture Disks and Fluid Transport Devices

The NAC-MPC canister, canister overpack, and storage cask do not contain rupture disks or fluid transport devices. There are no valves that are part of the confinement boundary for transport or storage. Quick-disconnect valves are installed in the canister vent and drain ports of the shield lid and in the canister overpack vent port of the inner lid. These valves are intended to be convenience items for the operator, as they provide a means of quickly connecting (or disconnecting) ancillary drain and vent lines to the canister or canister overpack. The quick-disconnect fittings consist of male and female halves. The male fitting is installed in the canister or canister overpack and the female fitting is used as the connecting piece. The male fitting is automatically closed when the mating fitting is removed; however, no credit is taken for this sealing feature. During storage and transport, these fittings are not accessible, as port covers that are welded in place cover them when the canister or canister overpack is closed. As presented for storage , the canister and canister overpack have no accessible valves or fittings.

9.1.4.2 Gaskets

The NAC-MPC canister, canister overpack, and storage cask have no mechanical seals or gaskets that form an integral part of the package, and there are no mechanical seals or gaskets in the confinement boundary.

9.1.5 Shielding Tests

Based on the conservative design of the NAC-MPC storage cask for shielding criteria and the detailed construction requirements, no shielding tests of the concrete storage cask are required.

9.1.6 Neutron-Absorber Tests

After manufacturing, a statistical sample of each lot of BORAL panels is tested using wet chemistry and/or neutron attenuation techniques to verify a minimum ^{10}B content at the ends of the panels. Any panel in which B^{10} loading is less than the specified minimum is rejected.

9.1.7 Thermal Tests

No thermal acceptance testing of the NAC-MPC system is required during construction. Temperature measurements are taken at the air outlets of the storage cask during operation in accordance with Chapter 12.0 as verification of the thermal performance of the storage system.

9.1.8 Cask Identification

A stamped stainless steel nameplate, as shown on Drawing No. 455-856 is permanently attached on the outer surface of the storage cask. The nameplate includes the following information:

Vertical Concrete Cask

Owner:	(Utility Name)
Designer:	NAC International Inc
Fabricator:	(Vendor Name)
Date of Manufacture:	(mm/dd/yy)
Model Number:	(MPC-SO)
Cask No.:	(XXX)
Date of Loading:	(mm/dd/yy)
Empty Weight:	(Pounds [kilograms])

9.2 Maintenance Program

The NAC-MPC storage system is a passive system. There are no active components or systems incorporated in the design. Consequently, there is a minimal amount of maintenance that is required over its lifetime.

The system has no valves, gaskets, rupture discs or seals, and there are no accessible penetrations. Consequently, there is no maintenance associated with these types of features.

9.2.1 Continuing Maintenance Requirements

Recommended maintenance in normal conditions:

1. Daily surveillance of the storage casks:

   Visual inspection of air vents for detection of blockage.

   Verify that "critter screens" are in place, whole and secure.

   Measure and record the ambient temperature and air outlet temperature for each vertical concrete cask upon placement in service. Thereafter, the temperatures shall be recorded on a daily basis to verify the continuing thermal performance of the system. If a storage cask containing a canister overpack is in service, then the air outlet temperature of the storage cask containing the canister overpack is monitored twice daily.

   Visual inspection of the ISFSI site for security and safeguards.

2. Annual inspection of the storage cask exterior:

   Visual inspection of surface for chipping, spalling or other surface defects. If found, a defect should be corrected by regrouting the affected area. Refer to Section 12.2.3.1.3 for surface defect limits and required actions.

   Reapplication of corrosion-inhibiting (external) coatings on accessible surfaces.

It is not necessary to inspect the canister or canister overpack during the storage period as long as normal conditions exist.

9.2.2 Required Maintenance of First Storage System Placed in Service

For the first storage system placed in service, the canister is loaded with spent fuel assemblies and the decay heat load is calculated for that canister. Then the canister is loaded into the vertical concrete cask to evaluate the cask's thermal performance by measuring the ambient and air outlet temperatures for normal air flow. The purpose of the test is to measure the heat removal performance of the storage system and establish baseline data. A letter report summarizing the results of the test and evaluation is submitted to the NRC within 30 days of placing the cask in service in accordance with 10 CFR 72.4.

Should the first canister not be loaded with spent fuel that has the design basis heat load, the user may use a lesser heat load for the test. However, a calculation of the temperature difference between the inlet and outlet temperatures must be performed using the same methodology and inputs documented in the Safety Evaluation Report. The calculation and the measured temperature data is reported to the NRC in accordance with 10 CFR 72.4.

9.2.3 Required Maintenance for a Canister Overpack System Placed in Service

For each canister overpack system placed in service, the canister overpack is loaded with a leaking canister and the decay heat load will be calculated for that canister. Then the canister overpack will be evaluated for the storage cask's thermal performance by measuring the ambient and air outlet temperatures for normal airflow. The purpose of the test is to measure the heat removal performance of the canister overpack system and establish baseline data. A letter report summarizing the results of the test and evaluation is submitted to the NRC within 30 days of placing the overpack cask in service in accordance with 10 CFR 72.4.

Should the canister overpack not be loaded with a canister containing spent fuel that has the design basis heat load, the user may use a lesser heat load for the test. However, a calculation of the temperature difference between the inlet and outlet temperatures must be performed using the same methodology and inputs documented in the Safety Evaluation Report. The calculation and the measured temperature data are reported to the NRC in accordance with 10 CFR 72.4.

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10.0 RADIATION PROTECTION

10.1 Ensuring That Occupational Radiation Exposures Are As Low As Reasonably Achievable (ALARA)

The NAC-MPC provides radiation protection for all areas and systems that may expose personnel to radiation or radioactive materials. The components of the NAC-MPC system that require operation, maintenance and inspection are designed, fabricated, located, and shielded so as to minimize radiation exposure to personnel.

10.1.1 Policy Considerations

It is the policy of NAC to ensure that the NAC-MPC system is designed so that operation, inspection, repair and maintenance can be carried out while maintaining occupational exposure as low as reasonably achievable (ALARA).

10.1.2 Design Considerations

The design of the NAC-MPC system complies with the requirement of 10 CFR 72.3 concerning ALARA, and meets the requirements of 10 CFR 72.126(a) and 10 CFR 20.1101 with regard to maintaining occupational radiation exposures ALARA. Specific design features that demonstrate the ALARA philosophy are:

- Material selection, and surface preparation, that facilitate decontamination.
- A basket configuration that allows spent fuel loading using accepted standard practice and current experience.
- Positive clean water flow in the transfer cask/canister annulus to minimize the potential for contamination of the canister surface during in-pool loading.
- Passive confinement, thermal, criticality, and shielding systems that require no maintenance.
- Thick steel and concrete walls to reduce the side surface dose rate to 40 mrem/hr (average).

- Nonplanar cooling air pathways to minimize radiation streaming at the inlets and outlets of the concrete cask.

- Use of remote, automated outlet air temperature measurement to reduce surveillance time.

10.1.3 Operational Considerations

The ALARA philosophy has been incorporated into the procedural steps necessary to operate the NAC-MPC in accordance with its design. The following features or actions, which comprise a baseline radiological controls approach, have been incorporated in the design or procedures to minimize occupational radiation exposure:

- Use of prefabricated, shaped temporary shielding during automated welding equipment set up and removal, manual welding, and weld inspection of the shielding and structural lids and for use during all of the canister closing and sealing operations.

- Use of automatic equipment for welding the shield lid and structural lid to the canister shell.

- Decontamination of the exterior surface of the transfer cask, welding of the shield lid, and pressure testing of the canister while the canister remains filled with water.

- Use of quick disconnect fittings at penetrations to facilitate required service connections.

- Use of remote handling equipment, where practical, to reduce radiation exposure.

The operational procedures at a particular facility will be determined by the user's operational conditions and facilities.

10.2 Radiation Protection Design Features

The description of the radiation shielding design is provided in Chapter 5.0. The design basis radiation exposure rates are summarized in this section and in Chapter 2.0. The principal radiation protection design features are the shielding necessary to meet the design objectives, the placement of penetrations near the edge of the canister shield lid to reduce operator exposure and handling time, and the use of shaped supplemental shielding for work on and around the shield and structural lids. This supplemental shielding reduces operator dose rates during the welding, inspection, draining, drying and backfilling operations that seal the canister.

Radiation exposure rates at various work locations were determined for the principal NAC-MPC operational steps. These exposure rates were determined using a combination of the SAS1 and SKYSHINE III computer codes. The use of SAS1 is described in Chapter 5.0. The SKYSHINE-III code is discussed in Section 10.4. The calculated dose rates decrease with time.

10.2.1 Design Basis for Normal Storage Conditions

The radiation protection design basis for the NAC-MPC storage cask is derived from 10 CFR 72 and the applicable ALARA guidelines. The design basis surface dose rates, and the calculated 1 meter dose rates are shown below. The calculated dose rates at these, and at other dose points, are also reported in Chapter 5.0, "Shielding Evaluation."

Concrete Storage Cask	Design Basis Maximum Surface Dose Rate (mrem/hr)	1 Meter Maximum Dose Rate (mrem/hr)
Side wall	50.0	20.0
Air inlet/air outlet	100.0	5.0
Top lid	55.0	15.0

Activities associated with closing the canister, including welding of the shield and structural lids, draining, drying, backfilling and testing, will employ temporary shielding to minimize personnel dose in the performance of those tasks.

10.2.2 Design Basis for Accident Conditions

Damage to the NAC-MPC cask after a design basis accident will not result in a radiation exposure at the controlled area boundary in excess of 5 rem to the whole body or any organ, including skin. The high energy missile impact is estimated to reduce the concrete shielding thickness, locally at the point of impact, by 6 inches. This reduction in shielding results in a calculated dose rate of 120 mrem/hr at one meter. There are no other design basis accident conditions that result in a greater estimated loss of shielding.

Two hypothetical accident events that evaluate storage cask tip over and the rupture of 100% of the fuel rods are considered in Chapter 11. There are no design basis events that result in the tip over of the NAC-MPC storage cask or the release of any radioactive material from the canister.

10.3 Estimated On-Site Collective Dose Assessment

Occupational radiation exposures (person-mrem) resulting from the use of the NAC-MPC storage system are calculated using estimated exposure rates presented in Chapter 5.0 and Section 10.2.1. Exposure was evaluated by identifying the tasks, and estimating the duration and number of personnel performing those tasks based on industry experience. The tasks identified were based on the design basis operating procedures, as presented in Chapter 8.0.

Dose rates were initially estimated based on the design basis fuel assembly for shielding, the Combustion Engineering Type A fuel assembly with a burnup of 36,000 MWD/MTU and a cool time of 8 years. Since use of these dose rates over predict the total dose for the use of the NAC-MPC system for a 16 cask storage array, the dose rates are adjusted to account for fuel cooling time representative of an ISFSI. The effect of the adjustment is to reduce the maximum estimated total dose for loading each canister by about 20 percent. This adjustment is described in Section 10.3.2. It is also applied in the calculation of the ISFSI boundary dose rates.

10.3.1 Estimated Collective Dose for Loading a Single NAC-MPC

This section estimates the collective dose due to the loading, sealing, transfer and placement of a single NAC-MPC containing design basis fuel. This analysis assumes that the exposure incurred by the operators is independent of background radiation, as background will vary with site specificity. The number of persons allocated to task completion is generally the minimum number required for the task.

Working area exposure rates are assigned based on the orientation of the worker with respect to the source and take into account the use of temporary shielding.

Table 10.3-1 summarizes the estimated total exposure, by task, attributable to the loading, transfer, sealing and placement of a design basis NAC-MPC.

Due to the additional cooling of casks in a typical array, the actual loading, transfer and storage dose associated with the 16 storage cask array is significantly lower than that of a cask array consisting of design basis casks. Based on the source term weighting factors presented in Section 10.3.2, the occupational dose is approximately 20% lower for a typical cask array.

10.3.2 Estimated Annual Dose Due to Routine Operations

Once in place, the ISFSI will require limited ongoing maintenance and surveillance throughout its design life. The annual dose evaluation considers the combination of the requirements specified in Chapter 12.0 and tasks that are anticipated to be representative of an operational facility. Typically, no maintenance of the storage system is expected to be required annually. Collective dose due to certain events, such as clearing the blockage of air vents, is accounted for in Chapter 11.0.

Routine operations are expected to include:

- A daily visual inspection of the cask array. This inspection consists of the electronic measurement of air outlet temperatures and inspection for blockage of the inlet and outlet vents. Outlet temperature indicators are located away from the cask array. Temperature surveillance is assumed to be performed by one operator and require 1 minute per cask. Inspection of the vents is assumed to take one operator 2 minutes per cask.

- A daily security inspection of the security fence and equipment surrounding the storage area. This surveillance is assumed to require 5 minutes and 1 security officer.

- Grounds maintenance performed every other week by 1 maintenance technician. Grounds maintenance is assumed to require 0.5 hour.

- Quarterly radiological surveillance. The surveillance consists of a radiological survey comprised of a surface radiation measurement on each cask, the determination and/or verification of general area exposure rates and radiological postings. This surveillance is assumed to require 1 hour and 1 person.

- Annual inspection of the general condition of the storage casks. This inspection is estimated to require 15 minutes per cask and require 2 technicians.

The storage array is conservatively assumed to have a fuel population having cooling times ranging from 8 to 20 years. To account for the different ages of the fuel, weighting factors are applied to the single cask dose rates. The application of these factors permits a more accurate representation of the exposure commitment necessary for the routine operation of the ISFSI. The

weighting factors are based on the decayed spectra of the fuel neutron and fuel gamma components of the source term. Table 10.3-2 presents the weighting factors applied to the individual casks in the array. The arrangement of the array is shown in Figure 10.3-1.

For this evaluation, it is conservatively assumed that the array consists of casks containing the design basis Combustion Engineering Type A 36,000 MWD/MTU burnup, 8 year cooled fuel, and a complete core discharge of less than 8 year cooled fuel. The less than 8 year cooled fuel is limited to 32,000 MWD/MTU and a 7 year cool time for Combustion Engineering assemblies and a 7.1 year cool time for United Nuclear assemblies. Minimum cool times are established based on shielding evaluations of the storage cask and the requirement that the design basis dose rates are not exceeded for any given burnup and cool time combination.

The remaining 12 casks in the array are representative of casks loaded with fuel taken from inventory already in storage in the spent fuel pool. The assumed cool times of the fuel in the casks in the array are shown in Table 10.3-3.

Based on these assumptions, the annual operation and surveillance requirements result in an estimated annual collective exposure of 626 person-mrem for the 16 cask ISFSI. The estimated annual exposure, by task, is shown in Table 10.3-4.

10.3.3 Estimated Collective Dose for Unloading a Single NAC-MPC

This section estimates the collective dose due to the transfer, opening and unloading a single NAC-MPC containing design basis fuel. This analysis assumes that the exposure incurred by the operators is independent of background radiation, as background radiation varies with each site. The number of persons allocated to task completion is generally the minimum number required for the task. Working area exposure rates are assigned based on the orientation of the worker with respect to the source and take into account the use of temporary shielding.

Table 10.3-5 summarizes the estimated total exposure, by task, attributable to the transfer, opening and unloading of a design basis NAC-MPC.

Figure 10.3-1 Typical ISFSI 16 Cask Array Layout

FIGURE WITHHELD UNDER 10 CFR 2.390

Table 10.3-1 Estimated Person-Mrem Exposure for Operation of the NAC-MPC

Activity	Personnel	Duration (hr)	Average Dose Rate (mrem/hr)	Exposure (pers-mrem)
Load Canister	2	7.5	5.0	75.7
Move to Decon Area	2	1.1	11.5	25.3
Setup, Weld Shield Lid, and Inspect Weld	2	7.9	21.5	339.8
Drain/Dry/Backfill and Leak Test Vacuum Drying	2	0.6	45.1	54.1
Weld and Inspect Port Covers	2	2.5	118.8	594.2
Setup, Weld Structural Lid and Inspect Weld	2	7.7	59.4	915.5
Transfer to Storage Cask	4	2.2	18.3	161.0
Position on ISFSI Pad	2	0.8	17.8	28.4
Total				2,194

Table 10.3-2 Storage Cask Radiation Spectra Weighting Factors

Cask	Neutron Weighting Factor	Gamma Weighting Factor	Cask	Neutron Weighting Factor	Gamma Weighting Factor
A-1	1	1	B-1	.83	.74
A-2	1	1	B-2	.80	.71
A-3	1	1	B-3	.78	.69
A-4	1	1	B-4	.75	.67
A-5	.96	.93	B-5	.72	.65
A-6	.93	.86	B-6	.70	.63
A-7	.90	.82	B-7	.67	.61
A-8	.86	.77	B-8	.65	.59

Table 10.3-3 Assumed Fuel Cooling Time for the Storage Casks in the ISFSI Array

Cask	Cooling Time	Cask	Cooling Time
A-1	8 yr.	B-1	13 yr.
A-2	8 yr.	B-2	14 yr.
A-3	8 yr.	B-3	15 yr.
A-4	8 yr.	B-4	16 yr.
A-5	9 yr.	B-5	17 yr.
A-6	10 yr.	B-6	18 yr.
A-7	11 yr.	B-7	19 yr.
A-8	12 yr.	B-8	20 yr.

Table 10.3-4 Estimate of Annual Exposures for a 16 Cask Array

Activity	Dose Rate Distance (meters)	Frequency	Time (hr)	Dose Rate (mrem/hr)	Personnel Required	Total Exposure (person-mrem)
Visual inspection and temperature readings	10	365	0.8	1.3	1	380
Security surveillance	10	365	0.08	1.3	1	38
Radiological surveillance	5	4	1.0	2.7	1	11
Annual inspection	0.3	1	4.0	20.2	2	162
Grounds maintenance	5	26	0.5	2.7	1	35
Total (person-mrem)						626

Table 10.3-5 Estimated Collective Dose for Unloading a Single NAC-MPC

Activity	Personnel	Duration (hr)	Average Dose Rate (mrem/hr)	Exposure (pers-mrem)
Move Storage Cask to Receiving Area	2	0.8	17.8	28.5
Transfer Canister to Transfer Cask	4	2.2	18.3	161.0
Setup, Cut Structural Lid	2	3.9	59.4	463.3
Cut Port Covers	2	1.3	118.8	308.9
Cool Down and Fill Canister with Water	2	8.0	45.1	721.6
Setup and Cut Shield Lid	2	4.0	21.5	172.0
Move to Pool	2	1.1	11.5	25.3
Unload Canister	2	7.5	5.0	75.0
Total		28.8		1,955.6

10.4 Exposures to the Public

NAC's version 5.0.0 of the SKYSHINE-III code is used to evaluate the placement of the controlled area boundary for the 16 storage cask array shown in Figure 10.3-1. Given the source geometry, spectra and desired detector locations, SKYSHINE III calculates dose rates using a combination of pre-calculated transmission and reflection data and the Monte Carlo technique to integrate over the source direction and energy variables.

The performance of the SKYSHINE-III Code is benchmarked by modeling a set of Kansas State University ^{60}Co skyshine experiments and by modeling two Kansas State University neutron computational benchmarks. The code compared well with these benchmarks for both neutron and gamma doses versus distance.

Version 5.0.0 of SKYSHINE-III has the capability for modeling ISFSI cask arrays. Each cask can be represented as either axial and radial conical point sources or as top and side surface sources. Surface source emission fluxes are provided from 1D SAS1 shielding evaluations. The source energy distribution for both neutron and gamma radiation are provided the design basis cask in Tables 5.4-11, 5.4-12, and 5.4-13. As stated in Section 10.2, the associated reference cask source strengths are multiplied by weighting factors to correct for the differences in cooling times.

Version 5.0.0 of SKYSHINE-III, explicitly calculates cask self shielding based on the cask geometry and arrangement of the cask array. A ray tracing technique is utilized. Given the source position on the cask surface and the direction cosines for the source emission, geometric tests are made to see if any adjacent casks are in the path of the emission. If so, the emission history does not contribute to the air scatter dose. Also, given the source position on the cask surface and the direction cosines for the source to detector location, geometric tests are made to see if any adjacent casks are in the source path. If so, the emission position does not contribute to the uncollided dose at the detector location.

Annual exposures based on a 2080 hour work year were determined at distances ranging from 100 to 300 meters surrounding a 2 x 8 cask array (Figure 10.3-1). The storage array is assumed to have a fuel population reflective of that of an operating reactor facility and that fuel cool time will range from 8 to 20 years.

Table 10.4-1 presents a summary of the results of the SKYSHINE-III evaluation and Figure 10.4-1 shows a plot of the limiting boundary distances. The results indicate that a required minimum distance varies around the ISFSI from approximately 150 meters on the longer-cooled 2 cask side to 190 meter on the shorter-cooled 8 cask side. An enveloping boundary 200 meters by 150 meters around the ISFSI will insure compliance with the requirements of 10 CFR 72.104(a), i.e., a dose rate not exceeding 25 mrem/ year.

Each ISFSI licensee will perform a site-specific dose analysis for the facility to show that the requirements of 10 CFR 72 are met. Site-specific boundary distances may vary significantly based on fuel type, fuel cooling time, exposure duration and number of casks in service.

Figure 10.4-1 Controlled Area Boundary Determination for a 16 Cask Array

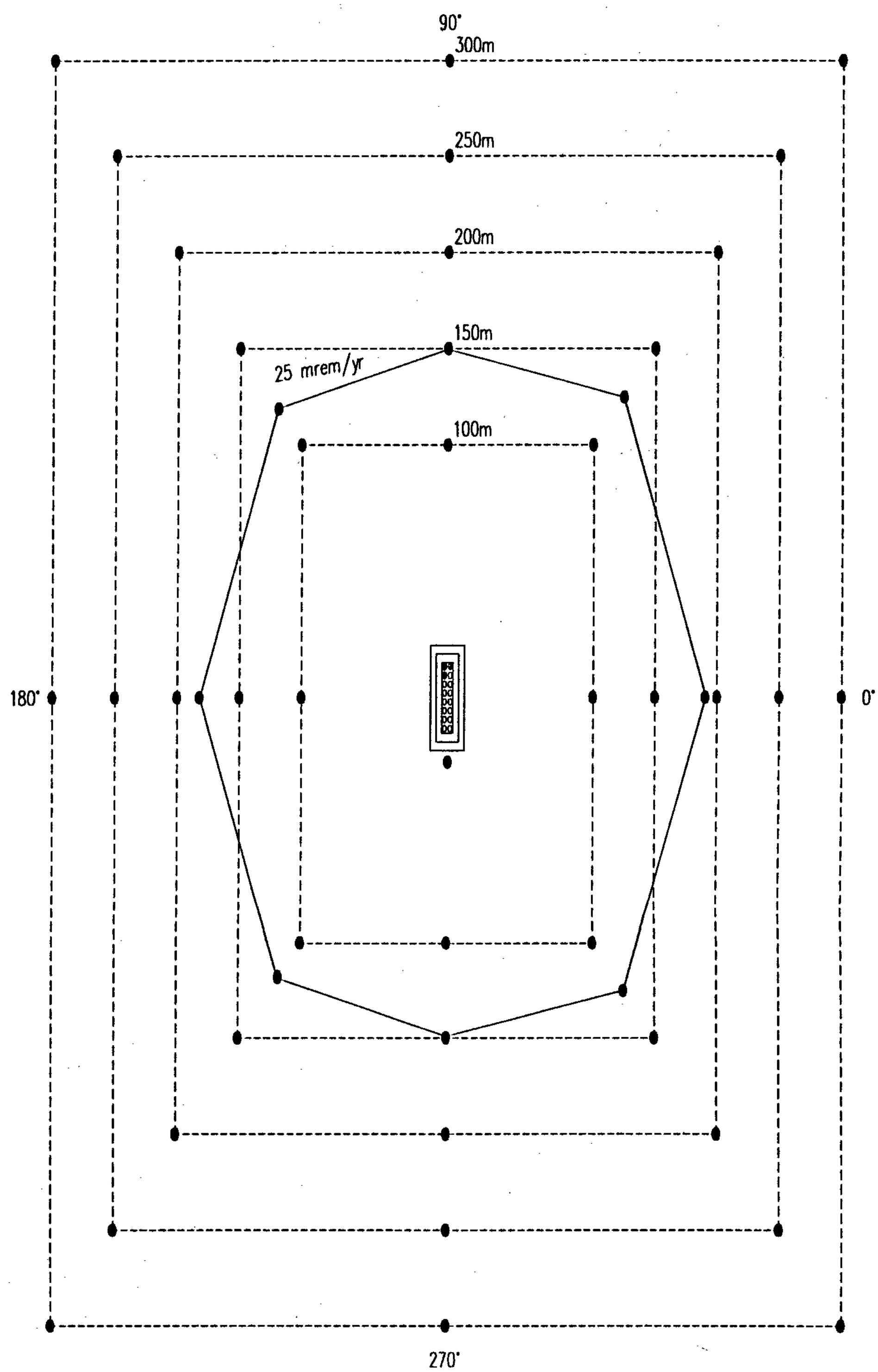

Table 10.4-1 Controlled Area Boundary for 2 x 8 Cask Array Based on Annual Exposure

Orientation (degrees)[1]	Boundary Distance with Work Year Occupancy (m)[2,3]
0	190.40
45	176.95
90	149.99
135	167.95
180	182.43
225	166.74
270	146.60
315	177.62

Notes:

1. Denotes counter clockwise orientation from X axis shown in Figure 10.3-1.
2. Boundary distance is from security fence. In case of 45, 135, 225, and 315 orientations, boundary distance is diagonally from corner of security fence.
3. Based on 2080 hours of occupancy.

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11.0 ACCIDENT ANALYSIS

The analyses of the off-normal and accident design events, including those identified by ANSI/ANS 57.9-1992, are presented in this section. Section 11.1 describes the off-normal events that could occur during the use of the NAC-MPC storage system, possibly as often as once per calendar year. Section 11.2 addresses very low probability events that might occur once during the lifetime of the ISFSI or hypothetical events that are postulated because their consequences may result in the maximum potential impact on the surrounding environment. Section 11.3 describes the design basis load conditions for the transportable storage canister. As described in Section 11.3, the canister is analyzed for loads imposed during transportation. These transport condition loads envelope the loads for the storage condition analyzed herein.

This chapter demonstrates that the NAC-MPC satisfies the requirements of 10 CFR 72.24 and 10 CFR 72.122 for off-normal and accident conditions. These analyses are based on conservative assumptions to ensure that the consequences of off-normal conditions and accident events are bounded by the reported results. The actual response of the NAC-MPC system to the postulated events will be much better than that reported, i.e., stresses, temperatures, and radiation doses will be lower than predicted. If required for a site specific application, a more detailed evaluation could be used to extend the limits defined by the events evaluated in this section.

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11.1 Off-Normal Events

This section evaluates postulated events that might occur once during any calendar year of operations. The actual occurrence of any of these events is unlikely.

11.1.1 Blockage of Half of the Air Inlets

This section evaluates the NAC-MPC storage cask for the steady state effects of a blockage of one-half of the air inlets at the normal ambient temperature (75°F).

11.1.1.1 Cause of Event

The likely cause of air inlet blockage is debris deposited in the inlets by wind, or by intrusion of a burrowing animal. It is expected that screens over the inlets would preclude such animals and would exclude debris from the inlet channels.

This event would be detected visually by the persons inspecting the air inlets and gathering outlet air temperature data on a daily basis. It could also be detected by security forces, or other operations personnel, engaged in other routine activities such as fence inspection, or grounds maintenance.

11.1.1.2 Analysis of the Blockage Event

Off-normal temperature conditions are evaluated using the thermal models described in Section 4.4.1. Air mass flow and air carried heat are calculated using the air flow model described in Section 4.4.1.1. The maximum component temperatures due to one-half of the air inlets being blocked are compared to the allowable component temperatures for the off-normal event (see Table 4.1-4).

Component	1/2 Inlets Blocked Max Temp. (°F)	Allowable Temp. (°F)
Fuel Cladding	565	1058
Support Disks	531	800
Heat Transfer Disks	529	700
Canister Shell	318	800
Concrete	168	350

This evaluation shows that the component temperatures are within the allowable temperature range for the condition of one-half of the inlets blocked.

11.1.1.3 Radiological Consequences

There are no significant radiological consequences for this event. Personnel will be subject to an estimated maximum contact dose rate of 240 mrem/hr when clearing the inlets. If it is assumed that a worker kneeling with his hands on the inlets would require 15 minutes to clear the inlets, the estimated maximum extremity dose is 60 mrem. The whole body dose would be significantly less.

11.1.1.4 NAC-MPC Performance

There are no adverse consequences for this off-normal condition. The maximum component temperatures are less then the allowable temperatures. The NAC-MPC storage cask continues to perform its function with one-half of the air inlets blocked.

11.1.1.5 Recovery and/or Corrective Actions

The debris blocking the inlets must be manually removed. The nature of the debris may indicate that other actions are required to prevent recurrence of the blockage.

11.1.2 Canister Off-Normal Handling Load

This section evaluates the consequence of loads on the transportable storage canister during the installation of the canister in the storage cask, or removal of the canister from the storage or transfer casks.

11.1.2.1 Cause of Event

Unintended loads could be applied to the canister due to misalignment or faulty crane operation, or inattention of the operators.

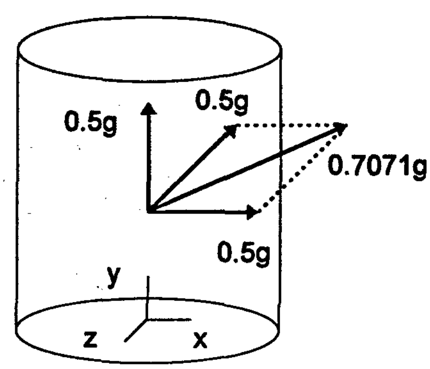
Detection of the event is expected to occur by observation of the event or banging or scraping noise associated with movement of the canister. The event is expected to be obvious to the operators at the time of occurrence.

11.1.2.2 Analysis of the Canister Off-Normal Handling Load Event

The canister structural analysis, including lifting loads, was evaluated using an ANSYS finite element model. The model is described in Section 3.4.4-1.

The off-normal handling load condition is assumed to consist of loads of 0.5 g applied in all directions (i.e., in the global x, y, and z directions) in addition to the 1.1 g lifting load (an additional 10 percent load is included as a dynamic load factor during lifts) applied in the finite element model. The stresses resulting from off-normal handling are estimated by combining the normal handling stresses at off-normal internal pressure (20 psig) with the stress results from a 20 g side and a 20 g bottom end impact of the canister ratioed to the off-normal 0.5 g-loading.

The 0.5g acceleration in the vertical direction is additive to the 1.1 g acceleration for normal lifting. The two 0.5g accelerations in the horizontal directions result in a single horizontal acceleration of 0.7071 g as shown below:



$$\sqrt{(0.5g)^2+(0.5g)^2}=0.7071g$$

The stresses obtained from the 20 g side and 20 g bottom end impacts of the canister were then scaled to obtain the additive off-normal handling stresses for 0.7071g side load ($\sigma_{0.7071g}$) and 0.5g vertical load ($\sigma_{0.5g}$) as follows:

$$\sigma_{0.7071g} = \sigma_{1\text{-ft,side}} \left(\frac{0.7071g}{20g} \right)$$

and,

$$\sigma_{0.5g} = \sigma_{1\text{-ft,bottom end}} \left(\frac{0.5g}{20g} \right)$$

Where 20 g is the deceleration applied in the canister model analysis.

The off-normal handling stresses for the side and the vertical g-loading were then added to the normal-handling stresses to obtain the total off-normal handling stresses.

The pertinent stress results from the 20 g side impact and 20 g bottom end of the canister are summarized below. These stress results are presented in Section 11.3.1.

Side: S_{pm} = 13,884 psi
S_{pm+pb} = 24,044 psi

Bottom End: S_{pm} = 1,961 psi
S_{pm+pb} = 4,273 psi

The side and bottom end impact stresses scaled to off-normal handling g-loads were calculated as:

Side:

$$(S_{pm})_{0.7071g} = (S_{pm})_{20g} \left(\frac{0.7071g}{20g} \right) = 13{,}884\text{psi} \left(\frac{0.7071g}{20g} \right) = 491\text{psi} (0.491\text{ksi})$$

$$\left(S_{pm+pb}\right)_{0.7071g} = \left(P_{pm+pb}\right)_{20g}\left(\frac{0.7071g}{20g}\right) = 24{,}044psi\left(\frac{0.7071g}{20g}\right) = 850psi(0.85ksi)$$

Vertical (bottom):

$$\left(S_{pm}\right)_{0.5g} = \left(S_{pm}\right)_{20g}\left(\frac{0.5g}{20g}\right) = 1{,}961psi\left(\frac{0.5g}{20g}\right) = 49psi(0.049ksi)$$

$$\left(S_{pm+pb}\right)_{0.5g} = \left(S_{pm+pb}\right)_{20g}\left(\frac{0.5g}{20g}\right) = 4{,}273psi\left(\frac{0.5g}{20g}\right) = 107psi(0.107ksi)$$

The total stresses for a load condition that includes off-normal handling is obtained by adding the off-normal handling stresses to the normal handling stresses.

$$\begin{aligned}\left(S_{pm}\right)_{Casew/Off-normal} &= \left(S_{pm}\right)_{Normal} + \left(S_{pm}\right)_{0.7071g} + \left(S_{pm}\right)_{0.5g}\\ &= \left(S_{pm}\right)_{Normal} + 0.491ksi + 0.049ksi\\ &= \left(S_{pm}\right)_{Normal} + 0.54ksi\end{aligned}$$

$$\begin{aligned}\left(S_{pm+pb}\right)_{Casew/Off-normal} &= \left(S_{pm+pb}\right)_{Normal} + \left(S_{pm+pb}\right)_{0.7071g} + \left(S_{pm+pb}\right)_{0.5g}\\ &= \left(S_{pm+pb}\right)_{Normal} + 0.85ksi + 0.107ksi\\ &= \left(S_{pm+pb}\right)_{Normal} + 0.96ksi\end{aligned}$$

The maximum primary membrane stress (S_{pm}) for normal handling occurs at location 13. The maximum primary membrane plus bending stress (S_{pm+pb}) for normal handling occurs at location 2. These stress locations are shown in Figure 3.4.4.1-4.

For location 13:

Normal Conditions Primary Membrane Stress (ksi)	12.07
Additional Primary Membrane Stress Due to Off-Normal Handling (ksi)	0.54
Off-Normal Handling Primary Membrane Stress (ksi)	12.61
Allowable Primary Membrane Stress (ksi)	20.30
Margin of Safety	+0.61

Margin of Safety	+0.61

For location 2:

Normal Conditions Primary Membrane Plus Bending Stress (ksi)	26.15
Additional Primary Membrane Plus Bending Stress Due to Off-Normal Handling (ksi)	0.96
Off-Normal Handling Primary Membrane Plus Bending Stress (ksi)	27.11
Allowable Primary Membrane Plus Bending Stress (ksi)	30.06
Margin of Safety	+0.11

These results show that the canister maintains positive margin of safety for the off-normal handling condition.

11.1.2.3 Radiological Consequences

There are no radiological consequences for this off-normal event.

11.1.2.4 NAC-MPC Performance

This evaluation shows that the stress induced in the canister as a consequence of the assumed off-normal handling loading is within the allowable stress for Service Level C loading. There is no deterioration of canister performance.

11.1.2.5 Recovery and/or Corrective Actions

Operations should be halted until the cause of the misalignment, interference or faulty operation is identified and corrected. Since the radiation level of the canister sides and bottom is high, extreme caution should be exercised if inspection of these surfaces is required.

11.1.3 Failure of Instrumentation

The NAC-MPC system uses an electronic temperature sensing system to read and record the outlet air temperature at each of the four air outlets on each storage cask. The temperatures are read and recorded during a daily inspection of the ISFSI.

11.1.3.1 Cause of Accident

Failure of the temperature measuring instrumentation could occur as a result of component failure, or as a result of another accident condition that interrupted power or damaged the sensing or reader terminals.

The failure is expected to be identified by the lack of a reading at the temperature reader terminal. Alternately, a malfunction could result in a disparity between outlet temperatures, or between similar storage casks.

11.1.3.2 Analysis of Instrumentation Failure

Since the temperatures of each outlet of each storage cask are recorded daily, there is early opportunity to identify and correct a defect. Because the canister and concrete cask are a large heat sink, and because there are few conditions that could result in a cooling air temperature increase, there is no concern about the temporary loss of remote sensing and monitoring of the outlet air temperature.

The principal condition that could cause an increase in temperature is the blockage of the cooling air inlets or outlets. The purpose of the daily inspection is to ensure that the inlets and outlets are not obstructed such that the cooling efficiency of the system is reduced. As shown in Section 11.2.8, even if all of the inlets and outlets for a single cask are blocked immediately after the temperature is read, it would take more than 24 hours before any component approached its allowable temperature limit. There would be no consequence, if the affected storage cask continued to operate in normal storage conditions.

11.1.3.3 Radiological Consequences For This Accident

There are no radiological consequences for this event.

11.1.3.4 NAC-MPC Performance

The NAC-MPC canister and storage cask are a large thermal sink. During the period of loss of instrumentation, no significant change in canister temperature will occur under normal conditions.

11.1.3.5 Recovery and Corrective Actions

This event requires that the temperature reporting equipment be either replaced or repaired and calibrated. Prior to repair or replacement, the temperature shall be recorded manually.

11.1.4 Severe Environmental Conditions (100°F and -40°F)

This section evaluates the NAC-MPC for the steady state effects of high and low ambient temperature conditions.

11.1.4.1 Cause of Event

Large geographical areas of the United States are subjected to sustained summer temperatures in the 90 to 100°F range and winter temperatures that are significantly below zero. To bound the expected steady state temperatures of the canister and storage cask during these severe ambient conditions, analyses were performed to calculate the steady state storage cask, canister, and fuel cladding temperatures for a 100°F ambient temperature and 24-hour average solar loads. Similarly, winter weather analyses were performed for a -40°F ambient temperature with no solar load. The maximum thermal load of 12.5 kW was applied for these analyses. Neither ambient temperature condition is expected to last more than several days.

Detection of off-normal ambient temperatures would occur during the daily measurement of ambient temperature and storage cask outlet air temperature.

11.1.4.2 Analysis of the Off-Normal Ambient Temperature Event

Off-normal temperature conditions are evaluated using the thermal models described in Section 4.4.1. The temperature profile for the concrete cask and for the air flow for the steady state conditions associated with a 100°F ambient condition are shown in Figures 11.1.4-1 and 11.1.4-2, respectively. Similar profiles for the -40°F ambient temperature condition are shown in Figures 11.1.4-3 and 11.1.4-4. The principal component temperatures for each of these ambient temperature conditions are summarized below.

Component	100°F Ambient Max Temp. (°F)	-40°F Ambient Max Temp. (°F)	Allowable Temp. (°F)
Fuel Cladding	587	453	1058
Support Disks	554	412	800
Heat Transfer Disks	552	411	700
Canister Shell	347	187	800
Concrete	196	5	350

This evaluation shows that the component temperatures are within the allowable values for the off-normal ambient conditions.

The thermal stress evaluation for these off-normal conditions are bounded by that for the accident condition with 125°F ambient temperature (Section 11.2.10), since the accident condition has the maximum temperature gradient through the storage cask concrete wall.

Stress intensities corresponding to thermal loads in the canister were evaluated using an ANSYS finite element model as described in Section 3.4.4. The thermal stresses occur in the canister as a result of the maximum temperature gradients in the canister. The finite element analysis assumes that the canister contains the maximum heat load of 12.5 kW, as this ensures the largest gradient for either load condition. (i.e., if the canister was at a uniform -40°F, no temperature gradient would exist, and no thermal stress would be induced in the canister) No other loads are applied, and the thermal stress is classified as secondary. The smallest margin of safety is +2.75, which occurs at location 13, at the center of the bottom plate (Figure 11.2.1-1). The thermal stresses for the support disks and weldments due to these off-normal conditions are bounded in the thermal stress analysis presented in Section 3.4.4.1.

11.1.4.3 Radiological Consequences

There are no radiological consequences for this off-normal event.

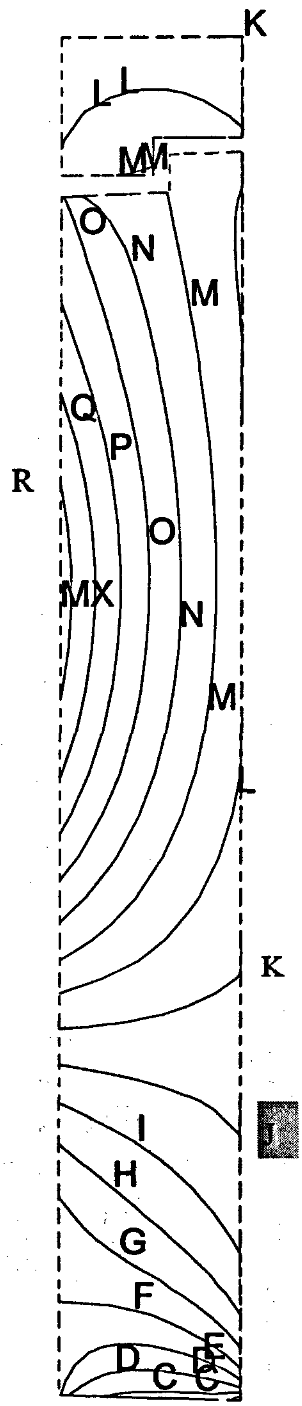
11.1.4.4 NAC-MPC Performance

There are no adverse consequences for this off-normal condition. The maximum component temperatures are within the allowable temperature values. The materials used are not subject to low temperature brittle fracture.

11.1.4.5 Corrective Actions

No corrective actions are required for this off-normal condition.

Figure 11.1.4-1 Temperature Profile of the Concrete Cask in 100°F Ambient Steady State Conditions



	°F
MX=	196
*A=	103
*B=	108
C=	113
D=	119
E=	124
F=	129
G=	134
H=	140
I=	145
J=	150
K=	156
L=	161
M=	166
N=	172
O=	177
P=	182
Q=	188
R=	193

MX = Maximum Temperature

*These temperatures occur over short distances around the inlet vent but are not shown due to the scale of the figure.

Figure 11.1.4-2 Temperature Profile of the Air Flow Stream in 100°F Ambient Steady State Conditions

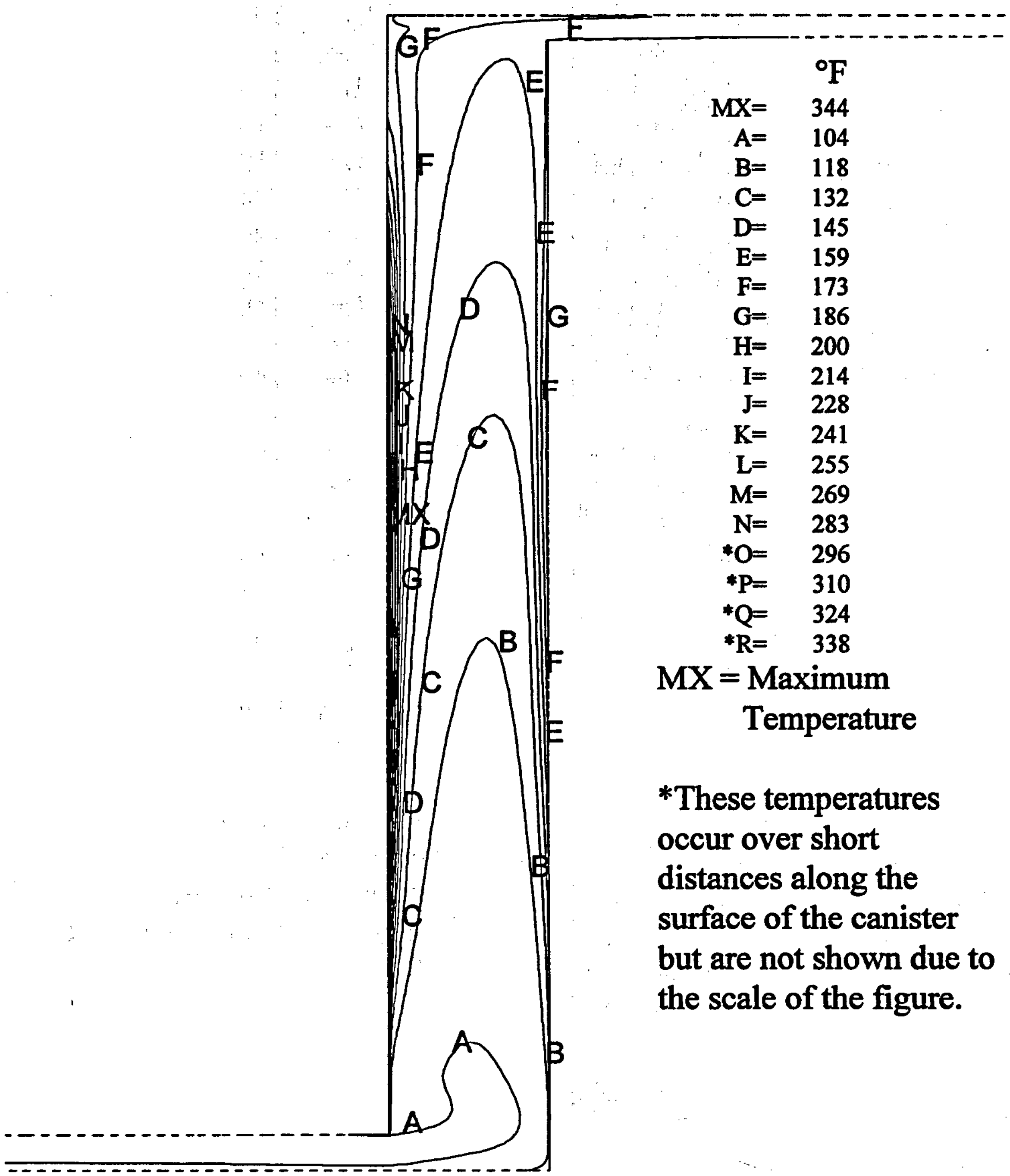


Figure 11.1.4-3 Temperature Profile of the Concrete in -40°F Ambient Steady State Conditions

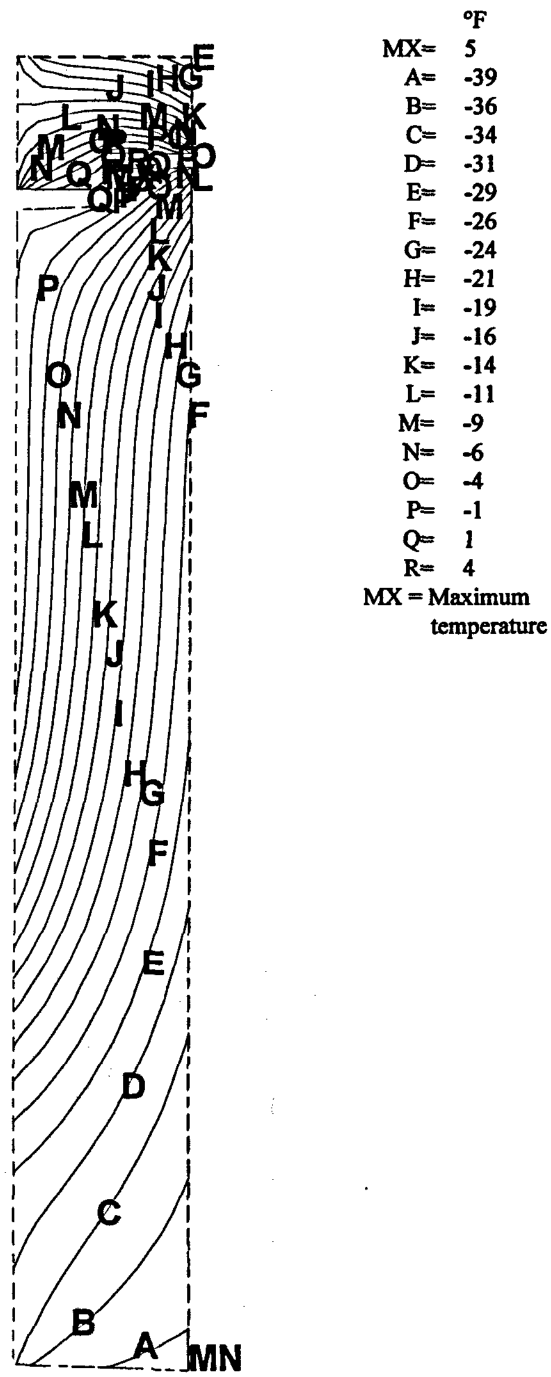
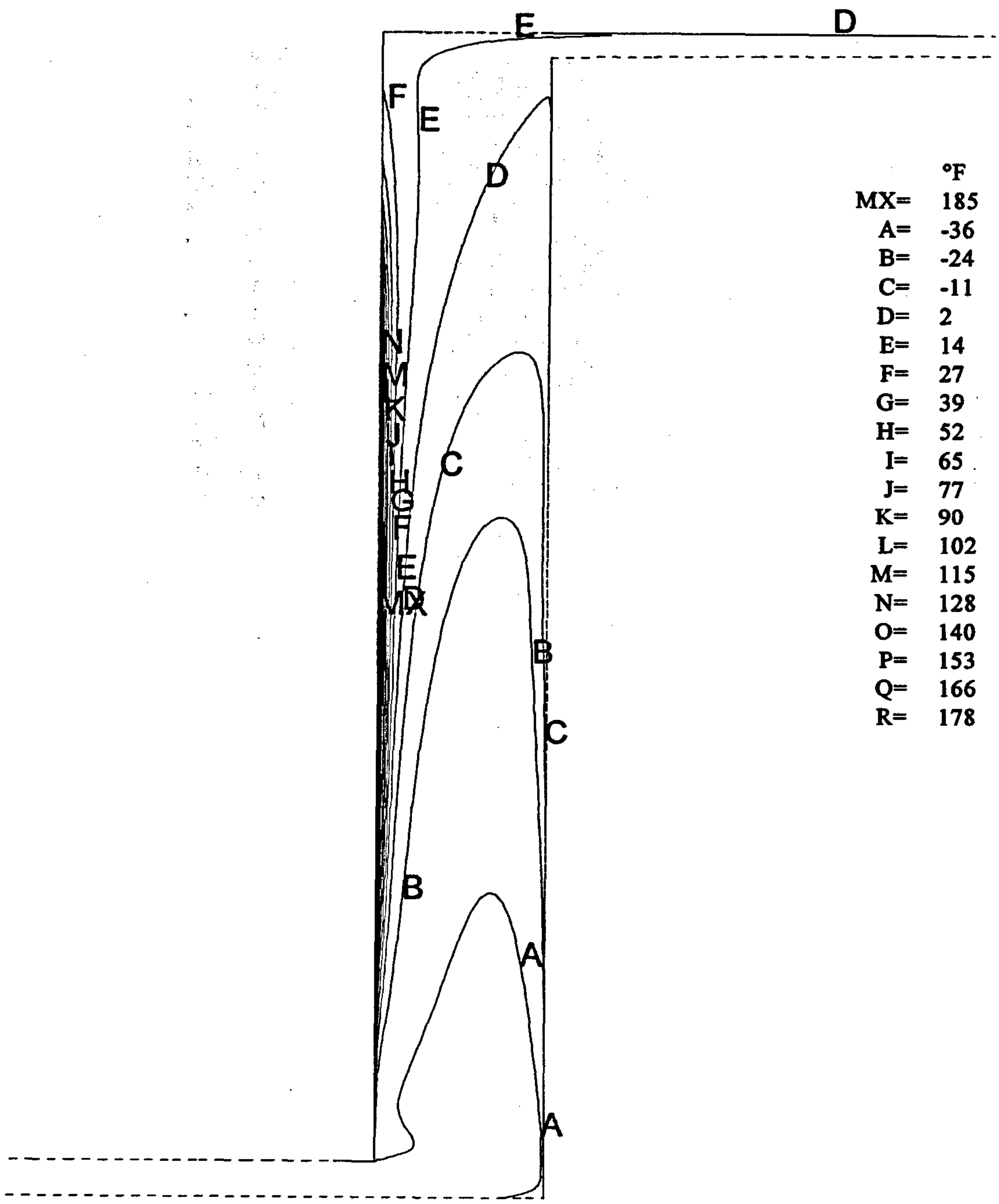


Figure 11.1.4-4 Temperature Profile of the Air Flow Stream in -40°F Ambient Steady State Conditions



11.1.5 Small Release of Radioactive Particulate From the Canister Exterior

The procedures for loading the canister provide for steps to ensure that the canister exterior surface does not come into contact with contaminated spent fuel pool water, and the exterior surface of the canister is surveyed by smear at the top end to verify canister surface conditions. No particulate release from the canister exterior surface is expected to occur in normal use.

11.1.5.1 Cause of Event

In spite of precautions taken to preclude contamination to the external surface of the canister, it is possible that a portion of the canister surface may become slightly contaminated and that the contamination will go undetected. Surface contamination could become airborne and be released as a result of the air flow over the canister surface.

Detection of the release of small amounts of radioactive particles over time would be difficult to ascertain. The release would likely not be at a level that would result in detection by any of the long-term radiation dose monitoring methods (such as TLDs) normally employed. It is possible that a suspected release could be verified by a smear survey of the air outlets.

11.1.5.2 Analysis

A calculation was made to determine the level of surface contamination that results in a dose of one (1) mrem annually at a point 100 meters from the ISFSI site. The calculation shows that at the minimum distance of 100 meters permitted by 10 CFR 72, a residual contamination limit of approximately 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α activity, on the surface of each of 16 casks yields a dose of one (1) mrem annually.

The method for determining the residual contamination limit is based on the plume dispersion, calculations presented in U. S. NRC Regulatory Guides 1.109 and 1.145.

11.1.5.3 Radiological Consequences

The projected dose at a boundary located 100 meters from the ISFISI is estimated to be less than one (1) mrem annually due to the postulated surface contamination. This dose is based on a postulated surface contamination of approximately 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α, for each of the 16 storage casks in the design basis ISFSI. This analysis is highly conservative and demonstrates that the potential off-site radiological consequences from the release of surface contamination on the canisters is negligible.

11.1.5.4 NAC-MPC Performance

Procedural steps are employed to ensure that the canister surface is generally free of surface contamination prior to its installation in the storage cask. The surface of the canister is free of traps that could hold contamination. The presence of external surface contamination on the canister is unlikely.

11.1.5.5 Corrective Actions

No corrective action is required since the radiological consequence is negligible.

11.2 Accidents

This section provides the results of analyses of the design basis and hypothetical accident conditions evaluated for the NAC-MPC system. The analyses presented show that the NAC-MPC system has substantial design margin of safety and provides protection to the public and to occupational personnel. In addition to these design basis accidents, this section addresses very low probability events that might occur over the lifetime of the ISFSI or hypothetical events that are postulated because their consequences may result in the maximum potential impact on the immediate environment.

11.2.1 Accident Pressurization

Accident pressurization is a hypothetical event that assumes the failure of all of the fuel rods contained within the canister. There are no storage conditions that are expected to lead to the rupture of all of the fuel rods.

11.2.1.1 Cause of Pressurization

The hypothetical breach of all of the fuel rods in a canister would release the fission and fill gases to the interior of the canister.

11.2.1.2 Analysis of Accident Pressurization

11.2.1.2.1 Maximum Canister Internal Pressure

The analysis requires the calculation of the free volume of the canister, calculation of the quantity of fill and fission gas in the 36 fuel assemblies, and the subsequent calculation of the pressure in the canister if these gases are added to the helium pressure (initially at 1 atm) already present in the canister (Section 4.4.5). The quantity of fission gases was conservatively estimated assuming that 30% of the total gases present are released from the fuel. The bulk temperature of the helium is conservatively taken to be 450°F.

The internal pressure is a function of rod-fill, fission and canister backfill gases. All of the gases except the fission gases are assumed to be helium. The total pressure for each volume are found by calculating the molar quantity of each gas and summing those directly. The design basis fuel assembly for the internal pressure calculation is the Combustion Engineering Type A assembly. This assembly has the highest fuel rod back-fill pressure (315 psig) and received the highest burnup (36,000 MWD/MTU) (Section 2.1.1).

The number of moles of the backfill gases are calculated using the Ideal Gas Law, PV = NRT. Backfill gases for the canister and cavity are assumed to be initially at 1 atmosphere. The quantity of fission gas is derived from the SAS2H source term evaluation of the CE Type A fuel assembly.

The number of moles of gas in the canister is:

$$N = N_{\text{TSC Back-Fill}} + N_{\text{Rod Back-Fill}} + 0.3\left(N_{\text{Fission Gas}}\right)$$

The number of moles of helium contained in the canister as backfill and the number of moles of gas in the fuel rods (as helium backfill and fission products) were calculated in Section 4.4.5.

The number of moles of gas due to the hypothetical failure of 100% of the fuel rods is:

$$N = \underbrace{75.26\,\frac{\text{Moles}}{\text{Cask}}}_{\text{(canister backfill)}} + \underbrace{77.95\,\frac{\text{Moles}}{\text{Cask}}}_{\text{(rod backfill)}} + \underbrace{0.3\left(423.44\,\frac{\text{Moles}}{\text{Cask}}\right)}_{\text{(fission gas)}}$$

$$N = 380.24\,\frac{\text{Moles}}{\text{Cask}}$$

Based on an assumed temperature of 450°F, the maximum pressure in the canister is:

$$P = \frac{\left(380.24\,\frac{\text{Moles}}{\text{Cask}}\right) \times \left(0.0821\,\frac{\text{atm}\,\ell}{\text{mole K}}\right) \times 505.4\text{ K}}{\left(4{,}877.93\,\frac{\ell}{\text{Cask}}\right)} = 3.23\text{ atm} \approx 47.5\text{ psia} \approx 32.8\text{ psig}$$

11.2.1.2.2 Maximum Canister Stress Due to Internal Pressure

The stresses that result in the canister due to the internal pressure were evaluated using the ANSYS finite element model described in Section 3.4.4. The pressure used for the model was 35 psig. The results of the analysis are shown in Tables 11.2.1-1 (primary membrane stress) and 11.2.1-2 (primary membrane plus bending stress). The location of the canister analysis sections are shown in Figure 11.2.1-1.

These results show that the minimum margin of safety for primary membrane stress is +1.86 at location 13. The minimum margin of safety for primary membrane plus bending stress is 0.97 at location 2.

11.2.1.3 Radiological Consequences

There are no radiological consequences for this accident.

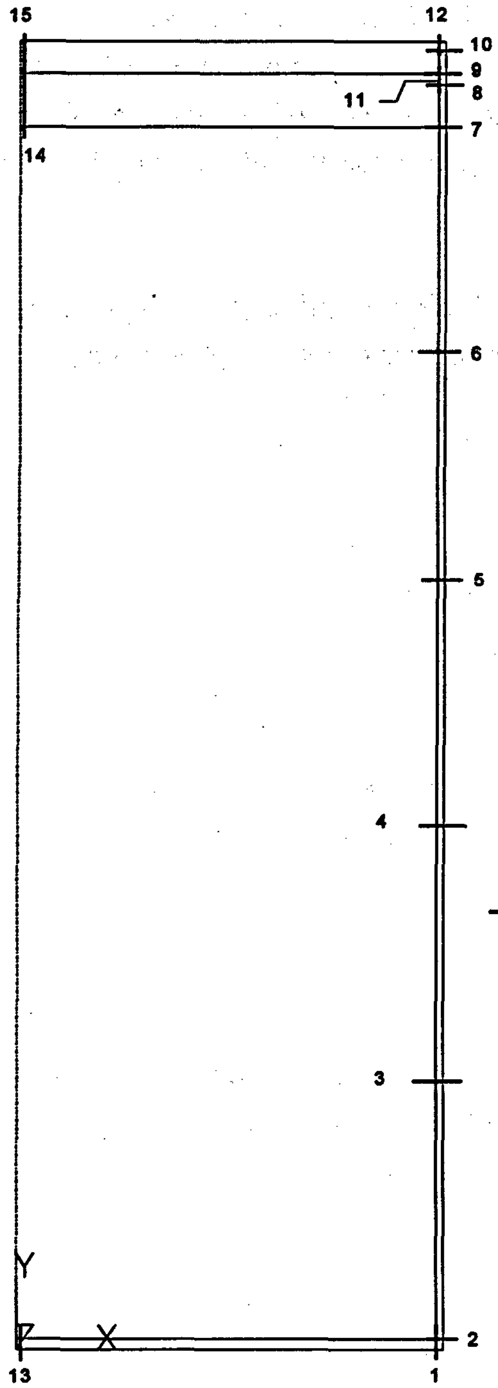
11.2.1.4 NAC-MPC Performance

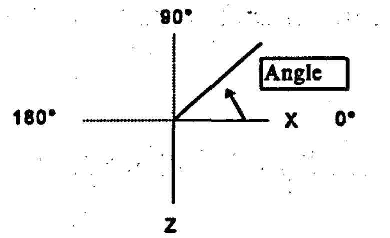
This analysis demonstrates that the canister performance is not significantly affected by the increase in internal pressure that results from the hypothetical rupture of all of the fuel rods contained in the canister. There is a positive margin of safety throughout the canister.

11.2.1.5 Recovery and/or Corrective Actions

There are no recovery or corrective actions required for this hypothetical accident event. The rupture of fuel rods within the canister is unlikely to be detected by any measurements or inspections that could be undertaken from the exterior of the canister or storage cask.

Figure 11.2.1-1 Section Location for Canister Stress Evaluation





Top View of Axis

Location of sections at Z=0 (Note: these sections are repeated at each angular division in the 180° model).

	Node 1		Node 2	
Loc.	X1	Y1	X2	Y2
1	34.695	0.0	34.695	1.0
2	34.695	1.0	35.32	1.0
3	34.695	23.7	35.32	23.7
4	34.695	46.4	35.32	46.4
5	34.695	69.1	35.32	69.1
6	34.695	91.8	35.32	91.8
7	34.695	114.5	35.32	114.5
8	34.695	118.5	35.32	118.5
9	34.695	119.5	35.32	119.5
10	34.695	121.62	35.32	121.62
11	34.695	118.5	34.695	119.5
12	34.695	121.62	34.695	122.5
13	0.01	0.0	0.01	1.0
14	0.01	114.5	0.01	119.5
15	0.01	119.5	0.01	122.5

Table 11.2.1-1 Canister Primary Membrane Stress (ksi) Due to Internal Pressure (35 psig) for the Accident Pressurization Condition

Location	Angle	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress	Margin of Safety
1	180	-1.9	9.1	2.8	2.1	.9	-.3	11.93	40.08	2.36
2	180	4.7	-3.7	-3.0	1.8	.3	.4	9.19	40.08	3.36
3	0	.0	1.0	1.8	.0	.0	.1	1.88	38.36	19.36
4	0	.0	1.0	1.9	.0	.0	.1	1.96	35.62	17.20
5	0	.0	1.0	1.9	.0	.0	.1	1.96	35.83	17.27
6	0	.0	1.0	1.9	.0	.0	.1	1.95	38.75	18.85
7	180	.0	1.0	.9	.0	.0	-.1	.99	40.08	39.35
8	180	.3	.7	.6	-.2	.0	.0	.56	40.08	71.11
9	0	-.6	.6	.4	-.1	.0	.1	1.24	40.08	31.35
10	17	.7	-.3	.4	.1	.0	-.1	1.07	40.08	36.35
11	0	-.1	-.3	.3	.0	.0	.0	.60	40.08	66.20
12	180	-.1	.8	.5	-.1	.0	.0	.94	40.08	41.47
13	171	2.1	.1	2.0	-2.2	-6.6	.0	13.99	40.08	1.86
14	137	-.1	-.1	-.1	.0	.1	.0	.20	40.08	197.91
15	171	.1	.0	.1	.0	.1	.0	.22	40.08	178.97

A stress of "0" indicates that the stress at the location is positive, but less than 0.1 ksi. Components x, y, and z correspond to the radial, circumferential, and axial directions, respectively.

Table 11.2.1-2 Canister Primary Membrane Plus Bending Stress (ksi) Due to Internal Pressure (35 psig) for the Accident Pressurization Condition

Location	Angle	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress	Margin of Safety
1	180	-12.7	1.0	1.8	3.0	1.1	-.6	16.10	60.12	2.73
2	180	2.1	-28.0	-10.3	2.2	.0	.9	30.50	60.12	.97
3	0	.0	1.3	2.0	.0	.0	.2	2.01	57.54	27.64
4	0	.0	1.0	2.0	.0	.0	.1	1.99	53.43	25.89
5	0	.0	1.0	2.0	.0	.0	.1	1.99	53.75	26.00
6	0	.0	1.0	1.9	.0	.0	.1	1.98	58.12	28.31
7	180	.0	1.2	.9	.0	.0	-.1	1.18	60.12	49.78
8	180	.2	.4	.5	-.3	.0	.0	.64	60.12	93.41
9	180	-.4	2.8	1.1	-.1	.0	-.1	3.14	60.12	18.14
10	171	.6	-2.2	-.2	-.1	.0	.1	2.81	60.12	20.40
11	0	-.8	-1.4	-.1	-.2	.0	.0	1.29	60.12	45.75
12	0	-1.1	.3	.2	.2	.0	.1	1.42	60.12	41.49
13	0	31.4	5.5	30.3	-2.1	-6.6	.1	28.61	60.12	1.10
14	0	-1.7	-.3	-1.7	.0	.1	.0	1.36	60.12	43.21
15	0	1.0	.1	1.0	.0	.1	.0	.92	60.12	64.12

A stress of "0" indicates that the stress at the location is positive, but less than 0.1 ksi.

11.2.2 Earthquake Event

11.2.2.1 Cause of Earthquake

Earthquakes are natural phenomena to which the cask might be subjected at any U.S. site. The design basis seismic event is described and discussed in Section 2.2.3.2. This analysis shows that the concrete storage cask containing the loaded canister does not tip over in the design basis earthquake. The design basis earthquake is one imparting vertical and horizontal accelerations of 0.25 g.

11.2.2.2 Earthquake Analysis

The concrete storage cask is a very stiff structure. Although free-standing, it has been analyzed as a cantilever fixed at the base (Roark). For the purpose of calculating seismic loads, the cask is treated as a rigid body attached to the ground and equivalent static analysis methods were used to calculated loads, stresses, and overturning moments.

The natural frequencies of the empty concrete storage cask and the storage cask and canister are calculated to be 89 cycles per second and 36.1 cycles per second, respectively. The natural frequency of the empty storage cask was calculated using the frequency equation:

$$fn = \left(\frac{Kn}{2\pi}\right)\sqrt{\frac{EIg}{WL^4}} \qquad \text{(Roark, Table 36, Case 3)}$$

The natural frequency of the storage cask containing the loaded canister is calculated using:

$$\frac{1}{\omega^2} = \frac{1}{\omega^2{}_F} + \frac{1}{\omega^2{}_S} \qquad \text{(Blevins, Equation 8 • 30)}$$

where:

$$\omega_F = \frac{\lambda^2}{2\pi L^2}\sqrt{\frac{EI}{M}} \qquad \text{and}$$

$$\omega_S = \frac{\lambda}{2\pi L}\sqrt{\frac{KG}{M}}$$

Since the natural frequency is above 33 cycles per second, there is no dynamic amplification and the storage cask and canister are considered to be rigid bodies (NUREG-0800). Static analysis is applied to the evaluation of the earthquake event response.

The following paragraphs present the calculations for acceleration, overturning/restoring forces, and moments for the fully loaded concrete cask.

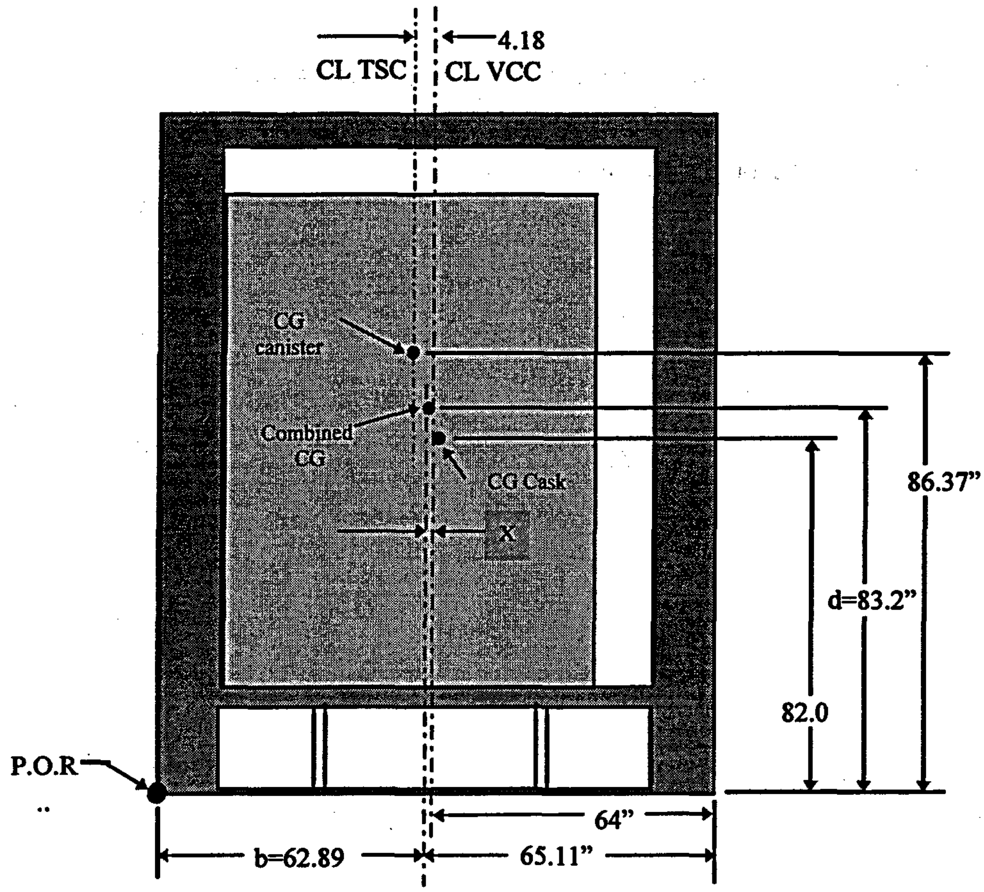
Because the canister is not attached to the concrete cask, the combined center of gravity (CG) for the concrete cask, with the canister in its maximum off-center position, must be calculated. For convenience, a point of rotation (P.O.R.) is established at the outside lower edge of the concrete cask.

The inside diameter of the concrete cask is 79.0" and the outside diameter of the canister is 70.64"; therefore, the maximum eccentricity between the two is $\left(\frac{79.0"-70.64"}{2}\right) = 4.18"$

The horizontal displacement, x, of the combined CG due to eccentric placement of the canister is:

$x = \left(\frac{54730 \times 4.18}{206100}\right) = 1.11"$, therefore, the distance from the postulated point of rotation to the horizontal center of gravity is: (64.0" - 1.11") = 62.89".

The vertical location of the CG remains at 83.2". The various moment arms resulting from this calculation are shown in the sketch below.



To maintain the concrete cask in equilibrium, the restoring moment, M_R must be greater than, or equal to, the overturning moment (i.e. $M_R \geq M_O$). The acceleration derivation is based on this premise. The maximum ground acceleration is found using Roark, Table 36, Case 3b:

let $a_x = a_y = a_z$ = three orthogonal acceleration components

G_H = resultant of the two horizontal acceleration components

$$= \sqrt{(a_x)^2 + (a_z)^2} = 1.414\, a_x$$

G_V = vertical acceleration component

$$= a_y = a_x$$

W_c = Concrete cask loaded weight
= center of gravity, CG, distance from reference line at base of VCC

b = horizontal distance from P.O.R. to CG

and $M_R \geq M_O$

or $(F_y)(b) \geq (F_x)(d)$

$$[(W_c)(1g) - (W_c)(G_V)](b) \geq [(W_c)(G_H)](d)$$

By rearranging:

$$(1g - a_x)\frac{b}{d} \geq 1.414 \times a_x$$

$$\left(\frac{b}{d}\right)(g) \geq \left(1.414 + \frac{b}{d}\right)(a_x)$$

$$a_x \leq \left(\frac{b/d}{1.414 + b/d}\right)g$$

By substituting the values for (b) and (d) into equation, the equation for acceleration from the sketch is:

$$a_x \leq \left(\frac{62.89/83.2}{1.414 + 62.89/83.2}\right) \times g \leq 0.34839g$$

Therefore, the minimum ground acceleration that may cause a tip over of a fully loaded concrete cask is 0.348g. Since the 0.25g design basis earthquake ground acceleration for the NAC-MPC system is less than 0.348g, the storage cask will not tip over.

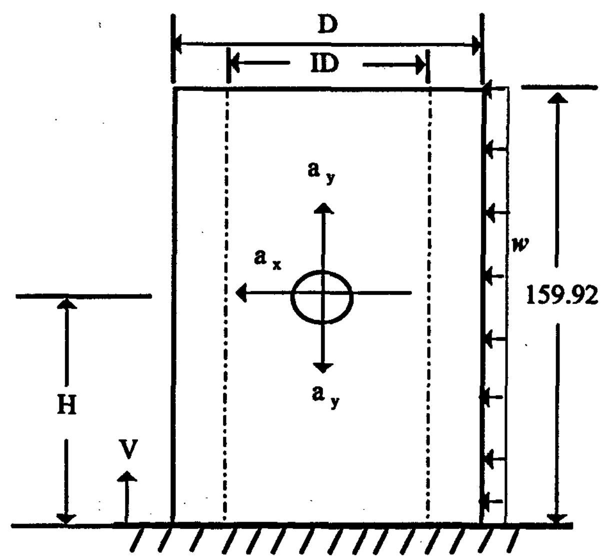
The margin of safety is (0.348/0.25) - 1 = +0.4.

The stresses in the concrete due to the design basis G-loads are conservatively calculated below. The fully loaded concrete cask is considered to be fixed at its base and subjected to seismic loads equal to 0.25 g in the two orthogonal horizontal directions and the vertical direction.

The accelerations are:

$a_x = (0.25^2 + 0.25^2)^{0.5} = 0.354$ g (horizontal direction)

$a_y = \pm 0.25$ g (vertical direction)



The following parameters are used in the calculation:

H	= 83.2 in. (Location of Center of Gravity)	
W_{vcc}	= 206,100 lb. (VCC weight)	
D	= 128 in. (concrete exterior diameter)	
ID	= 86 in. (concrete interior diameter)	
A	$= \pi (D^2 - ID^2) / 4$	= 7,059.2 in.^{2}
I	$= \pi (D^4 - ID^4) / 64$	= 10.492 × 10^6 in.^{4}
S_{outer}	= 2I /D	= 163,937.5 in.^{3}
S_{inner}	= 2I / (ID)	= 244,000.0 in.^{3}
w	$= a_x W_{vcc} / 159.92$	= 456.22 lb / in.

The maximum bending moment (M) at support is:

$$M = w (159.92)^2 / 2 = 5.834 \times 10^6 \text{ in.-lb}$$

With a_y = +0.25 g, the maximum tensile stress at the outer and inner surfaces of the concrete shell are:

$$\sigma_{v\,outer} = (M / S_{outer}) + (a_y (W_{vcc}) / A) = +35.59 + 7.30 = 42.9 \text{ psi}$$

$$\sigma_{v\,inner} = (M / S_{inner}) + (a_y (W_{vcc}) / A) = +23.91 + 7.30 = 31.2 \text{ psi}$$

With a_y = -0.25 g, the maximum compressive stress at the outer and inner surfaces of the concrete shell are:

$$\sigma_{v\ outer} = (M\ /\ S_{outer}) + (a_y\ (W_{vcc})\ /\ A) = -35.59 - 7.30 = -42.9\ \text{psi}$$
$$\sigma_{v\ inner} = (M\ /\ S_{inner}) + (a_y\ (W_{vcc})\ /\ A) = -23.91 - 7.30 = -31.2\ \text{psi}$$

The compressive stresses are included in the load combination No. 5 in Table 3.4.4.2-1, since they are governing stresses for the load combination. As shown in Tables 3.4.4.2-1 and 3.4.4.2-2, the maximum combined stresses for the load combination of dead, live, thermal and earthquake are below the allowable stress.

11.2.2.3 Radiological Consequences

There are no radiological consequences for this accident.

11.2.2.4 NAC-MPC Performance

This analysis shows that the Yankee NAC-MPC vertical concrete cask performance is not affected by the design basis earthquake. The vertical concrete cask does not tip over for the design-basis earthquake having ground accelerations of 0.25 g.

11.2.2.5 Recovery and/or Corrective Actions

Inspection of the storage casks is required following an earthquake accident. While the cask does not tip over, there is a potential for movement of a cask relative to other casks and for superficial damage at the bottom edge due to that movement. The temperature monitoring system should be checked for operation as movement of a cask could have disconnected the monitoring system.

11.2.3 Explosion

The flood analysis presented in Section 11.2.6 shows that the NAC-MPC system would not experience adverse effects due to a pressure of 22 psig applied to the canister. The vertical concrete cask will also be unaffected. This pressure is considered to bound any explosions occurring in the vicinity of the ISFSI.

11.2.3.1 Cause of Accident

An explosion is an unlikely event because administrative controls will exclude explosive substances in the vicinity of the ISFSI. No flammable or explosive substances are stored or used at the storage facility; therefore, an explosion affecting the site is extremely unlikely. This evaluation is provided in order to provide a bounding pressure that could be used in the event that the potential of an explosion must be considered at a given site.

11.2.3.2 Evaluation of the Explosion Event

The NAC-MPC canister shell was evaluated in Section 11.2.6 for the effects of a flood having a depth of 50 feet. The water exerts an external hydrostatic pressure of 22 psig on the canister, which results in stress in the canister shell.

The maximum primary membrane stress calculated in the canister is 8.82 ksi. The allowable stress for accident conditions is 40.08 ksi. The margin of safety for primary membrane stress is +3.54.

The maximum primary membrane plus bending stress calculated in the canister is 19.18 ksi. The allowable primary membrane plus bending stress for accident conditions is 60.12 ksi. The margin of safety for primary membrane plus bending stress is +2.13.

Consequently, there is no adverse consequence to the canister as a result of the 22 psig external pressure. This pressure conservatively bounds an explosion event.

The concrete cask is a monolithic structure that is not affected by the explosion overpressure.

11.2.3.3 Radiological Consequences

There are no radiological consequences for this accident.

11.2.3.4 NAC-MPC Performance

This analysis shows that the NAC-MPC system performance is not affected by explosion over pressure.

11.2.3.5 Recovery and/or Corrective Actions

In the unlikely event of a nearby explosion, inspection of the storage casks is required to ensure that the air inlets and outlets are free of debris, and to ensure that the monitoring system is intact. There are no recovery or corrective actions required for this accident event.

11.2.4 Failure of All Fuel Rods With a Subsequent Ground Level Breach of the Canister

This section addresses the potential mechanistic failure of the canister and subsequent release of radioactive gas, volatile and particulate material from the canister.

As described in Chapters 3, 4, and 11, the NAC-MPC is evaluated for normal conditions, and for a series of off-normal and accident events that include cask tip over, cask drop, flooding, fire and explosion, lightning, earthquake, loss of shielding, adiabatic heat up, and tornado generated missiles. The evaluations show that for these design basis events, there is no mechanistic failure of the confinement boundary of the canister, i.e., the canister maintains its structural integrity. As described in Chapter 7, and in Section 8.1.1, the canister is tested to demonstrate that it is leaktight as defined by ANSI N14.5-1997.

Therefore, no further evaluation of this potential accident condition is required.

11.2.5 Fire Accident

This section evaluates the effects of a hypothetical fire accident as a bounding condition. A fire accident is a very unlikely occurrence in the storage cask lifetime.

11.2.5.1 Cause of Accident

There is no probable cause for this accident event. There are no flammable materials in the area of the ISFSI. While it is possible that a transport vehicle could start a fire while transferring a loaded storage cask at the ISFSI, this fire would be confined to the vehicle and would be rapidly extinguished by the persons performing the transfer operations.

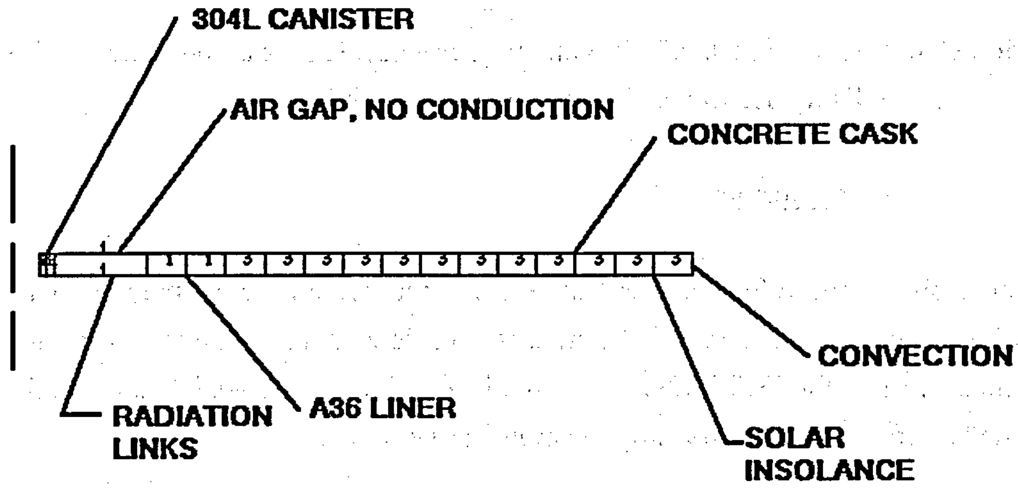
Detection of the event would be by observation of fire or smoke.

11.2.5.2 Accident Analysis

The bounding condition hypothetical fire accident is very conservatively assumed to be that defined by 10 CFR 71.73.c.(3), a 1475°F fire for 30 minutes duration, with an assumed emissivity coefficient of at least 0.9.

The event was evaluated using a two dimensional axis-symmetric ANSYS finite element model of the canister shell and the concrete cask. The method of analysis is to apply the fire accident heat load, assuming that the NAC-MPC is at normal steady state conditions. Solar heat load is ignored during the fire. A convection heat transfer coefficient of 0.02446 Btu/hr-in^2-°F is applied to account for heat transfer to the concrete cask surface. This coefficient is twice the theoretical value (Wix) to account for uncertainty in the fire accident condition and the data from which the theoretical value is derived. Following the 30 minute fire condition, solar insolation and convection is restored. The ANSYS model is used to calculate the maximum temperatures that occur during the fire or subsequent cool down transient. The maximum temperatures for the canister shell and concrete are applied as initial uniform temperatures of 319°F and 165°F, respectively (Table 4.4.3-1). A canister shell temperature of 431°F is conservatively used in the analysis. A heat flux representing the 12.5 kW thermal load is applied with a 1.15 peaking factor (Section 4.4.1).

A one-inch thick section, perpendicular to the vertical axis of the cask, is modeled as:



The model was constructed of PLANE55 thermal elements and LINK31 radiation elements. LINK31 elements were used to model the gap between the canister shell and concrete cask liner. No conduction by the air in the gap was assumed. The model precludes axial variance in temperature by coupling the degrees of freedom of the top and bottom layer of nodes.

The thermal transient analysis of the fire consists of two parts: the time during the 30-minute fire and the time following the fire accident. The initial temperatures of the model correspond to normal operating steady state conditions of the concrete cask. The fire condition is initiated by applying an effective film coefficient, in conjunction with radiation, corresponding to an emissivity of 0.9 for the concrete with an ambient temperature of 1475°F. During the 30-minute fire, all inlets and outlets are completely blocked and the thermal flux is applied to the canister surface to represent the fuel heat. Solar insolance is not applied to the surface of the VCC during the fire.

At the end of the 30-minute fire, the film coefficient at the surface of the VCC is replaced with a value representing free convection from the vertical surface in conjunction with solar insolance. The calculation of the film coefficient is described in Section 4.4.1.1.2. The fire does not permanently impare the operation of the cooling system, so the annulus region is able to reject the fuel decay heat by air mass transport after the fire. However, the thermal transient model does not include the rejection of heat by the air annulus. To permit the analysis to return the VCC temperatures to the normal operating conditions that existed prior to the fire, the flux

associated with the fuel heat load is not applied after the fire. Once the fire condition is discontinued, the VCC temperature will continue to rise for a period of time due to stored thermal energy from the fire condition. The transient analysis is continued until it is clear that the maximum temperature of the VCC has been reached and the temperature has begun to drop.

The peak temperature of the concrete cask outer surface is reached within 1 hour of the start of the fire. The concrete surface temperature begins to drop as soon as the fire equivalent heat load is removed. The concrete returns to its normal storage condition temperature in about 6 hours. The peak temperature of the concrete inner surface occurs about 17 hours after the fire accident event. The peak temperature of the concrete is 194°F. The rate of heat-up of the inner surface is shown in Figure 11.2.5.2-1.

The peak temperature of 194°F is approximately 28°F higher than the normal temperature. Based on this increase, the temperature of the fuel cladding is estimated to be 709°F, which is below the short-term allowable temperature of 1058°F.

11.2.5.3 Radiological Consequences

There are no significant radiological consequences for this accident. There may be local spalling of concrete during the fire event, which could lead to some minor reduction in shielding effectiveness. The principal effect would be local increases in radiation dose rate on the cask surface.

11.2.5.4 NAC-MPC Performance

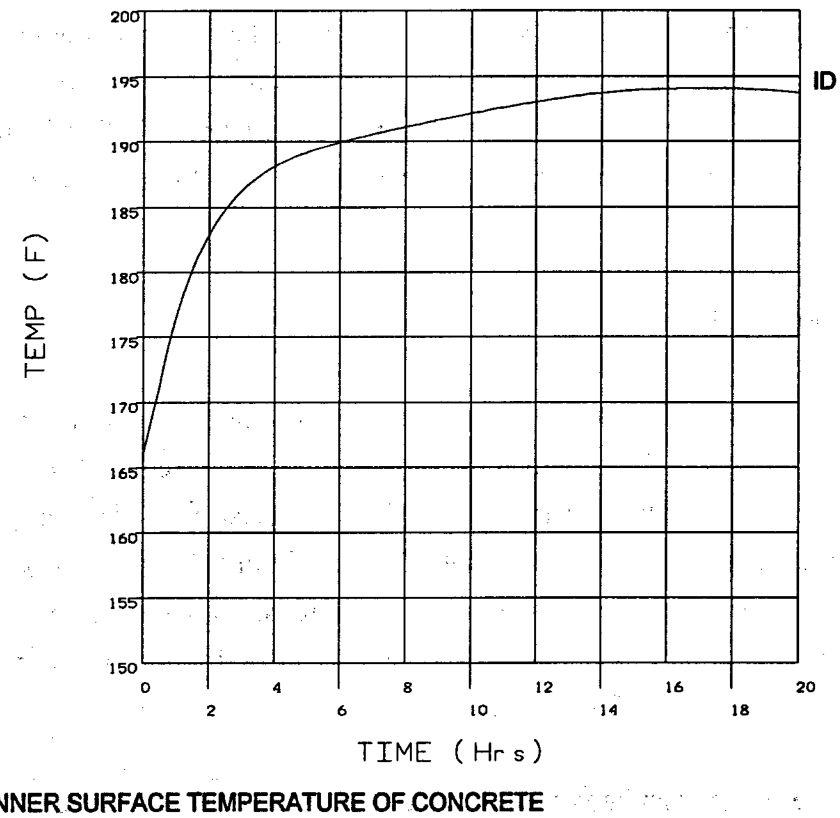
The peak temperature of the concrete inner surface is 194°F, which is reached at 17 hours after the fire starts. The concrete temperature is significantly less than the short-term limit of 350°F. The peak temperature of the concrete outer surface is 1380°F and occurs at 0.5 hour (i.e., just prior to the end of the fire). The peak fuel temperature of 709°F is less than the short-term allowable fuel temperature of 1058°F. The fuel, canister, and support disk are not significantly affected by the accident.

Even for the severe 10 CFR 71 hypothetical thermal accident (fire), the NAC-MPC meets its storage performance requirements.

11.2.5.5 Recovery and/or Corrective Actions

In the unlikely event of such a severe fire at an ISFSI site, the operator will take appropriate immediate response to suppress and extinguish the fire. Following the fire, the concrete cask should be inspected for general deterioration of the concrete, loss of shielding (spalling of concrete), exposed reinforcing bar, and surface discoloration that could affect heat rejection. This inspection would determine the repair activities necessary to return the concrete storage cask to its design basis configuration.

Figure 11.2.5.2-1 Time History of the Peak Temperature of the Inner Surface of the Concrete (Fire Accident)



11.2.6 Flood

This evaluation shows that the NAC-MPC system is not adversely affected by a design basis flood having a depth of water of 50 feet and a flow velocity of 15 feet per second.

11.2.6.1 Causes of Flood

The probability of a flood event is highly dependent on land contour and environmental factors that are specific to each ISFSI site. Most reactor sites are not susceptible to flooding as a result of site selection characteristics. This evaluation considers design basis flood conditions of a 50-foot depth of water having a velocity of 15 feet per second. This flood is fully immersing for the NAC-MPC system.

11.2.6.2 Flood Analysis

The concrete cask is considered to be resting on a flat level concrete pad when subjected to a flood velocity pressure distributed uniformly over the projected area of the concrete cask. Because of the concrete cask geometry, rigidity, and large mass, it is analyzed as a rigid body. Assuming full immersion of the concrete cask and steady-state flow conditions, the drag force, F_D, is calculated using classical fluid mechanics for turbulent flow conditions. A safety factor of 1.1 for stability against overturning and sliding is applied. The coefficient of friction between carbon steel and concrete used in this analysis is 0.35 (Funk).

The buoyancy force, F_b, is calculated from the weight of water (62.4 lb/ft^3) displaced by the fully immersed concrete cask. The displacement volume of the concrete cask containing the loaded canister is 1030 ft^3. The displacement volume is the occupied volume less the free space in the central annular cavity of the concrete cask.

$$F_b = \text{Vol} \times 62.4 \text{ lb/ft}^3$$
$$= 64.27 \text{ kip}$$

Assuming the steady-state flow conditions for a rigid cylinder, the total drag force of the water on the concrete cask is given by the formula:

$$F_D = (C_D)(\rho)(V^2)\left(\frac{A}{2}\right) \qquad \text{(Roberson)}$$

$$= 21.72 \text{ kip}$$

where,

C_D = Drag coefficient, which is dependent upon the Reynolds Number (Re). For flow velocities greater than 6 ft/sec, the value of C_D approaches 0.7. (Roberson)

ρ = mass density of water = 1.94 slugs/ft^3

D = VCC outside diameter (128 in. / 12 = 10.67 ft)

V = velocity of water flow (15 ft/sec)

A = projected area of the VCC normal to water flow (10.67 ft × 13.33 ft = 142.2 ft^2)

The drag force required to overturn the concrete cask is determined by summing the moments of the drag force and the submerged weight (weight of the cask less the buoyant force) about a point on the bottom edge of the cask. This method assumes a pinned connection, i.e., the cask will rotate about the point on the edge rather than slide. When these moments are in equilibrium, the cask is at the point of overturning.

$$F_D \times \left(\frac{h}{2}\right) = (W_{VCC} - F_b) \times r$$

and

$$F_D = 113.42 \text{ kip}$$

where:

h = concrete cask overall height (159.92 in., use 160 in. / 12 in./ft = 13.33 ft)

W_{vcc} = concrete weight = 206.1 kips

F_b = buoyant force = 64.27 kips

r = concrete cask radius (64 in. / 12 in./ft = 5.33 ft)

Solving the drag force equation for the velocity, V, that is required to overturn the concrete cask:

$$V = \sqrt{\frac{2F_D}{C_D \rho A}}$$

$= 32.68$ ft/sec. (including safety factor of 1.1)

To prevent sliding, the minimum coefficient of friction (with a safety factor of 1.1) between the carbon steel bottom plate of the concrete cask and the concrete surface upon which it rests is,

$$\mu_{min} = \frac{(1.1)F_{D15}}{F_y}$$

where, F_y = the immersed weight of the concrete cask

$$\mu_{min} = \frac{(1.1)21.72\text{kip}}{(206.10 - 64.27)\text{kip}} = 0.17$$

The analysis shows that the minimum coefficient of friction, μ, required to prevent sliding of the concrete cask is 0.17. The coefficient of friction between the steel bottom plate of the concrete cask and the concrete surface of the storage pad (0.35) is greater than the coefficient of friction required to prevent sliding of the concrete cask. Therefore, the concrete cask will not slide under design-basis flood conditions.

The water velocity required to overturn the concrete cask is greater than the design-basis velocity of 15 ft/sec. Therefore, the concrete cask will not be overturned under design basis flood conditions.

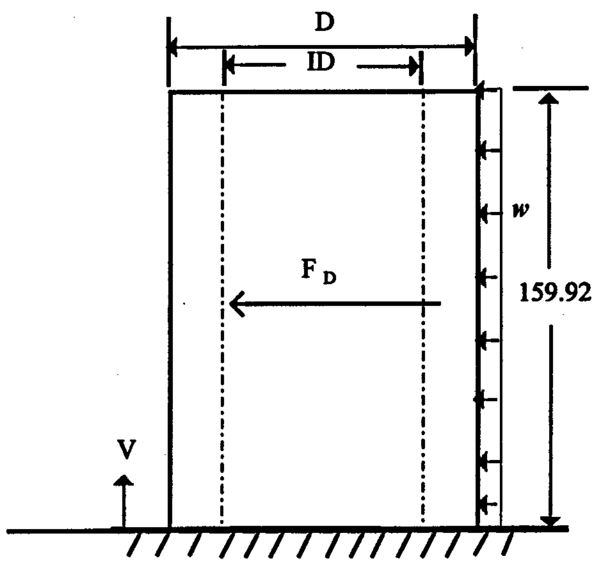
The flood depth of 50 feet exerts a hydrostatic pressure on the canister and the concrete cask. The water exerts a pressure of 22 psig (50 x 62.4/144) on the canister, which results in stresses in the canister shell.

The maximum primary membrane stress in the canister is 8.82 ksi. The allowable stress for accident conditions (2.45m) is 40.08 ksi. The margin of safety for primary membrane stress is +3.54.

The maximum primary membrane plus bending stress is 19.18 ksi. The allowable primary membrane plus bending stress for accident conditions (3.65m) is 60.12 ksi. The margin of safety is +2.13.

Consequently, there is no adverse consequence to the canister as a result of the hydrostatic pressure due to the flood condition.

The concrete cask is a thick monolithic structure and is not affected by the design basis flood hydrostatic pressure. However, the stresses in the concrete due to the drag force (F_D) are conservatively calculated as shown below. The concrete cask is considered to be fixed at its base.



F_D	= 21,720 lb		
D	= 128 in. (concrete exterior diameter)		
ID	= 86 in. (concrete interior diameter)		
A	$= \pi (D^2 - ID^2) / 4$	= 7,059.2 in.^{2}	
I	$= \pi (D^4 - ID^4) / 64$	= 10.492 x10^6 in.^{4}	(Moment of Inertia)
S_{outer}	= 2I /D	= 163,937.5 in.^{3}	(Section Modulus for inner surface)
S_{inner}	= 2I / (ID)	= 244,000.0 in.^{3}	(Section Modulus for outer surface)
w	$= F_D / 159.92$	= 135.82 lbf / in.	
M	$= w (159.92)^2 / 2$	= 1.737 x 10^6 in.-lb	(Bending Moment at the base)

Maximum stresses at the base surface:

$\sigma_{v\,outer} = M / S_{outer}$ = 10.6 psi (tension or compression)

$\sigma_{v\,inner} = M / S_{inner}$ = 7.1 psi (tension or compression)

The compressive stresses are included in load combination No. 7 in Table 3.4.4.2-1, since they are the governing stresses for the load combination. As shown in Tables 3.4.4.2-1 and 3.4.4.2-2, the maximum combined stresses for the load combination due to dead, live, thermal and flood loading, are below the allowable stress.

11.2.6.3 Radiological Consequences

There are no radiological consequences for this accident.

11.2.6.4 NAC-MPC Performance

This analysis shows that the Yankee NAC-MPC vertical concrete cask system performance is not affected by the design basis flood. The analysis demonstrates that the concrete cask will not slide and will not overturn in the design-basis flood. The hydrostatic pressure exerted by the 50 foot depth of water does not produce significant stress in the canister.

11.2.6.5 Recovery and/or Corrective Actions

Inspection of the storage casks is required following this accident event. While the casks do not tip over or slide, there is a potential for the collection of debris or the accumulation of silt at the base of the cask, which could clog or obstruct the air inlets. Operation of the temperature monitoring system must be verified, as flood conditions may have impaired its operation.

11.2.7 Fresh Fuel Loading in the Canister

This section evaluates the effects of an inadvertent loading of up to 36 fresh, unburned Yankee class fuel assemblies in the canister. This event is not a credible event.

11.2.7.1 Cause of Accident

The cause of this event would be operator and/or procedural error. The design basis criticality condition demonstrates that the canister is designed to accommodate fresh fuel without a resulting criticality event.

This accident is expected to be identified immediately by observation of the condition of the fuel installed in the canister or by a review of the fuel handling records.

11.2.7.2 Analysis of Fresh Fuel Loading in the Canister

The criticality analysis presented in Chapter 6 assumes the loading of up to 36 Yankee class fuel assemblies having no burn up. This analysis shows that the maximum K_{eff} for the canister in the dry normal condition is 0.4463. The maximum K_{eff} in the accident conditions is 0.8978. The accident condition assumes the most reactive configuration of the fuel and full moderator intrusion.

The design of the NAC-MPC is adequate to preclude any effects due to this accident condition.

11.2.7.3 Radiological Consequences For This Accident

There are no radiological consequences for this event.

11.2.7.4 NAC-MPC Performance

The criticality control features of the NAC-MPC canister and basket ensure that the K_{eff} of the fuel is less than 0.95 for all loading conditions of fresh fuel. There is no adverse impact on the NAC-MPC due to this event.

11.2.7.5 Recovery and Corrective Actions

This event requires that the canister be unloaded when the incorrect loading is identified. The controls placed on the movement of fuel assemblies is such that this accident event will not occur.

11.2.8 Full Blockage of Air Inlets and Outlets

This section evaluates the NAC-MPC for the steady state effects of full blockage of the air inlets and outlets at the normal ambient temperature (75°F). It estimates the duration of the event that would result in the concrete reaching its design basis limiting temperature of 350°F.

11.2.8.1 Cause of Event

The likely cause of complete air inlet and outlet blockage is the covering of the cask with earth in a catastrophic event such as greater than design basis earthquake or a land slide. This event is a bounding condition accident that is not credible.

This event would be detected by inspection of general conditions at the site following such an event. It would be detected visually by the persons inspecting the ISFSI site.

11.2.8.2 Analysis of the Blockage Event

The accident temperature conditions are evaluated using the thermal models described in Section 4.4.1. The analysis assumes initial normal storage conditions, with the sudden loss of convective cooling of the canister. Heat is then rejected from the canister to the storage cask liner by radiation and conduction. The loss of convective cooling results in the fairly rapid and sustained heat-up of the canister and the concrete cask. To account for the loss of convective cooling in the ANSYS air flow model (Section 4.4.1.1), the elements in the model were replaced with thermal elements, employing the axis-symmetric option. This option assures that there is no axial temperature difference across the element. This model is used to evaluate the thermal transient resulting from the postulated boundary conditions.

The thermal transient analysis evaluated the concrete temperature conditions for 100 hours. At the end of 24 hours, the concrete temperature is 287°F, an increase of 122°F, compared with the initial (normal conditions) concrete temperature, 165°F. The maximum temperature in the concrete will exceed the thermal design criteria temperature of 350°F at 45.7 hours after the start of the event.

Other conservative assumptions include no internal convection and no heat transfer to the surrounding environment (i.e., the dirt covering the cask in the case of a landslide).

The maximum canister shell temperature is 536°F at 45.7 hours after the start of the event. Considering the maximum temperature difference of 250°F between the canister shell and fuel region (as shown in Table 4.1-4, the ΔT between canister shell and fuel clad is 563 - 319 = 244°F for normal condition of storage), the maximum fuel temperature will reach 786°F (536° + 250°) in the same 45.7-hour period, which is less than the short-term allowable temperature of 1058°F.

11.2.8.3 Radiological Consequences

There are no significant radiological consequences for this event, as the NAC-MPC retains its shielding performance. Dose is incurred as a consequence of uncovering the storage cask and vent system. Since the dose rates at the air inlets and outlets are higher than the nominal rate (35 mrem/hr) at the cask wall, personnel will be subject to an estimated maximum dose rate of 100 mrem/hr when clearing the inlets and outlets. If it is assumed that a worker kneeling with his hands on the inlets or outlets would require 15 minutes to clear each inlet or outlet, the estimated extremity dose is 200 mrem for the 8 vents. The whole body dose would be slightly less. In addition, some dose is incurred clearing debris away from the cask body. This dose is estimated at 50 mrem, assuming 2 hours is spent near the cask exterior surface.

11.2.8.4 NAC-MPC Performance

There are no adverse consequences for this accident condition, assuming that debris is cleared within a reasonable time (< 45 hours). The maximum component temperatures are less than the allowable temperatures. The NAC-MPC continues to satisfactorily perform the cooling function with all the inlets and outlets blocked.

11.2.8.5 Recovery and/or Corrective Actions

The debris blocking the vents must be manually removed. In addition, a considerable effort may be involved in clearing the area around the storage casks. No actions are required with regard to the casks proper, provided that the vents are cleared within 45 hours.

11.2.9 Lightning

This analysis demonstrates that the NAC-MPC storage cask does not experience adverse effects due to a lightning strike.

11.2.9.1 Cause of Accident

A lightning strike is a random weather related event. Since the NAC-MPC storage cask is located on an unsheltered pad, the storage cask may be subject to a lightning strike. The probability of a lightning strike is primarily dependent on the geographical location of the ISFSI site, as some geographical regions experience a higher frequency of storms containing lightning than others.

The analysis of the consequence of a lightning strike assumes that the lightning strikes the upper most metal surface and proceeds through the storage cask liner to the ground. The electrical current flow path results in current induced Joulean heating along that path.

A lightning strike on a storage cask may be visually detected at the time of the strike, or by visible surface discoloration at the point of entry or exit of the current flow. Most reactor sites in locations experiencing a frequency of lightning bearing storms have lightning strike detection systems as an aid to ensuring stability of site electric power.

11.2.9.2 Analysis of the Lightning Strike Event

The current path analyzed is from a strike point on the outer radius of the top flange of the storage cask, down through the carbon steel liner and the bottom plate to the ground.

The integrated maximum current for a lightning strike is a peak current of 250 kiloamps over a period of 260 microseconds, and a continuing current of up to 2 kiloamps for 2 seconds in the case of severe lightning discharges (Cianos).

From Joule's Law, the amount of thermal energy developed by the combined currents is given by (Summer):

$$Q = 0.0009478R\left[I_1^2(dt_1) + I_2^2(dt_2)\right]$$
$$= (22.98 \times 10^3)\ R\ \text{Btu}$$

where,

Q = thermal energy (BTU)
I_1 = peak current (amps)
I_2 = continuing current (amps)
dt_1 = duration of peak current (seconds)
dt_2 = duration of continuing current (seconds)
R = resistance (ohms)

The maximum lightning discharge is assumed to attach to the smallest current-carrying component, that is, the top flange connected to the outer lid.

The propagation of the lightning through the carbon steel cask liner, which is both permeable and conductive, is considered to be a transient. For static conditions, the current would be distributed throughout the shell. In a transient condition the current will be near the surface of the conductor. It is assumed that the current is contained in a 90 degree sector of the circular cross section of the steel liner as opposed to the entire cross section. The depth of the current penetration (δ) is estimated as (Fink):

$$\delta = 1 \Big/ \sqrt{\pi \mu f \sigma}\ \ (\text{m})$$

where:

μ = permeability of the conductor = $100\mu_0$ (Summer)
and μ_0 = 4πE-7 Henries/m
σ = electrical conductivity (seimens/meter) = $1/\rho$
= 1/resistivity = 1/9.78E-08 (ohm-m) (Fink)
f = frequency of the field (Hz)

The pulse is represented conservatively as a half sine form, so that the equivalent $f = 2 \times \tau$, where τ is the referenced pulse duration. There are two skin depths to be computed, corresponding to different pulse duration. The larger effective frequency will result in a smaller effective area to conduct the current. The effective resistance is computed as (Fink):

$$R = \frac{\rho l}{a}$$

where,

R = resistance (ohms)
ρ = resistivity = 9.78E-08 (ohm-m)
l = length of conductor path
a = area of conductor (m^2)
$= (R_{shell})(\ \delta)(\pi/4)$
R_{shell} = 35.75 inches = 0.9081 m

Using the current level of the pulse and the duration in conjunction with the carbon steel liner, the resulting energy into the shell is:

	Peak	Continuous	Expression
Time (s) τ	2.60 E-06	2.0	-------------
Peak Current (KA)	250	2	-------------
Frequency (Hz)	2000(conservative)	2.5E-01	$1/(2\tau)$
Skin depth (m) δ	3.52E-04	3.15E-02	$1/\sqrt{\pi\mu f\sigma}$
Conductor length (m) L	4.1	4.1	---------------
Conductor area (m^2) A_c	2.51E-4	2.24E-2	$R_{shell}\,\delta(\pi/4)$
Resistance (ohm) Ω	1.60E-03	1.79E-5	$(L/A)\rho$
Q (Btu)	24.6	.14	$R = \frac{\rho\, l}{a}$

It is conservatively assumed that this thermal energy dissipation occurs in the localized volume of the carbon steel involved in the current flow path through the flange to the inner liner. Assuming no heat loss or thermal diffusion beyond the current flow boundary, the maximum temperature increase in the flange due to this thermal energy dissipation is calculated as (Black):

$$\Delta T = \frac{Q}{mc}$$

where,

ΔT = temperature change (°F)
Q = thermal energy (BTU)
c= 0.113 Btu/lb °F
m = mass (lbm)

The ΔT_1 for the peak current (250KA, 260 μsec) for the region of the current is computed based on the mass associated with this region.

$$m = (.284\ lb/in^3) \times A_c \times L = (.284)(2.51E\text{-}4)(159.92)/C_f = 17.7\ lbm$$

$$C_f = (.0254^2)\ \text{(converts } m^2 \text{ to } in^2\text{)}$$

$$\Delta T_1 = 24.6/(17.7 \times .113) = 12.3°F$$

The ΔT_2 for the continuous current (2KA, 2 sec) for the region of the current is computed based on the mass associated with this region.

$$m = (.284\ lb/in^3) \times A_c \times L = (.284)(2.24E\text{-}2)(159.92)/(.0254^2) = 1577\ lbm$$

$$\Delta T_2 = .14/(1577 \times .113) = 0.001°F$$

The ΔT_1 would correspond to the increase in the maximum temperature of the steel. For the concrete to experience an increase in temperature, the heat must disperse from the steel liner surface throughout the steel. Using the total thickness of the steel, over the 90 degree sector, the increase in temperature is:

$$m = (.284 \text{ lb/in}^3) \times (39.25^2 - 35.75^2)\pi/4 \times L = 9{,}364 \text{ lbm}$$

$$\Delta T_1 = (24.6+.14)/(9{,}364 \times .113) = 0.02 \text{ F}$$

Therefore the increase in temperature of the concrete is not significant.

11.2.9.3 Radiological Consequences

There are no radiological consequences for this accident.

11.2.9.4 NAC-MPC Performance

This analysis shows that the NAC-MPC vertical concrete cask's performance is not affected by a lightning strike. When lightning strikes the cask and travels through the 3.5-inch thick carbon steel storage cask liner, the maximum increases in the steel and concrete temperatures is 12.3°F and 0.0°F, respectively.

11.2.9.5 Recovery and/or Corrective Actions

There are no recovery or corrective actions required for this accident event.

11.2.10 Maximum Anticipated Heat Load (125°F Ambient Temperature)

This analysis evaluates the NAC-MPC response to storage operation with an ambient temperature of 125°F. The NAC-MPC is evaluated at steady state conditions.

11.2.10.1 Cause of Accident

The cause of this condition is a weather event that causes the NAC-MPC to be subject to a 125°F ambient temperature with full solar insolance. A contents heat load of 12.5 kW is assumed.

The condition is analyzed in accordance with the requirements of ANSI/ANS 57.9 to evaluate a credible worse case thermal loading. This condition is considered in the load combinations described in Chapter 2.

Detection of the ambient high temperature condition would occur during the daily measurement of ambient temperature and storage cask outlet air temperature.

11.2.10.2 Analysis of the 125°F Ambient Temperature Event

The severe high temperature condition is evaluated using the thermal models described in Section 4.4.1. The principal component temperatures for this ambient condition are:

Component	125°F Ambient Max Temp. (°F)	Allowable Max Temp. (°F)
Fuel Cladding	607	1058
Support Disks	575	800
Heat Transfer Disks	574	700
Canister Shell	372	800
Concrete	228	350

This evaluation shows that the component temperatures are within the allowable temperature for the severe high ambient temperature conditions.

This event is considered an "accident condition" for the purpose of this evaluation. Consequently, the thermal stress (secondary) occurring in the canister due to this thermal loading is not evaluated.

However, the thermal stresses for the concrete cask are calculated using the same methodology as shown in Section 3.4.4.2 for the stress calculation for normal conditions of storage. The same finite element model is used with the boundary temperatures based on concrete cask thermal analysis results (Section 4.4.4.1). The maximum vertical and circumferential (compressive) stresses at the concrete inside surface are calculated to be 660.1 psi and 127.5 psi, respectively. These stresses are included in the load combination (No. 4) as presented in Table 3.4.4.2-1. The maximum tensile forces in the vertical and hoop reinforcing bars are 19,380 lbs. and 23,196 lbs., respectively. Comparison of these forces and the allowable forces is shown in Table 3.4.4.2-2. As shown in Tables 3.4.4.2-1 and 3.4.4.2-2, the maximum combined concrete stress and reinforcing bar force for the load combination of dead (D), live (L) and accident temperature (T_a) are below the allowable stress and force, respectively.

11.2.10.3 Radiological Consequences

There are no radiological consequences for this event.

11.2.10.4 NAC-MPC Performance

There are no adverse consequences for this accident condition. The maximum component temperatures are less than the allowable temperatures for accident conditions, and are also less than the temperature limits for normal conditions of storage.

11.2.10.5 Corrective Actions

No corrective actions are required for this accident condition.

11.2.11 Storage Cask 6-Inch Drop

This analysis evaluates a loaded concrete storage cask for a 6-inch drop onto a concrete storage pad. This evaluation shows that neither the concrete storage cask nor the canister experience significant adverse effects due to the 6-inch drop accident.

11.2.11.1 Cause of Accident

The concrete storage cask, containing the loaded canister, must be raised approximately 3-inches in order to install the inflatable air-pads beneath it. The air pads use pressurized air to allow the cask to be moved across the surfaces of the transporter and the ISFSI pad to the designated positions. The cask is raised using hydraulic jacks installed at jack-points in the air inlets.

This accident assumes the failure of one or more of the jacks or of the air pad system, resulting in a drop of the cask. A lift of about 3-inches is required to install and remove the air pads. This analysis conservatively evaluates the consequences of a 6-inch drop.

This accident would be detected by persons jacking or moving the storage cask.

11.2.11.2 Analysis of the 6-Inch Drop Event

A bottom end impact is assumed to occur normal to the concrete pad surface, transmitting the maximum g-load to the concrete storage cask and the canister. The energy absorption is computed as the product of the compressive force acting on the storage cask and its displacement. Conservatively assuming the storage pad is an infinitely rigid surface, exhibiting a uniform isotropic crush strength, the concrete body of the storage cask will crush until the impact energy is absorbed.

A compressive strength of 4000 psi is used for the storage cask concrete. This is conservative since it is the minimum specified value and it ignores any energy absorption by the internal friction of the aggregate as crushing proceeds.

The canister rests upon a stand/inlet system, shown in Figure 11.2.11-1, designed to allow cooling of the canister. Following the initial impact, the inlet system will partially collapse, providing an energy absorption mechanism that somewhat reduces the deceleration force on the canister. A detailed evaluation is provided in Section 11.2.11.2.2. The weight of the empty concrete storage cask is 151,364 pounds. The loaded canister weight is 54,730 pounds.

11.2.11.2.1 Evaluation of the Concrete Storage Cask

In the 6-inch bottom drop, the cylindrical portion of the concrete is in contact with the steel bottom baseplate that also supports the stand/inlet system. The baseplate is assumed to be part of an infinitely rigid storage pad. No credit is taken for the crush properties of the storage pad or the underlying soil layer. Therefore, energy absorbed by the crushing of the cylindrical concrete region of the storage cask equals the product of the compressive strength of the concrete, the crush depth of the concrete, and the projected area of the concrete cylinder. Crushing of the concrete continues until the energy absorbed equals the potential energy of the storage cask at the initial drop height. The canister is not rigidly attached to the concrete cask, so it is not considered to contribute to the concrete crushing. The energy balance equation is

$$w(h+\delta) = P_o A \delta,$$

where,

h = 6 in., the drop height,

δ = the crush depth of the concrete cask,

P_o = 4000 psi, the compressive strength of the concrete,

A = $\pi(R_1^2 - R_2^2)$
= 7,059 in^2, the projected area of the concrete shield wall,

w = 151,364 lb × 1.1, the weight of the concrete cask, conservatively multiplied by 1.1 to account for variations in the concrete.

It is assumed that the maximum force that can be exerted on the concrete cask is the compressive strength of the concrete multiplied by the area of the concrete being crushed.. Therefore, the deceleration of the storage cask is dependent upon the compressive strength of the concrete, the cross-sectional area of the storage cask cylindrical body, and the weight of the empty storage cask with lid. The deceleration due to crush is:

$$a_{vcc} = \frac{P_o A}{w} = 169.6 \quad \text{g's.}$$

The crush distance computed from the energy balance equation is:

$$\delta = \frac{hw}{P_o A - w} = \frac{(6)(151{,}364 \times 1.1)}{(4000)(7{,}059) - (151{,}364 \times 1.1)} = 0.036 \text{inch}$$

11.2.11.2.2 Evaluation of the Canister for a 6-inch Bottom-End Drop of the Storage Cask

Upon a bottom-end impact of the concrete storage cask on the storage pad, the canister produces a force on the stand/inlet system located near the bottom of the storage cask. It is expected that the steel plate above the air inlet channels will yield. Calculating the flow stress, σ_f, for the material:

$$\sigma_f = \frac{\sigma_y + \sigma_u}{2}$$

$$= 45{,}400 \text{ psi,}$$

where,

σ_u = 58,000 psi, A36 carbon steel ultimate strength at 200 °F,

σ_y = 32,800 psi, A36 carbon steel yield strength at 200 °F.

The flow stress results in the deformation of the steel plate above the air inlet vents, and produces a force through the section. The total force is

$$F = 8(\sigma_f bt),$$

$$= 1.092 \times 10^6 \text{ pounds}$$

where,

b = 1.5 in., the width of the load bearing area,

t = 2.0 in, the thickness of the stand.

This force results in an acceleration to the loaded canister (weighing w_c = 54,730 pounds) of:

$$g = \frac{F}{w_c} = 19.95 g's.$$

The area of contact between the canister bottom and stand is twice as large as the cross-sectional area of the region that yields; therefore, the stand's platform will not be perforated. The expected crush distance, δ, of the crush area is computed by an energy balance equation. The crush distance is:

$$\delta = \frac{hw_c}{P_oA - w_c} = \frac{(6)(54{,}730 \times 1.1)}{(45{,}400)(8)(2)(1.5) - (54{,}730 \times 1.1)} = 0.35 in.$$

which will reduce the height of the air inlet region by only 0.35 inches.

11.2.11.3 Radiological Consequences

There are no radiological consequences for this accident.

11.2.11.4 NAC-MPC Performance

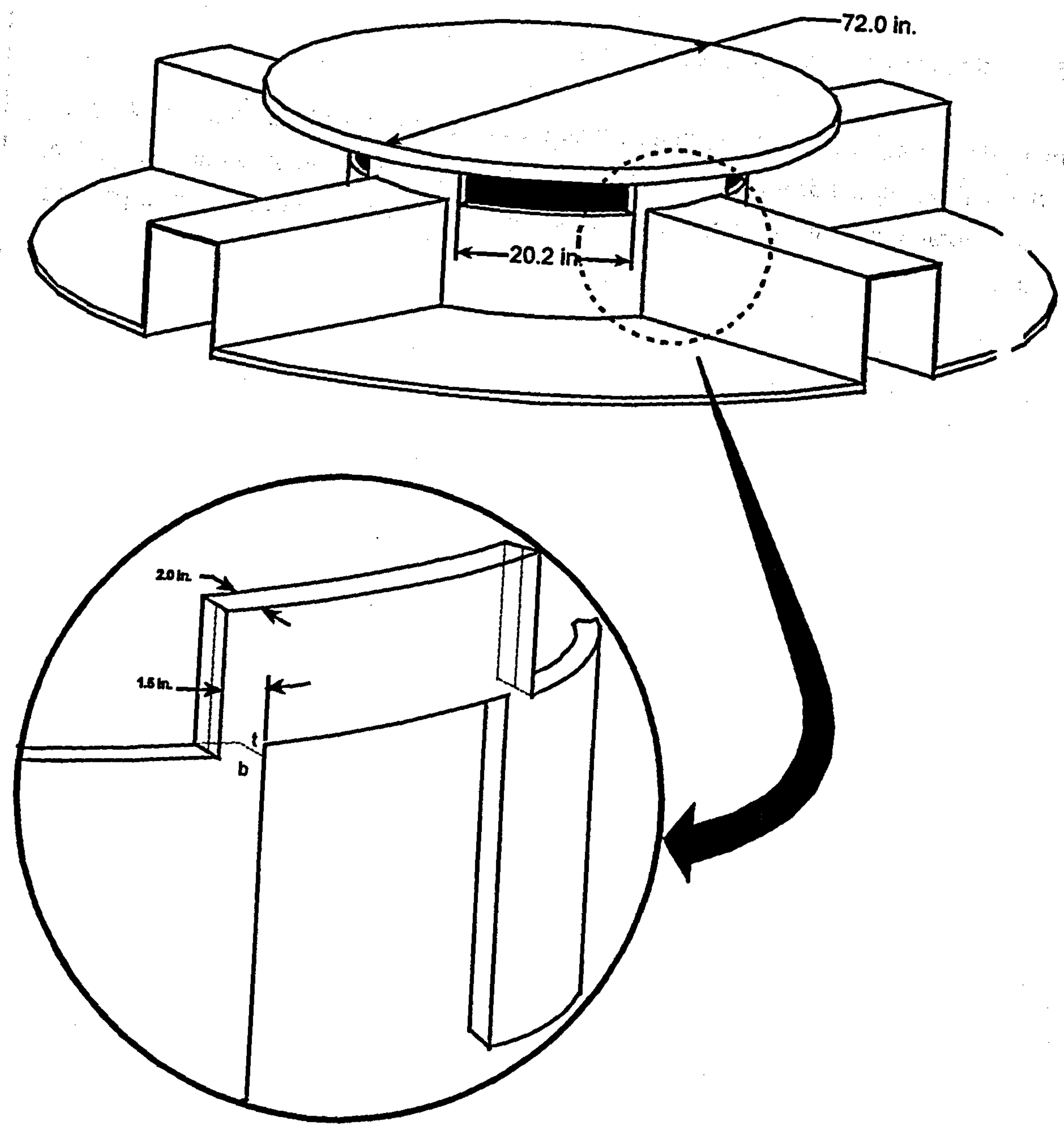
Evaluations of the NAC-MPC concrete storage cask for a 6-inch bottom end drop accident results in a maximum deceleration of 169.6 g's for the storage cask which does not reduce the shielding effectiveness of the cask. The base support, which contains the air inlets, is crushed approximately 0.35 inch. The effect of the reduction of the inlet area by the 6-inch drop is to reduce cooling air flow. The consequences of the loss of one-half of the air inlets is evaluated in Section 11.1.1, which bounds this condition.

The maximum deceleration of 19.95 g for the canister and its internals as a result of the 6-inch storage cask drop, is bounded by the 56.1 g loading evaluated in Section 11.3, where the adequacy of the canister is demonstrated. The NAC-MPC storage cask system is structurally adequate to withstand a 6-inch drop accident.

11.2.11.5 Recovery and/or Corrective Actions

Even though the storage cask system remains functional, and no immediate recovery steps are required, the canister should be moved to a new concrete storage cask as soon as one is available. The damaged storage cask should be inspected for stability, and repaired as required prior to continued use.

Figure 11.2.11-1 Storage Cask Base Plate



11.2.12 Tip Over of the Vertical Concrete Cask

This is a hypothetical accident condition that presents a bounding case for evaluation. There are no design basis accidents that result in the tip over of the vertical concrete cask (concrete cask).

11.2.12.1 Cause of Tip Over

A tip over event is possible in an earthquake that exceeds the design basis described in Section 11.2.2. There are no other events that are expected to result in a tip over of the concrete cask.

A tip over of the concrete storage cask would be observed during a survey of the site following the earthquake or other catastrophic event. The tipped over orientation of the concrete cask would be obvious by inspection.

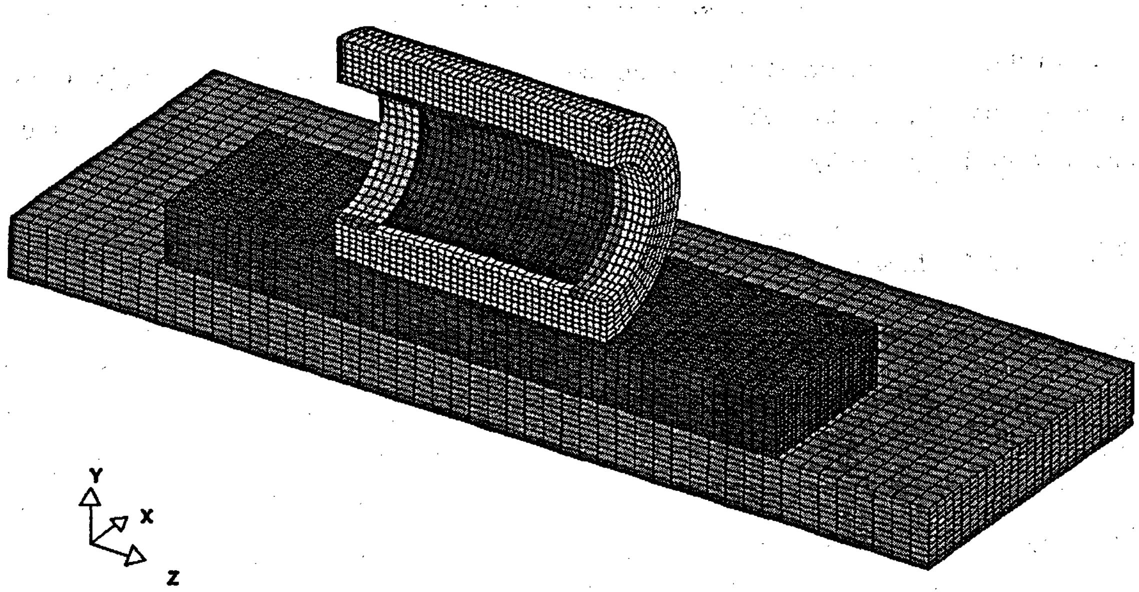
11.2.12.2 Analysis of the Tip Over Event

For a tip over event to occur, the center of gravity of the concrete cask and loaded canister must be displaced beyond the outer radius of the concrete cask, i.e., the point of rotation. When the center of gravity passes beyond the point of rotation, the potential energy of the concrete cask and canister will be converted to kinetic energy as the concrete cask and canister rotate toward a horizontal orientation on the ISFSI pad. The subsequent motion of the cask is governed by the structural characteristics of the cask, ISFSI pad and underlying soil.

The objective of the evaluation of the response of the concrete cask during the tip over event is to determine the maximum acceleration to be used in the structural evaluation of the loaded canister and basket (Section 11.2.12.3) and the canister overpack (Section 11.4.1.1.3). The methodology to determine the concrete cask response follows the methodology contained in NUREG/CR-6608 ("Summary and Evaluation of Low-Velocity Impact Tests of Solid Steel Billet Onto Concrete Pads"). The LS-DYNA program is used in this evaluation.

11.2.12.2.1 Model Description

As shown below, the finite element model includes a half section of the concrete cask, the concrete ISFSI pad and soil subgrade. The concrete pad in the model corresponds to a pad 30-feet by 30-feet square and 3-feet thick, supporting one concrete cask in the middle of the pad. The soil under the concrete pad is considered to be 45-feet by 45-feet square, and 3-feet thick. As shown below, only one-half of the concrete cask, pad and soil configuration is modeled due to symmetry.



11.2.12.2.2 Material Properties

The concrete is represented as a homogeneous isotropic material. The concrete cask (outer shell) and the pad are modeled as material Type Number 16 in LS-DYNA. The required input data is:

Compressive strength	= 4,000 psi
Density	= 140 pcf
Poisson's Ratio	= 0.22
Modulus of Elasticity	= 3.6E6 psi
Bulk Modulus	= 2.1E6 psi

The material properties used in the model for the soil below the ISFSI pad are:

Density	= 136 pcf
Poisson's Ratio	= 0.4

Modulus of Elasticity = $390.0\sqrt{A_{pad}}$ psi (Barkan)

where,

A_{pad} is the area of the concrete pad in square inches.

For the 30 x 30 square foot pad, the modulus of elasticity of the soil is calculated as 140,400 psi.

The concrete cask steel liner has the properties:

Density	= 0.284 lb/in^3
Poisson's ratio	= 0.31
Modulus of elasticity	= 29E6 psi

To account for the weight of the shield plug, the loaded canister, and the concrete cask pedestal, effective elements are used for the first row of elements for the steel liner in the model. These densities represent the regions (7.2° in the circumferential direction) of the steel liner subjected to the weight of the shield plug, the loaded canister and the pedestal, during the side impact (tip over) condition. The contact angle (7.2°) is determined based on the canister/basket analysis for the tip over condition (Section 11.2.12.3). Based on the status of the gap elements at the outer surface of the canister shell (representing the interface between the canister shell and the concrete cask steel liner) in the finite element model used in Section 11.2.12.3, the contact angle between the canister shell and the concrete cask liner is between 4.5° and 9° for the half-symmetry model.

11.2.12.2.3 <u>Boundary Conditions and Initial Conditions</u>

A friction coefficient of 0.25 is used at the interface between the steel liner and the concrete shell, between the concrete cask and the pad, and between the pad and the soil. For all the embedded faces (3 side surfaces and the bottom surface) of the soil in the model, the displacements in the direction normal to the surface are restrained. The symmetry boundary conditions are applied for all nodes at the plane of symmetry.

The initial condition corresponds to the concrete cask in a horizontal position with an initial vertical velocity into the concrete pad. The pad and soil are initially at rest.

The initial velocity is simulated by applying an angular velocity (ω) of 1.565 rad/sec to the entire cask. The angular velocity value is computed by considering energy conservation at the cask "center of gravity over corner" tip condition versus the side impact condition.

From energy conservation:

$$mgh = \frac{I\omega^2}{2}$$

where,

mg = total weight of the loaded concrete cask = 206,094 lbs

h = height change of the concrete cask center of gravity (L_{CG}) = $\sqrt{R^2 + \left(\frac{L_{CG}}{2}\right)^2} - R$

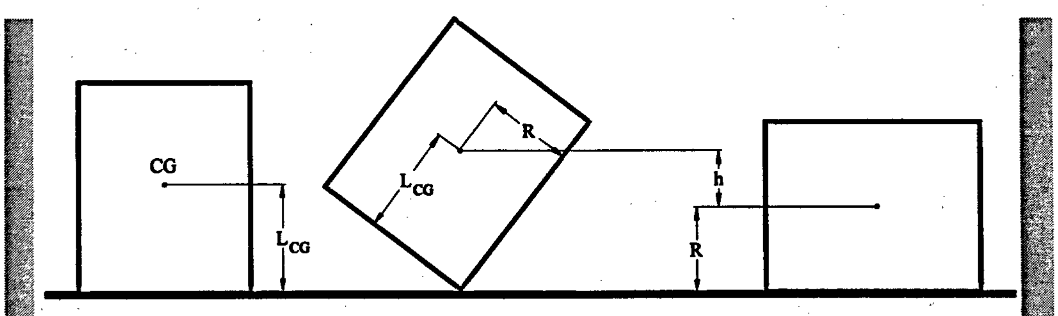
= 40.97 inches

where,

L_{CG} = location of the center of gravity above the pad for the concrete cask = 83.2 inches

R = radius of the concrete cask = 64 inches

I = total mass moment of inertia of the concrete cask about the pivot point
= 6,899,360 lb-sec²-inch



Concrete Cask Tip-Over Height Change

The mass moment of inertia for the concrete shell and the steel liner is calculated using the formula for a hollow right circular cylinder (Blevins).

$$I = \frac{m}{12}(3R_1^2 + 3R_2^2 + 4L^2) + md^2$$

where,

m	= the mass
R_1 and R_2	= the outer and inner radius of the cylinder
L	= height of the cylinder
d	= distance between two pivot axes

For the mass of the shield plug, loaded canister and the pedestal, the formula for the moment of inertia for a solid cylinder is used:

$$I = \frac{m}{12}(3R^2 + 4L^2) + md^2$$

where,

m = mass of the cylinder
R = radius of the cylinder
L = height of the cylinder
d = distance between the two pivot axes

The angular velocity is given by $\omega = \sqrt{\frac{2mgh}{I}} = 1.565$ radians/sec

11.2.12.2.4 Filter Frequency

The accelerations are evaluated at the inner surface of the cask liner, which physically corresponds to the interface of the liner and the loaded canister nearest the plane of impact. Following the methodology contained in NUREG/CR-6608, the Butterworth filter is applied to the nodal accelerations. The filter frequency is based on the fundamental mode of the cask.

The fundamental natural frequency of a beam in transverse vibration due to flexure only is given by Blevins as:

$$f = \frac{\lambda^2}{2\pi}\sqrt{\frac{EI}{\rho AL^4}}$$

where:

$\lambda = 3.92660231$ for a pin-free beam.

The frequencies of the concrete (f_c) and the steel liner (f_s) are computed as:

Area of concrete cask $= \pi\,\{(64)^2 - (43)^2\} = 2{,}247\pi$ in^2

Moment of inertia of concrete cask $= \frac{\pi}{4}\{(64)^4 - (43)^4\} = 3{,}339{,}603.75\pi$ in^4

$f_c = 31.4\ \lambda^2 = 484.1$ Hz

Area of steel liner $= \pi\,\{(43)^2 - (39.5)^2\} = 288.75\pi$ in^2

Moment of inertia of steel liner $= \frac{\pi}{4}\{(43)^4 - (39.5)^4\} = 246{,}105.23\pi$ in^4

$f_s = 36.1\ \lambda^2 = 556.6$ Hz

Since the concrete cask is short compared to its diameter, the contribution of the flexibility due to shear is also incorporated. This is accomplished by using Dunkerley's formula (Blevins). The system frequency is:

$$\frac{1}{f^2} = \frac{1}{f_c^2} + \frac{1}{f_s^2}$$

Thus, the system frequency $f = 365.3$ Hz. A cut-off frequency of 375 Hz is conservatively applied to filter the analysis results and measure the peak accelerations.

11.2.12.2.5 Results of the Transient Analysis

The accelerations at key locations of the concrete cask liner, which are required in the evaluation of the loaded canister/basket model (Section 11.2.12.3) or the canister overpack model (Section 11.4.1.1), are:

Acceleration at Specific Locations at the Concrete Cask Liner

Location on Component	Position Measured from the bottom of the Concrete Cask (inches)	Acceleration (g's)
Top support disk	125.5	27.7
Top of the canister structural lid	145.6	30.4
Top of the Shield Plug	156.4	32.4

Note that these analysis results (g's) bound the acceleration for the configuration when the canister overpack is used in the storage cask. Addition of the canister overpack to the storage cask results in an increase of the total mass of the system, which is expected to reduce the acceleration. The acceleration at the top of the shield plug can also be used as the acceleration for the canister overpack lids since the weight and location (elevation inside the storage cask) of the shield plug are essentially identical to those of the overpack lids.

11.2.12.2.6 Validation of the Analysis Methodology

Tip over tests of a steel billet onto a concrete pad were conducted and reported in NUREG/CR-6608. The purpose of the test was to provide data, against which, analysis methodology could be validated. Using the geometry described in the benchmark along with the modeling methodology, these analyses were performed using the soil input data in Section 11.2.12.2.2.

Using the filter frequency reported in the benchmark, the following results are obtained.

Comparison of Accelerations of NUREG/CR-6608 Benchmark

Nodes / Gauge Location	Maximum Experiment	NAC Analysis
16115 / A1	237.5	237.1
17265 / A5	231.5	229.4

11.2.12.3 Analysis of the Canister and Basket

Structural evaluations are performed for the transportable storage canister and fuel basket support disks for tip-over accident conditions. An ANSYS finite element model is used to evaluate this side impact loading condition. Based on the comprehensive evaluation of the basket during transport conditions, the basket drop angle is evaluated at 45° for the storage tip over accident. Thermal conditions are bounded by evaluating the canister and basket using material properties at 75°F and applying the stress allowables for the maximum temperatures at the extreme heat thermal accident condition.

Comparison of maximum stress results to the allowable stress intensities shows that the canister and support disks are structurally adequate for the concrete cask tip over condition and satisfies the stress criteria in accordance with the ASME Code, Section III, Division I, Subsection NB and NG, respectively.

11.2.12.3.1 Canister and Basket Model

A finite element analysis, using the ANSYS program, is performed to evaluate the canister and support disks for the tip over accident condition. Output is in the form of linearized stresses taken across component sections. Additionally, a buckling evaluation is performed on the support disk in accordance with NUREG/CR-6322.

A symmetric one-half (180°) model is used to represent the canister and basket assembly. As shown in Figure 11.2.12.3-1, the model consists of the upper portion of the canister, the top weldment and the five support disks. The canister is constructed using ANSYS solid (SOLID45) elements. ANSYS SHELL63 elements are used to model the top weldment and the support disks. The model for the canister assembly includes the shield and structural lids. Figure 11.2.12.3-2 shows the basket top weldment and five support disks. A detailed view of the basket support disk, showing applied loads, is shown in Figure 11.2.12.3-3. For the evaluation of the basket support disk, a basket angle of 45° is considered. This orientation is the most critical during side impact conditions. The weight of the fuel assembly, aluminum heat transfer disks, rods and spacers, and fuel tube (factored by appropriate g-load) are conservatively represented as concentrated forces at mid-span of the ligaments of the support disks.

The canister and basket model uses ANSYS CONTAC52 and COMBIN40 elements to simulate contact between adjacent components. Interaction between the basket and canister is modeled using three-dimensional gap elements (CONTAC52) along the periphery of the support disks. Contact between the canister and concrete cask liner is also modeled using CONTAC52 elements. Contact between the canister's structural lid and shield lid is modeled using COMBIN40 combination elements in the axial (UY) degree of freedom. The backing ring is modeled using a ring of COMBIN40 spring gap elements connecting the shield lid and the canister in the axial direction at the lid lower outside radius. In addition, CONTAC52 elements are used to model interaction between the structural lid and canister shell, and the shield lid and canister shell, just below the respective lid weld joints. The size of the CONTAC52 gaps is determined from the nominal dimensions of contacting components. The COMBIN40 elements between the structural and shield lids are assigned a gap size of 0.08 inches, based on the flatness tolerances of the structural and shield lids. A gap of 1E-8 in. is used between the backing ring and shield lid. Note that the gap sizes in the axial direction do not have a significant effect on the side impact analysis results. All gap-spring elements are assigned a stiffness of 1E6 lb./in.

Symmetry boundary conditions are applied at the plane of symmetry of the model, as well as at the cut boundary of the model (canister shell near the 5^{th} support disk). All nodes on the concrete cask side gap elements at the outer surface of the canister shell are fixed in all degrees of freedom (UX, UY, and UZ). In addition, the axial (UY) and in-plane rotational degrees of freedom (ROTX and ROTZ) of the basket nodes are fixed.

Loading of the model includes an internal pressure of 11.5 psig (normal condition of storage) applied to the canister, concentrated loads are applied to all slots (except the central slot where there is no fuel assembly) and the inertial loads.

For the inertial loads, a maximum acceleration of 45g is conservatively applied to the entire model. The maximum acceleration of the steel liner at the locations of the top support disk and the top of the canister lid during the tip over event is determined to be 27.7g and 30.4g, respectively. The main pulse of deceleration lasts for 10 milliseconds. To determine the effect of the rapid application of the inertia loading for the top support disk, a dynamic load factor (DLF) is computed using the mode shapes of a loaded support disk. The mode shapes are extracted using ANSYS for the first four modes. Using the acceleration time history developed from Section 11.2.12.2, the DLFs for each modal frequency are computed using a single degree of freedom model. The maximum DLF and corresponding frequencies are:

Mode Number	Frequency (Hz)	DLF
1	44	1.44
2	169	1.35
3	234	1.05
4	273	1.07

Applying the maximum DLF to the 27.7 g results in a peak acceleration of 40.0 g. The canister lid region is significantly stiffer than the basket disk due to its monolithic structure. Applying the DLF of 1.07 to the maximum acceleration time history value of 30.4 g results in a maximum of 32.5 g. Therefore, applying 45 g to the entire canister/basket model is conservative.

Based on the results presented in the concrete cask tip-over evaluation, the acceleration of the top support disk (disk 1 located at 125.5 in. from the base of the cask) to the 5th support disk (disk 5 located at 107.9 in. from the base of the cask) decreases 16%. When a uniform acceleration is applied to the model, stresses increase 14% from the top support disk (disk 1) to the 5th support disk. Since the decrease in acceleration is greater than the increase in stresses, only the top portion of the model need be evaluated. Therefore, to bound the support disk stresses and reduce the computer run-time, only the top 5 support disks (1 through 5) and the top weldment are included in the model.

A uniform temperature of 75°F is applied to the model to determine material properties during solution. During postprocessing, temperatures of 575°F and 372°F are conservatively used for the support disks and the canister, respectively, to determine the allowable stresses. These temperatures are the maximum calculated temperatures for the accident (extreme heat) thermal condition (ambient temperature = 125°F).

11.2.12.3.2 Analysis Results for the Canister

The stress results of the canister for the tip over accident condition are summarized in Tables 11.2.12.3-1 and 11.2.12.3-2 for primary membrane and primary membrane plus bending stresses, respectively. The sectional stresses at 14 axial locations are obtained for each angular division of the model (a total of 41 angular locations for each axial location). The locations for the stress sections are shown in Figure 11.2.12.3-4.

The stress evaluation for the canister is performed in accordance with the ASME Code, Section III, Subsection NB, by comparing the linearized stresses of cross sections of the structure against the allowable stresses. Allowable stresses are conservatively taken at a temperature of 372°F (maximum canister temperature is 319°F for normal condition of storage). The allowable stresses for accident conditions are taken from Subsection NB as shown below. The S_m and S_u are 16.05 ksi and 59.17 ksi, respectively for Type 304L stainless steel (canister shell and structural lid). The S_m and S_u are 19.06 ksi and 64.85 ksi, respectively for Type 304 stainless steel (shield lid).

	Accident (Level D) Allowable Stress
P_m	Lesser of 0.7 S_u or 2.4 S_m
P_m+P_b	Lesser of 1.0 S_u or 3.6 S_m

During the tip over accident, the canister shell at the structural and shield lids is subjected to the inertial load of the lids, which results in highly localized bearing stresses (Sections 8 through 12 at angular locations of 0 and 4.5 degrees). This stress is predominant because the weights of the structural and shielding lids are transferred to the canister shell through the thickness of the weld (5/8 inch weld for structural lid and 1 inch weld for shield lid). According to ASME Section III, Appendix F, bearing stresses need not be evaluated for Level D service (accident) conditions. Therefore, the P_m stresses are not presented for the region local to the impact (angular locations of 0 and 4.5 degree) for Sections 8, 9, and 10 in Table 11.2.12.3-1. Stresses are conservatively presented for all locations (including bearing region) for Sections 11 and 12 (conservative).

The inertial load of the shield lid also results in localized bending stresses at the canister shell (at the shield lid weld, i.e. Section 8). This stress state is identified as the case of a cylindrical shell at the junction with a head, as shown in Table NB-3217-1 of the ASME Code, Section III, Subsection NB. The localized bending stress at the structural discontinuity is classified as secondary (Q) stress. In accordance with ASME Section III, Appendix F, secondary stresses are not considered for the stress evaluation for Level D (accident) conditions. Therefore, the P_m+P_b stresses are not presented for the region local to the impact for Section 8 (angular locations of 0 and 4.5 degree) in Table 11.2.12.3-2.

The stress evaluation results for tip-over accident conditions show that the minimum margin of safety in the canister is +0.25 for P_m (Sections 12) and +0.10 for P_m+P_b (Section 10).

11.2.12.3.3 Analysis Results for the Support Disk

To evaluate the most critical regions of the support disk, a series of cross sections are considered. To aid in the identification of these sections, Figure 11.2.12.3-5 shows the locations on a support disk. Table 11.2.12.3-3 lists the cross sections versus Point 1 and Point 2, which spans the cross section of the ligament in the plane of the support disk.

The stress evaluation for the support disk is performed according to ASME, Section III, Subsection NG. According to this subsection, linearized stresses of cross sections of the structure are to be compared against the allowable stresses. The allowable stresses for tip over accident conditions are taken from Subsection NG as shown below at the maximum support disk temperature of 575°F (accident-extreme heat). The S_m and S_u are 42.3 ksi and 127.1 ksi, respectively, for 17-4 PH stainless steel.

	Accident (Level D) Allowable Stresses
P_m	Lesser of 0.7 S_u or 2.4 S_m
P_m+P_b	Lesser of 1.0 S_u or 3.6 S_m

The stress evaluation results for the support disks for tip-over impact condition are presented in Tables 11.2.12.3-4 through 11.2.12.3-13. The tables list the 40 highest P_m and P_m+P_b stress intensities for Disks 1 through 5. The minimum margin of safety is +0.21, which occurs in Disk 5 (See Figure 11.2.12.3-4 for identification of support disks). The highest P_m and P_m+P_b stresses occur in Disk 5, with the minimum margin of safety of 1.51 and 0.21, respectively. Locations of the 10 highest P_m and P_m+P_b linearized stresses for Disk 5 are given in Figure 11.2.12.3-6 and 11.2.12.3-7.

11.2.12.3.4 Support Disk Buckling Evaluation

The fuel basket support disks are subjected to compressive and/or inertial loads during impact conditions. For the tip over accident, the support disks experience in-plane loads. The in-plane loads apply compressive forces and in-plane bending moments on the support disk. Buckling of the support disk is evaluated in accordance with the methods and acceptance criteria of NUREG/CR-6322. Because the ASME Code identifies 17-4PH disk material as a ferritic steel, the formulas for non-austenitic steel are used.

The buckling evaluation of the support disk web is based on the Interaction Equations 31 and 32 in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members subjected to stresses beyond the yield limit of the material, i.e., for members deformed elastically as a result of axial load or bending moment. Other equations applicable to the calculations are noted as they are applied. The maximum forces and moments for the tip over accident are based on the finite element analysis stress results.

Symbols and Units

P = applied axial compressive loads, kips
M = applied bending moment, kips-inch
P_a = allowable axial compressive load, kips
P_{cr} = critical axial compression load, kips
P_e = Euler buckling loads, kips
P_y = average yield load, equal to profile area times specified minimum yield stress, kips (for normal operating condition)
C_c = column slenderness ratio separating elastic and inelastic buckling
C_m = coefficient applied to bending term in interaction equation
M_m = critical moment that can be resisted by a plastically designed member in the absence of axial load, kip-in.
M_p = plastic moment, kip-in.
F_a = axial compressive stress permitted in the absence of bending moment, ksi
F_e = Euler stress for a prismatic member divided by factor of safety, ksi
k = ratio of effective column length to actual unsupported length
l = unsupported length of member, in.
r = radius of gyration, in.
S_y = yield stress, ksi
A = cross sectional area of member, in^2
Z_x = plastic section modulus, in^3
λ = allowable reduction factor, dimensionless.

From NUREG/CR-6322, the following equations are used to evaluate the support disk:

$$\frac{P}{P_{cr}} + \frac{C_m M}{M_m\left[1 - \frac{P}{P_e}\right]} \leq 1.0$$ (Equation 31)

$$\frac{P}{P_y} + \frac{M}{1.18\,M_p} \leq 1.0$$ (Equation 32)

where,

$$P_{cr} = 1.7 \times A \times F_a$$

$$F_a = \frac{P_a}{A} \quad \text{for} \quad P_a = P_y\left[\frac{1 - \frac{\lambda^2}{4}}{1.11 + 0.5\lambda + 0.17\lambda^2 - 0.28\lambda^3}\right]$$

and $\lambda = \frac{1}{\pi}\left(\frac{kl}{r}\right)\sqrt{\frac{S_y}{E}}$ (accident conditions)

$$Pe = 1.92 \times A \times Fe$$

$$F_e = \frac{\pi^2 \cdot E}{1.3\left(\frac{k \cdot l}{r}\right)^2}$$ (Level D–Accident)

$$P_y = S_y \times A$$

$C_m = 0.85$ for members with joint translation (sideways).

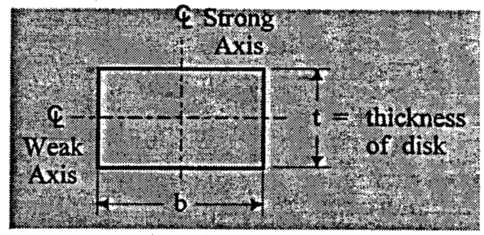
$$M_p = S_y \times Z_x$$

$$M_m = M_p \cdot \left(1.07 - \frac{\left(\frac{1}{r}\right) \cdot \sqrt{S_y}}{3160}\right) \leq M_p$$

Buckling evaluation is performed in all sections in the disk ligaments defined in Figure 11.2.12.3-5. Using the cross-sectional stresses calculated at each section located in the web for each loading condition the maximum corresponding compressive forces (P) and bending moment (M) are determined as,

$P = \sigma_m A,$

$M = \sigma_b S,$



where, σ_m is the membrane stress, σ_b is the bending stress, A is the area ($b \times t$), and S is the section modulus ($tb^2/6$).

To determine the margin of safety:

$$P_1 = P/P_{cr} \qquad M_1 = \frac{C_m M}{(1 - P/P_e) M_m} \qquad (P_1 + M_1 \leq 1)$$

and

$$P_2 = P/P_y \qquad M_2 = \frac{M}{1.18\, M_p} \qquad (P_1 + M_1 \leq 1)$$

The margins of safety are:

$$MS1 = \frac{1}{P_1 + M_1} - 1$$

and

$$MS2 = \frac{1}{P_2 + M_2} - 1$$

Buckling evaluation results are provided in Tables 11.2.12.3-14 through 11.2.12.3-18. As the tables demonstrate, the support disks meet the requirements of NUREG/CR-6322.

11.2.12.4 Radiological Consequences

There is an adverse radiological consequence in the hypothetical tipover event since the bottom end of the storage cask, and the canister, have significantly less shielding than the sides and tops of these same components. The dose rate at 1 meter is calculated to be approximately 156 rem/hour, and the dose at 5 meters is estimated to be approximately 1 rem/ hour. Consequently, following a tipover event, supplemental shielding should be used until the concrete cask can be righted. Stringent access controls must be applied to ensure that personnel do not enter the area of radiation shine from the exposed bottom of the tipped over concrete cask.

11.2.12.5 NAC-MPC Performance

Functionally the NAC-MPC does not suffer significant adverse consequences from the tip over event. The storage cask and canister maintain design basis shielding, geometry control of contents, and contents confinement performance requirements.

Damage to the edges or surface of the concrete cask may occur in the tipover, which could result in marginally higher dose rates at the bottom edge or at surface cracks in the concrete. This increased dose rate is not expected to be significant, but would be dependent on the specific damage incurred.

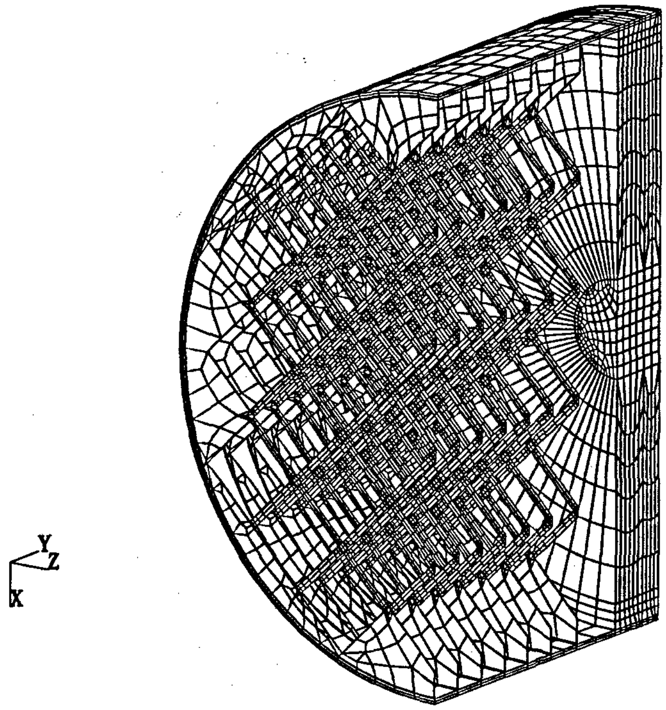
11.2.12.6 Recovery and/or Corrective Actions

The most important recovery step required following a cask tipover accident is the uprighting of the concrete cask to eliminate the high dose rate from the exposed bottom end. The uprighting operation will require a heavy lift capability and rigging expertise. The concrete cask must be returned to the vertical by rotation around a convenient bottom edge. The concrete cask should be returned to the vertical using a method and rigging that controls the rotation to vertical.

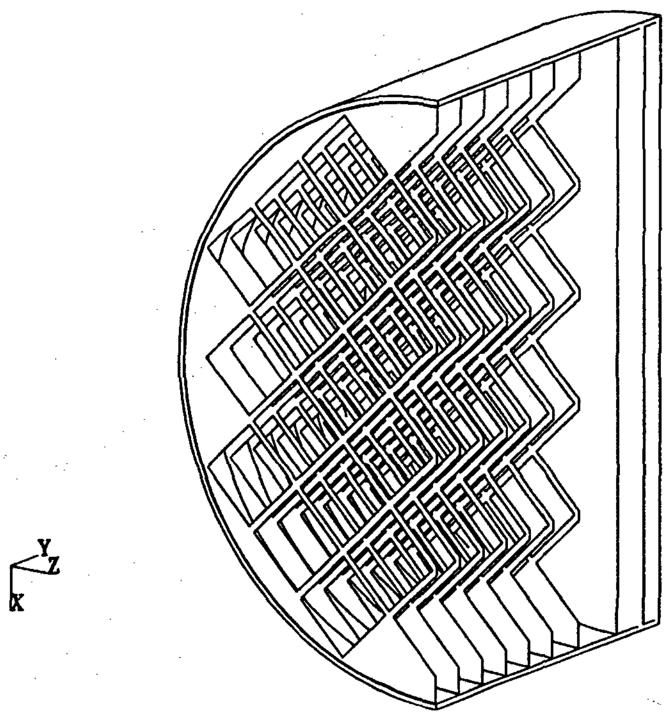
Surface and top and bottom edges of the concrete cask would be expected to exhibit cracking and possibly loss of concrete down to the layer of reinforcing bar. If only minor damage occurs, the concrete may be repairable using grout. Otherwise, it may be necessary to remove the canister and install it in a new storage cask.

The storage pad must be repaired to preclude the intrusion of water that could cause further deterioration of the pad in freeze-thaw cycles.

Figure 11.2.12.3-1 Three-Dimensional Canister and Basket Model



Model With Element Edges Displayed



Model Without Element Edges Displayed

Figure 11.2.12.3-2 Basket Assembly

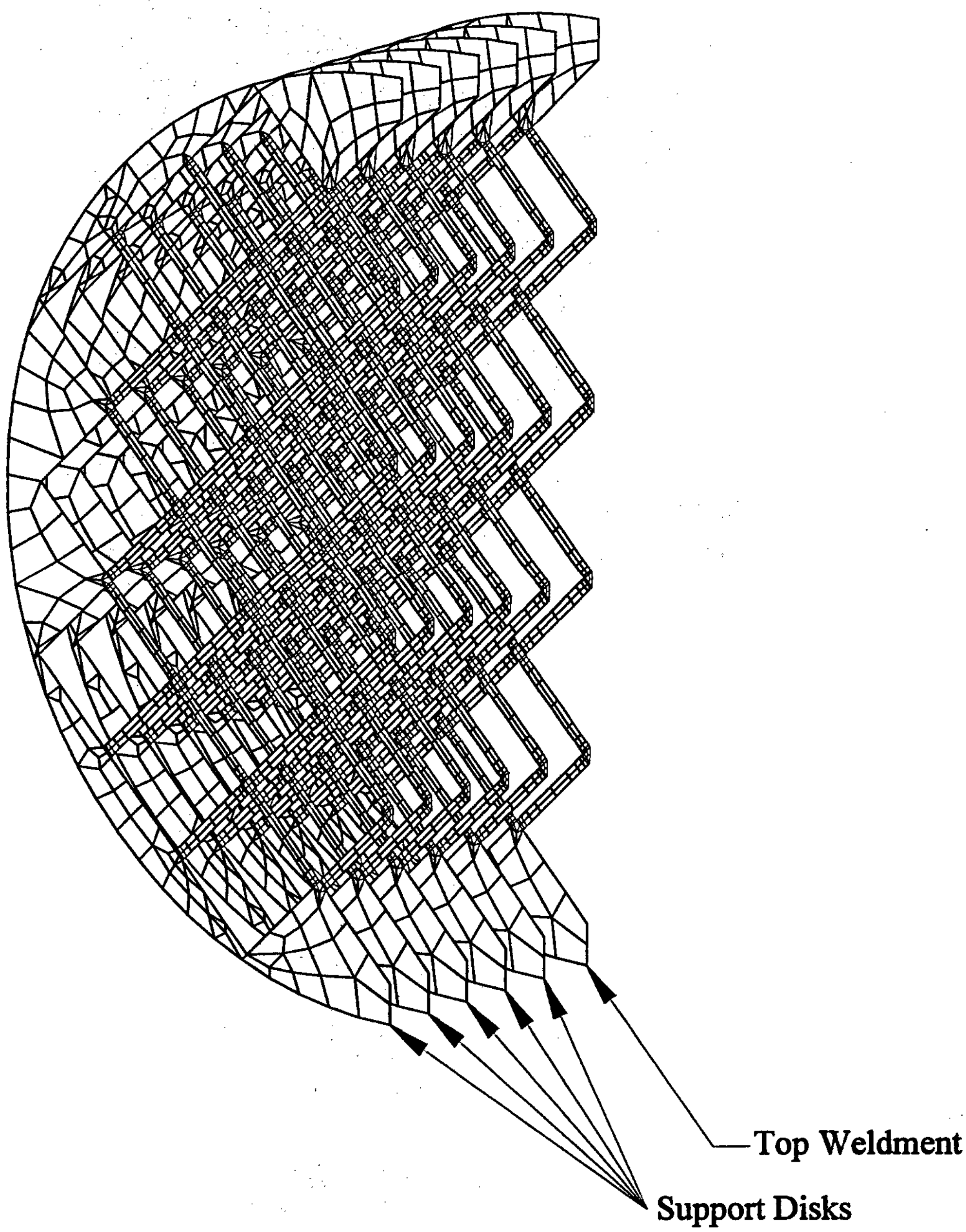


Figure 11.2.12.3-3 Support Disk Detail

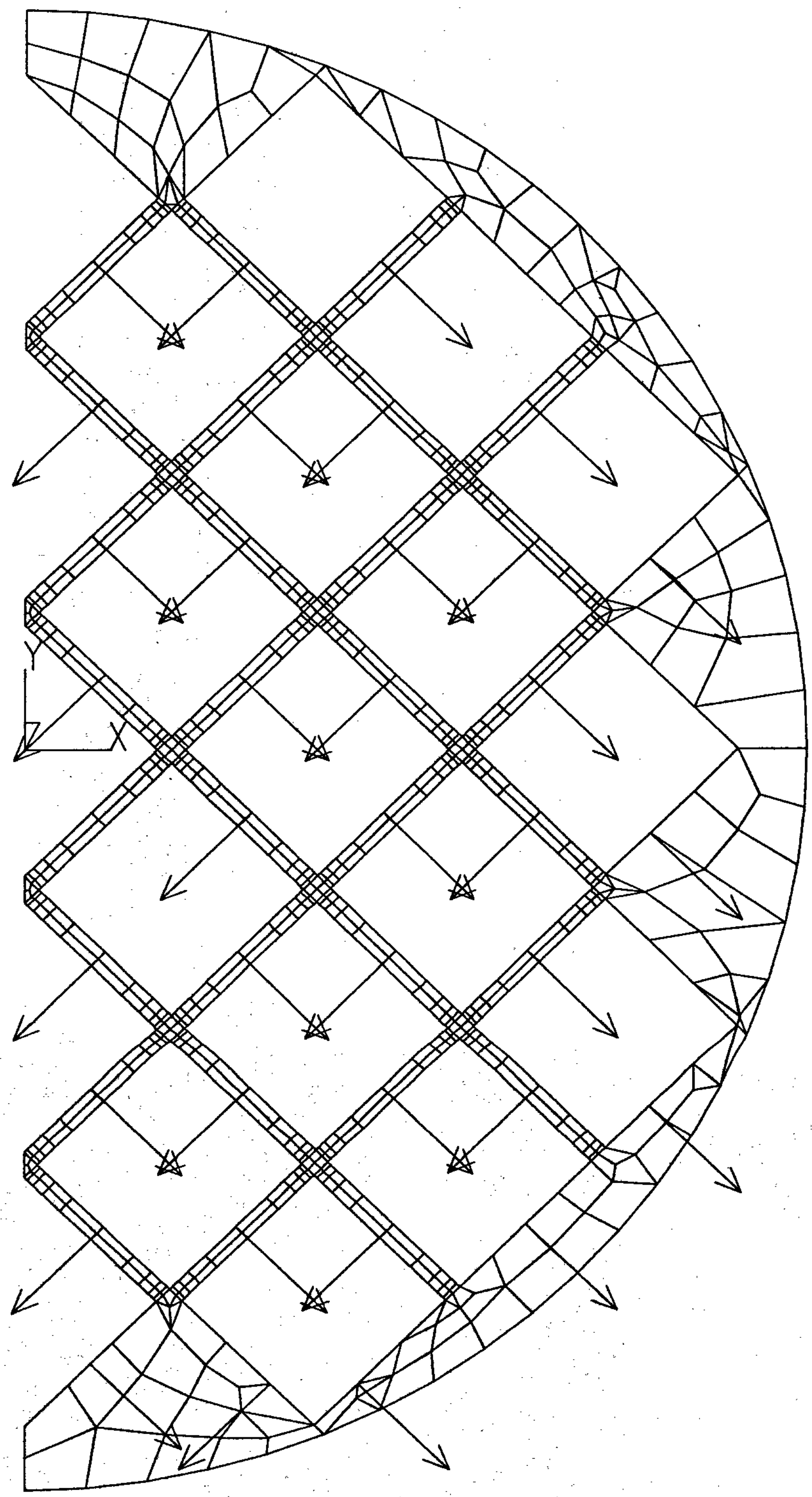


Figure 11.2.12.3-4 Canister Stress Sections Locations

Section	Node 1		Node 2	
	X	Y	X	Y
1	34.695	84.720	35.320	84.720
2	34.695	89.130	35.320	89.130
3	34.695	93.540	35.320	93.540
4	34.695	97.950	35.320	97.950
5	34.695	102.360	35.320	102.360
6	34.695	107.250	35.320	107.250
7	34.695	114.500	35.320	114.500
8	34.695	118.500	35.320	118.500
9	34.695	119.500	35.320	119.500
10	34.695	121.620	35.320	121.620
11	34.695	118.500	34.695	119.500
12	34.695	121.620	34.695	122.500
13	0.000	114.500	0.000	119.480
14	0.000	119.520	0.000	122.500

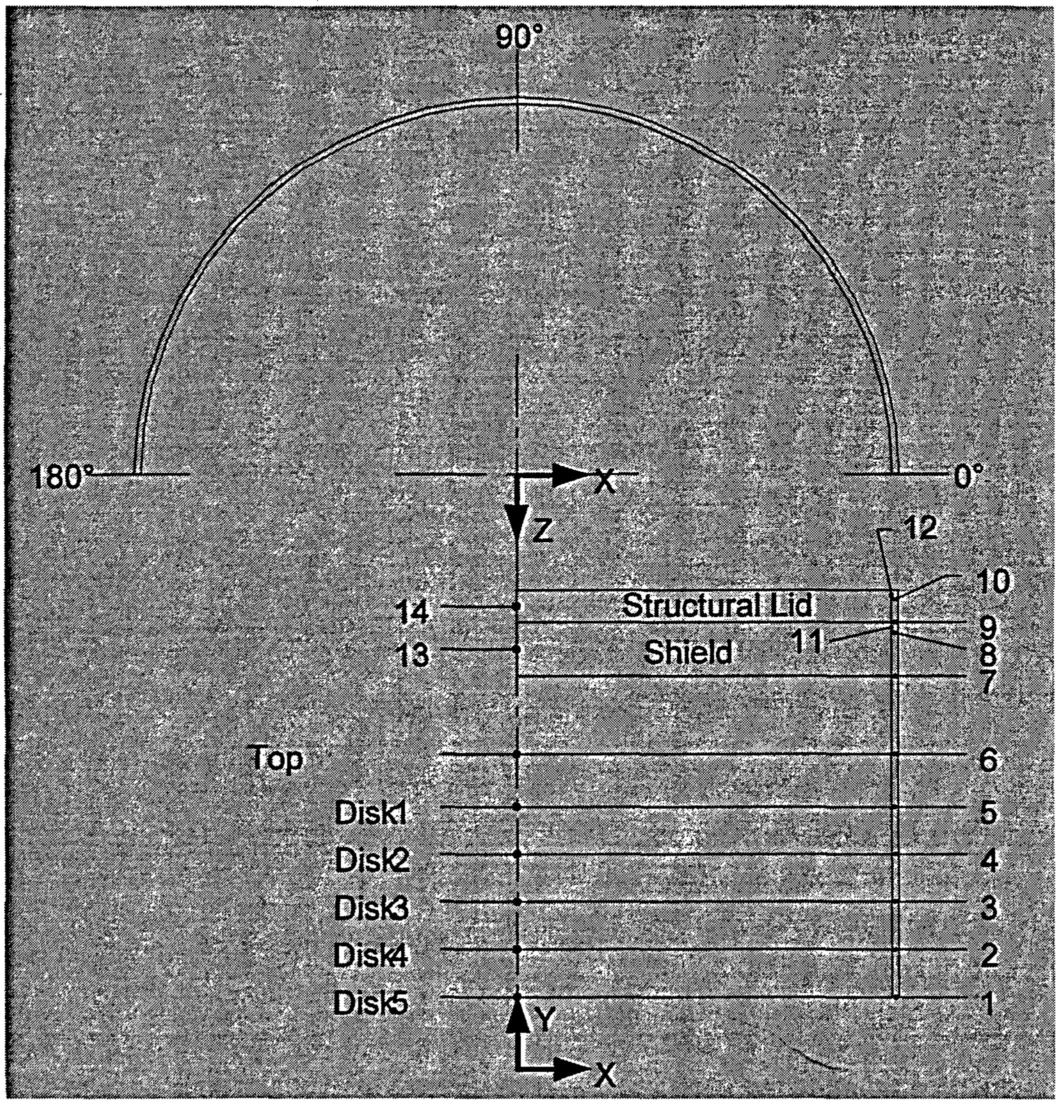


Figure 11.2.12.3-5 Location of Support Disk Sections to Obtain Linearized Stresses

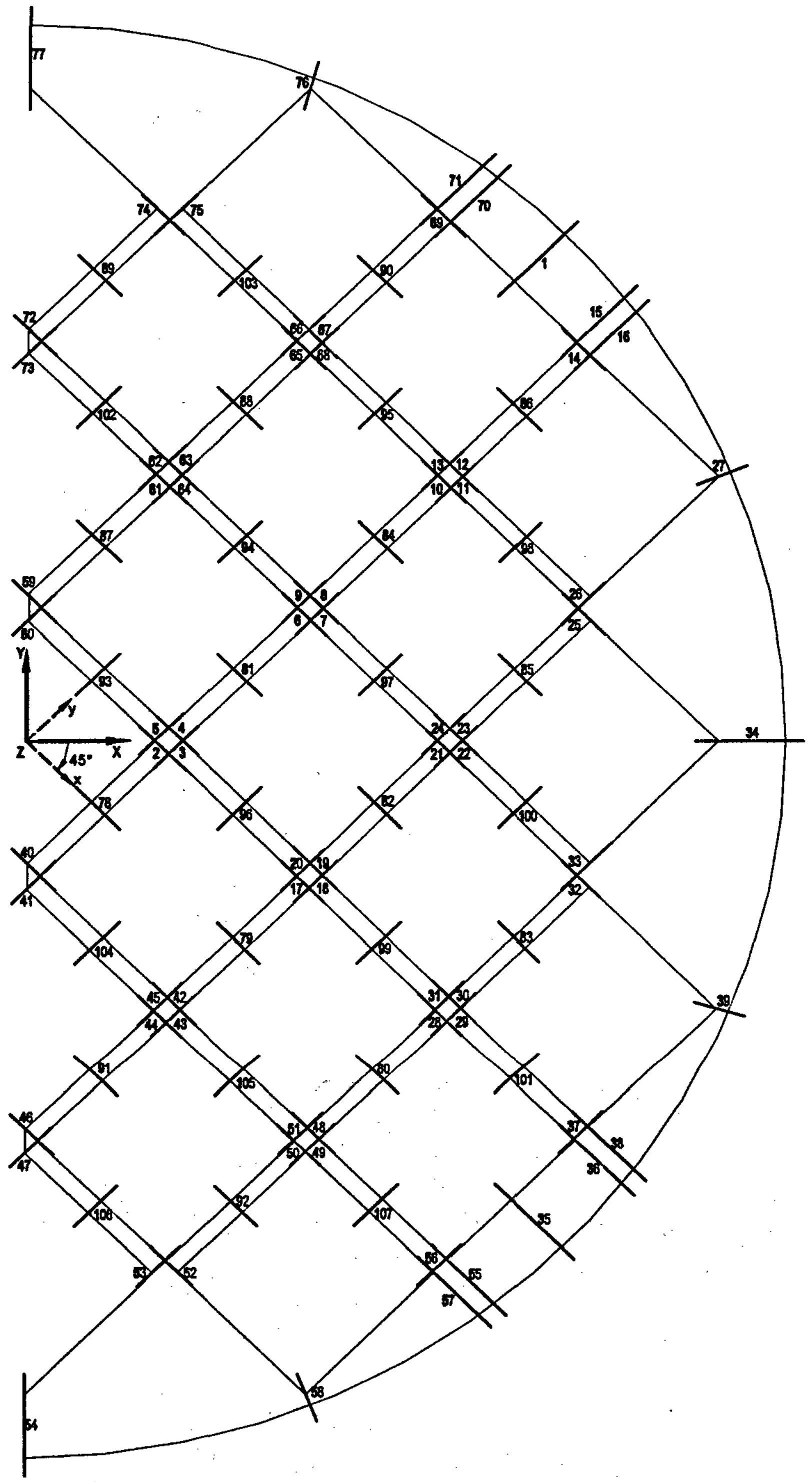


Figure 11.2.12.3-6 Locations of the 10 Highest P_m Support Disk Linearized Stress Sections

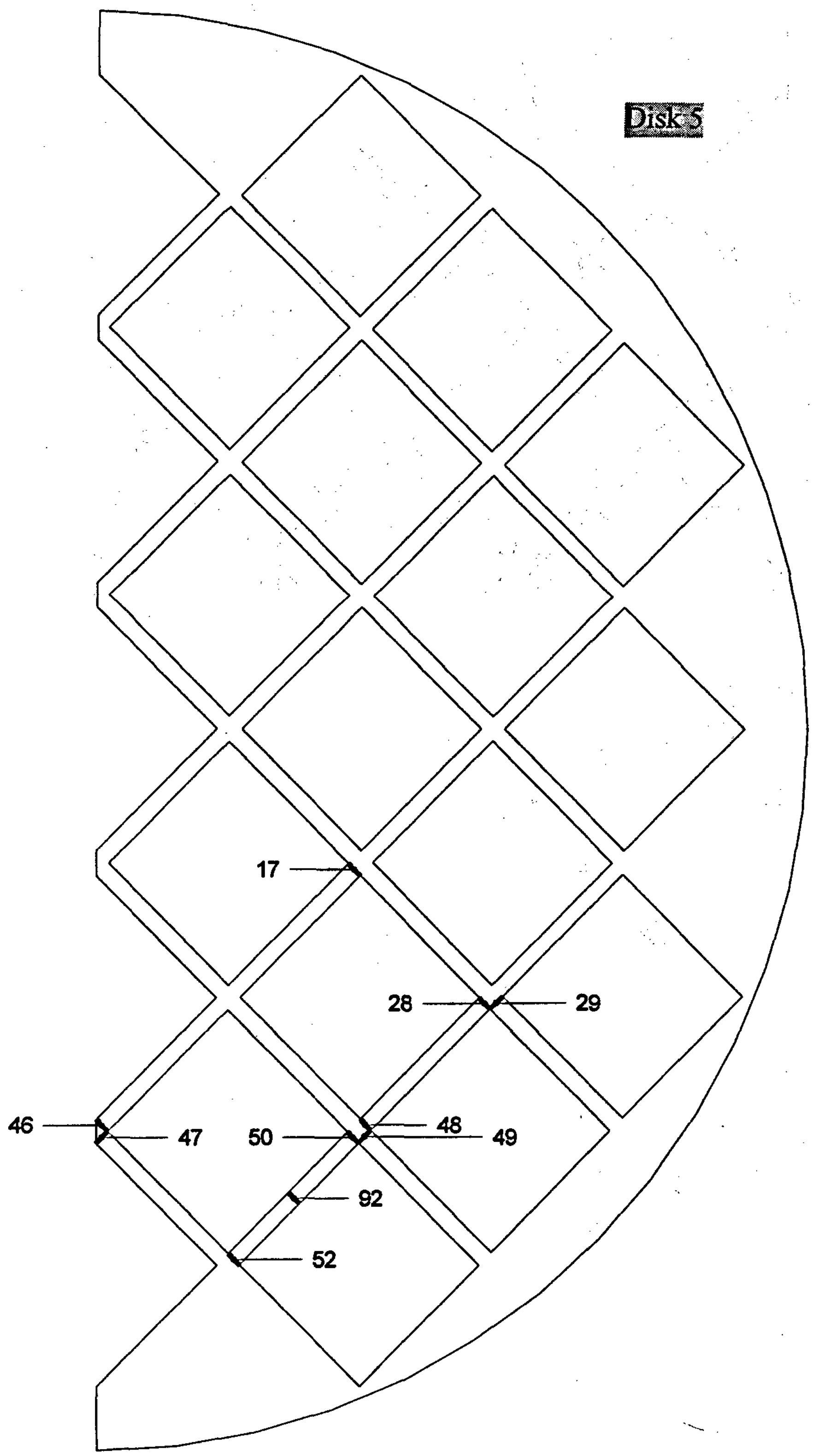


Figure 11.2.12.3-7 Locations of the 10 Highest P_m+P_b Support Disk Linearized Stress Sections

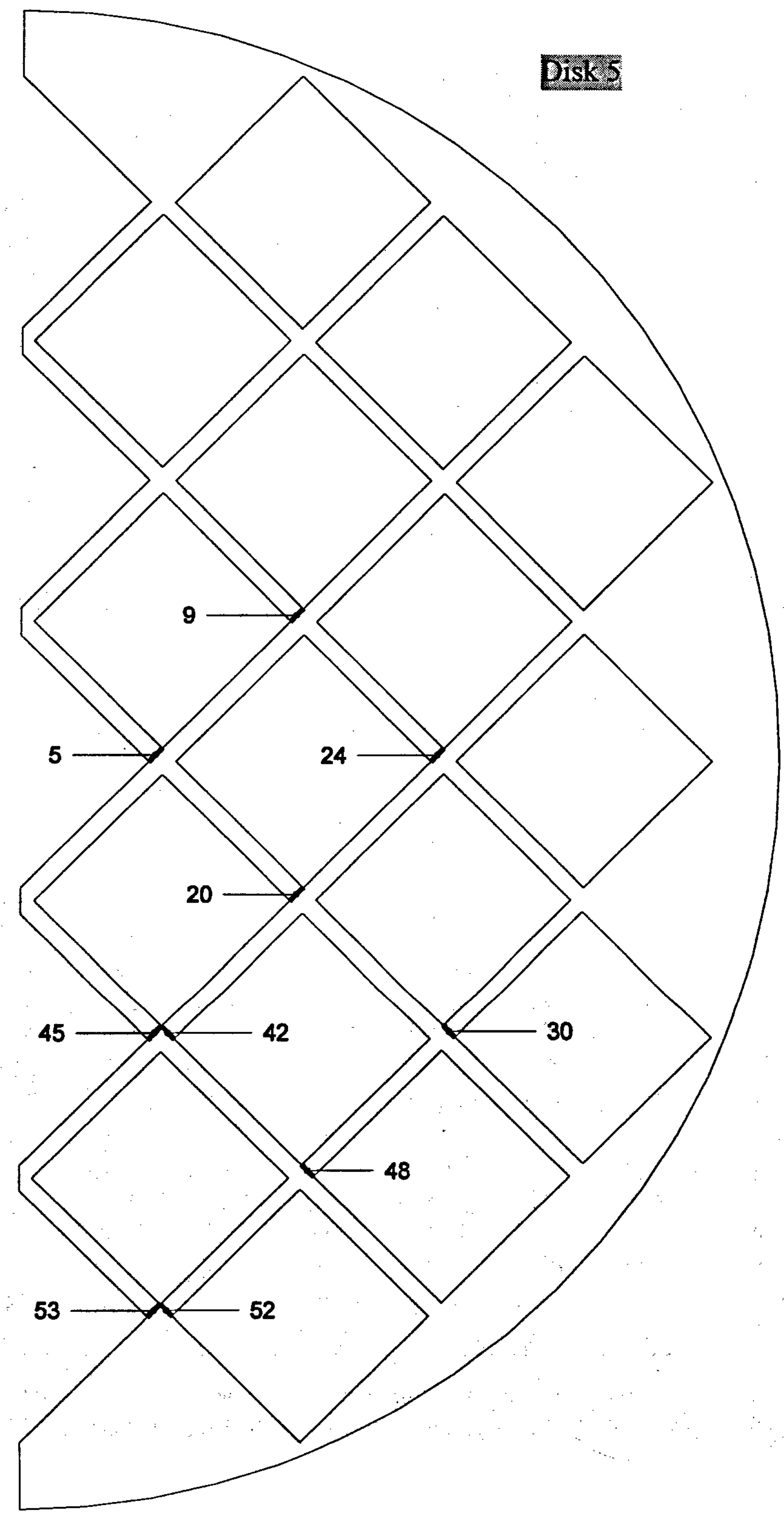


Table 11.2.12.3-1 Canister Primary Membrane Stresses

Section	Angle	Sx (ksi)	Sy (ksi)	Sz (ksi)	Sxy (ksi)	Syz (ksi)	Sxz (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
1	0.00	-4.10	-3.80	16.60	0.90	0.10	-1.70	21.67	38.52	0.78
2	0.00	-1.20	3.30	15.20	-0.60	0.20	0.00	18.67	38.52	1.06
3	0.00	-1.80	2.80	12.50	0.30	0.20	0.30	15.40	38.52	1.50
4	99.00	4.00	-3.90	0.20	7.10	0.90	-0.70	16.43	38.52	1.34
5	94.50	3.80	-2.00	0.20	9.40	0.70	-0.30	19.63	38.52	0.96
6	90.00	1.40	-0.50	0.00	11.50	0.00	-0.10	23.08	38.52	0.67
7	85.50	-0.40	-0.40	0.00	11.40	-0.90	0.00	22.85	38.52	0.69
8*	0.00	-1.03	8.71	1.75	0.18	5.93	2.87	16.13	38.52	1.39
9*	0.00	1.16	5.04	-0.25	1.27	3.30	1.19	9.36	38.52	3.12
10*	0.00	4.03	1.56	2.44	1.01	3.21	3.03	10.53	38.52	2.66
11	0.00	-37.60	-37.70	-22.30	9.70	2.40	-0.60	25.84	38.52	0.49
12	0.00	-39.90	-11.20	-17.60	-4.80	1.60	-1.70	30.77	38.52	0.25
13	0.00	-1.10	0.00	0.40	-0.10	0.00	0.00	1.55	45.74	28.51
14	0.00	-1.50	0.00	0.40	0.00	0.00	0.00	1.97	38.52	18.57

Notes:

* Stresses are not presented for the region with localized bearing stresses. Per ASME Section III, Appendix F, bearing stresses need not be evaluated for Level D service (accident) conditions.

Table 11.2.12.3-2 Canister Primary Membrane + Bending Stresses

Section	Angle	Sx (ksi)	Sy (ksi)	Sz (ksi)	Sxy (ksi)	Syz (ksi)	Sxz (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
1	0.00	-4.40	-0.50	32.20	0.90	0.30	-1.20	36.87	57.79	0.57
2	0.00	-1.90	0.70	29.50	-0.60	0.50	0.60	31.63	57.79	0.83
3	0.00	-2.70	1.60	25.90	0.40	0.20	0.80	28.72	57.79	1.01
4	0.00	-2.10	-0.20	24.90	-0.10	0.00	0.60	26.96	57.79	1.14
5	0.00	-2.90	2.00	22.60	0.00	-0.10	-0.40	25.51	57.79	1.27
6	90.00	1.80	2.00	0.00	-14.40	0.00	-0.10	28.89	57.79	1.00
7	0.00	-1.50	-27.80	-42.70	-1.10	2.20	-5.20	42.76	57.79	0.35
8*	0.00	-41.00	0.00	2.10	0.00	0.00	6.70	45.14	57.79	0.28
9	0.00	-16.50	27.90	-11.60	-10.20	2.80	1.80	49.72	57.79	0.16
10	0.00	-30.60	21.20	-17.90	3.00	2.30	2.10	52.62	57.79	0.10
11	0.00	-21.60	-19.10	-13.00	-15.00	0.90	-0.90	30.23	57.79	0.91
12	0.00	-40.00	-9.80	-15.90	-6.10	0.60	-2.40	32.92	57.79	0.76
13	0.00	-1.30	0.00	0.70	-0.10	0.00	0.00	1.94	57.79	28.76
14	0.00	-0.90	0.00	1.50	0.00	0.00	0.00	2.44	57.79	22.73

Notes:

* Stresses are not presented for the region with bearing stress (membrane) and secondary (Q) stress (bending). Per ASME Section III, Appendix F, both bearing stresses and secondary stresses are not required for evaluation for Level D service (accident) conditions.

Table 11.2.12.3-3 Listing of Cross Sections for Stress Evaluation of Support Disk

Section Number	Point 1	Point 2	Coordinates (in.)			
			Point 1		Point 2	
			X	Y	X	Y
1	1	2	22.15	22.15	24.39	24.39
2	3	4	5.84	0	6.46	-0.62
3	5	6	6.46	-0.62	7.07	0
4	7	8	7.07	0	6.46	0.62
5	9	10	6.46	0.62	5.84	0
6	11	12	12.29	6.46	12.91	5.84
7	13	14	12.91	5.84	13.48	6.41
8	15	16	13.48	6.41	12.86	7.03
9	17	18	12.86	7.03	12.29	6.46
10	19	20	18.7	12.86	19.32	12.25
11	21	22	19.32	12.25	19.85	12.78
12	23	24	19.85	12.78	19.23	13.4
13	25	26	19.23	13.4	18.7	12.86
14	27	28	25.07	19.23	25.69	18.61
15	29	30	25.07	19.23	27.13	21.3
16	31	32	25.69	18.61	27.67	20.59
17	33	34	12.29	-6.46	12.86	-7.03
18	35	36	12.86	-7.03	13.48	-6.41
19	37	38	13.48	-6.41	12.91	-5.84
20	39	40	12.91	-5.84	12.29	-6.46
21	41	42	18.75	0	19.32	-0.57
22	43	44	19.32	-0.57	19.89	0
23	45	46	19.89	0	19.32	0.57
24	47	48	19.32	0.57	18.75	0
25	49	50	25.16	6.41	25.73	5.84
26	51	52	25.16	6.41	25.69	6.94
27	53	54	31.52	12.78	31.97	12.96
28	55	56	18.7	-12.86	19.23	-13.4
29	57	58	19.23	-13.4	19.85	-12.78
30	59	60	19.85	-12.78	19.32	-12.25
31	61	62	19.32	-12.25	18.7	-12.86
32	63	64	25.16	-6.41	25.69	-6.94
33	65	66	25.16	-6.41	25.73	-5.84
34	67	68	31.57	0	34.49	0
35	69	70	22.15	-22.15	24.39	-24.39
36	71	72	25.07	-19.23	27.13	-21.3
37	73	74	25.07	-19.23	25.69	-18.61
38	75	76	25.69	-18.61	27.67	-20.59
39	77	78	31.52	-12.78	31.95	-12.9
40	79	80	0	-5.84	0.62	-6.46
41	81	82	0.62	-6.46	0	-7.07
42	83	84	6.46	-12.29	7.03	-12.86
43	85	86	7.03	-12.86	6.41	-13.48
44	87	88	6.41	-13.48	5.84	-12.91

Table 11.2.12.3-3 Listing of Cross Sections for Stress Evaluation of Support Disk (continued)

Section Number	Point 1	Point 2	Coordinates (in.)			
			Point 1		Point 2	
			X	Y	X	Y
45	89	90	5.84	12.91	6.46	12.29
46	91	92	0	18.75	0.57	19.32
47	93	94	0.57	19.32	0	19.89
48	95	96	12.86	18.7	13.4	19.23
49	97	98	13.4	19.23	12.78	19.85
50	99	100	12.78	19.85	12.25	19.32
51	101	102	12.25	19.32	12.86	18.7
52	103	104	6.41	25.16	6.94	25.69
53	105	106	6.41	25.16	5.84	25.73
54	107	108	0	31.57	0	34.49
55	109	110	19.23	25.07	21.3	27.13
56	111	112	19.23	25.07	18.61	25.69
57	113	114	18.61	25.69	20.59	27.67
58	115	116	12.78	31.52	12.96	31.97
59	117	118	0	7.07	0.62	6.46
60	119	120	0.62	6.46	0	5.84
61	121	122	6.46	12.29	5.84	12.91
62	123	124	5.84	12.91	6.41	13.48
63	125	126	6.41	13.48	7.03	12.86
64	127	128	7.03	12.86	6.46	12.29
65	129	130	12.86	18.7	12.25	19.32
66	131	132	12.25	19.32	12.78	19.85
67	133	134	12.78	19.85	13.4	19.23
68	135	136	13.4	19.23	12.86	18.7
69	137	138	19.23	25.07	18.61	25.69
70	139	140	19.23	25.07	21.3	27.13
71	141	142	18.61	25.69	20.59	27.67
72	143	144	0	19.89	0.57	19.32
73	145	146	0.57	19.32	0	18.75
74	147	148	6.41	25.16	5.84	25.73
75	149	150	6.41	25.16	6.94	25.69
76	151	152	12.78	31.52	12.9	31.95
77	153	154	0	31.57	0	34.49
78	155	156	2.92	2.92	3.54	3.54
79	157	158	9.37	9.37	9.95	9.95
80	159	160	15.78	15.78	16.31	16.31
81	161	162	9.37	3.54	9.99	2.92
82	163	164	15.83	2.92	16.4	3.49
83	165	166	22.24	9.33	22.77	9.86
84	167	168	15.78	9.95	16.4	9.33
85	169	170	22.24	3.49	22.81	2.92
86	171	172	22.15	16.31	22.77	15.69
87	173	174	3.54	9.37	2.92	9.99
88	175	176	9.95	15.78	9.33	16.4
89	177	178	3.49	22.24	2.92	22.81
90	179	180	16.31	22.15	15.69	22.77
91	181	182	2.92	15.83	3.49	16.4

Table 11.2.12.3-3 Listing of Cross Sections for Stress Evaluation of Support Disk (continued)

Section Number	Point 1	Point 2	Coordinates (in.)			
			Point 1		Point 2	
			X	Y	X	Y
92	183	184	9.33	-22.24	9.86	-22.77
93	185	186	2.92	2.92	3.54	3.54
94	187	188	9.37	9.37	9.95	9.95
95	189	190	15.78	15.78	16.31	16.31
96	191	192	9.37	-3.54	9.99	-2.92
97	193	194	15.83	2.92	16.4	3.49
98	195	196	22.24	9.33	22.77	9.86
99	197	198	15.78	-9.95	16.4	-9.33
100	199	200	22.24	-3.49	22.81	-2.92
101	201	202	22.15	-16.31	22.77	-15.69
102	203	204	2.92	15.83	3.49	16.4
103	205	206	9.33	22.24	9.86	22.77
104	207	208	3.54	-9.37	2.92	-9.99
105	209	210	9.95	-15.78	9.33	-16.4
106	211	212	3.49	-22.24	2.92	-22.81
107	213	214	16.31	-22.15	15.69	-22.77

Table 11.2.12.3-4 Support Disk 5 Primary Membrane Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	2.70	32.00	3.30	35.40	89.00	1.51
48	6.60	27.20	3.20	34.40	89.00	1.59
19	15.70	33.90	0.90	33.90	89.00	1.62
50	32.90	32.00	0.70	33.30	89.00	1.67
92	1.40	32.00	0.70	32.00	89.00	1.78
47	19.10	31.90	0.50	32.00	89.00	1.78
46	2.80	20.70	9.70	30.40	89.00	1.92
17	29.80	9.70	0.10	29.80	89.00	1.99
28	29.20	27.20	0.90	29.50	89.00	2.01
29	14.80	29.30	0.90	29.30	89.00	2.03
44	28.70	14.70	0.10	28.70	89.00	2.10
21	28.60	4.50	0.30	28.60	89.00	2.11
30	5.10	22.80	2.90	28.50	89.00	2.12
25	27.70	0.50	1.20	28.30	89.00	2.14
80	1.40	27.20	0.80	27.20	89.00	2.27
32	25.30	22.70	1.10	25.70	89.00	2.46
59	0.20	9.70	11.40	24.80	89.00	2.58
83	1.40	22.80	2.90	23.20	89.00	2.84
42	11.60	9.80	3.90	22.80	89.00	2.91
40	4.10	11.10	10.80	22.80	89.00	2.91
43	12.30	21.50	0.30	21.50	89.00	3.13
19	14.70	4.50	3.50	20.40	89.00	3.36
53	19.20	6.70	3.30	20.00	89.00	3.45
39	9.80	18.10	3.40	19.30	89.00	3.61
106	19.20	1.40	0.50	19.20	89.00	3.64
37	14.90	16.10	2.60	18.20	89.00	3.90
2	17.20	7.10	2.20	17.70	89.00	4.03
56	15.80	13.20	2.60	17.40	89.00	4.12
10	17.00	0.00	0.70	17.10	89.00	4.19
23	16.60	0.40	2.60	17.10	89.00	4.22
6	16.40	3.50	0.20	16.40	89.00	4.41
13	2.60	12.10	3.20	16.00	89.00	4.55
27	6.60	0.30	7.30	15.90	89.00	4.60
26	6.90	7.60	3.20	15.90	89.00	4.61
107	15.70	1.40	0.90	15.80	89.00	4.63
18	11.50	15.40	0.70	15.50	89.00	4.74
20	8.30	4.10	4.10	15.00	89.00	4.95
58	1.10	11.20	5.50	14.90	89.00	4.97
101	14.80	1.40	0.90	14.90	89.00	4.98
91	1.40	14.70	0.20	14.70	89.00	5.06

Table 11.2.12.3-5 Support Disk 5 Primary Membrane + Bending Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	16.80	104.30	5.50	104.80	127.10	0.21
45	95.60	27.50	2.90	95.80	127.10	0.33
5	94.50	33.20	4.70	94.90	127.10	0.34
20	94.00	25.00	2.90	94.10	127.10	0.35
48	11.60	93.50	2.60	93.60	127.10	0.36
42	15.00	92.40	0.60	92.40	127.10	0.38
53	89.50	26.20	7.60	90.50	127.10	0.41
24	83.80	17.80	2.60	83.90	127.10	0.51
30	10.50	79.90	2.40	80.00	127.10	0.59
9	76.40	19.90	2.80	76.60	127.10	0.66
51	75.50	29.10	4.60	76.00	127.10	0.67
19	8.70	75.80	1.00	75.80	127.10	0.68
26	75.20	1.60	0.30	75.20	127.10	0.69
4	23.20	73.00	1.60	73.00	127.10	0.74
56	68.30	22.30	8.90	70.00	127.10	0.82
13	69.30	5.80	0.00	69.30	127.10	0.83
37	66.20	28.90	9.10	68.30	127.10	0.86
2	43.70	65.30	7.60	67.70	127.10	0.88
31	65.70	24.30	3.90	66.00	127.10	0.93
62	63.70	17.50	2.40	63.80	127.10	0.99
92	2.90	60.00	0.70	60.00	127.10	1.12
66	55.70	26.30	6.10	56.90	127.10	1.23
80	2.80	55.90	0.90	55.90	127.10	1.27
44	45.20	47.60	9.00	55.50	127.10	1.29
33	55.10	15.30	3.90	55.50	127.10	1.29
47	28.40	50.10	9.20	53.50	127.10	1.38
17	45.10	42.50	9.00	52.90	127.10	1.40
3	52.00	30.20	3.30	52.50	127.10	1.42
12	29.60	50.00	7.00	52.10	127.10	1.44
54	11.10	41.70	20.40	51.90	127.10	1.45
41	50.00	37.20	4.10	51.20	127.10	1.48
50	39.90	42.30	9.90	51.10	127.10	1.49
8	29.90	48.60	5.80	50.20	127.10	1.53
60	48.20	39.30	4.30	49.90	127.10	1.55
23	32.80	44.20	8.00	48.30	127.10	1.63
46	29.50	1.20	18.60	46.70	127.10	1.72
67	26.90	43.50	6.40	45.70	127.10	1.78
91	3.70	45.00	0.10	45.00	127.10	1.83
63	27.30	43.20	5.30	44.80	127.10	1.84
49	8.60	42.30	9.30	44.70	127.10	1.85

Table 11.2.12.3-6 Support Disk 4 Primary Membrane Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	2.50	31.20	3.30	34.30	89.00	1.59
49	15.80	33.40	0.90	33.40	89.00	1.66
48	6.30	26.40	3.20	33.30	89.00	1.67
50	32.50	31.10	0.80	32.90	89.00	1.71
47	18.90	31.70	0.60	31.70	89.00	1.80
92	1.40	31.20	0.70	31.20	89.00	1.85
46	3.00	20.40	9.40	30.00	89.00	1.97
17	29.80	9.50	0.00	29.80	89.00	1.99
28	29.00	26.40	0.90	29.20	89.00	2.04
29	15.00	28.90	0.90	28.90	89.00	2.08
44	28.60	14.40	0.10	28.60	89.00	2.11
21	28.60	4.30	0.30	28.60	89.00	2.12
25	27.60	0.70	1.20	28.40	89.00	2.13
30	4.80	22.00	2.90	27.50	89.00	2.24
80	1.40	26.40	0.90	26.40	89.00	2.37
32	25.10	21.90	1.10	25.50	89.00	2.49
59	0.20	9.80	11.20	24.50	89.00	2.63
42	11.50	9.60	3.80	22.40	89.00	2.97
33	1.40	22.00	2.90	22.40	89.00	2.98
40	4.00	11.10	10.50	22.20	89.00	3.00
43	12.40	21.50	0.40	21.50	89.00	3.14
19	14.50	4.30	3.40	20.00	89.00	3.45
53	19.00	6.30	3.20	19.80	89.00	3.50
39	9.90	18.10	3.30	19.30	89.00	3.61
106	18.90	1.40	0.50	19.00	89.00	3.69
37	15.10	16.10	2.60	18.20	89.00	3.89
2	17.40	7.10	2.10	17.80	89.00	3.99
56	15.90	13.10	2.60	17.40	89.00	4.11
10	17.20	0.00	0.70	17.20	89.00	4.17
23	16.40	0.60	2.60	16.90	89.00	4.28
6	16.60	3.60	0.10	16.60	89.00	4.37
26	7.10	7.90	3.20	16.30	89.00	4.47
13	2.70	12.20	3.20	16.20	89.00	4.49
107	15.90	1.40	0.90	15.90	89.00	4.59
27	6.40	0.30	7.20	15.60	89.00	4.72
18	11.70	15.40	0.70	15.50	89.00	4.74
20	8.50	4.30	4.10	15.20	89.00	4.85
58	1.20	11.30	5.60	15.10	89.00	4.89
101	15.00	1.40	0.90	15.10	89.00	4.90
45	8.90	3.50	4.10	14.80	89.00	5.00

Table 11.2.12.3-7 Support Disk 4 Primary Membrane + Bending Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	16.70	102.50	6.40	103.00	127.10	0.23
45	94.30	26.70	2.80	94.40	127.10	0.35
5	93.70	32.70	1.60	94.00	127.10	0.35
20	92.90	24.30	2.80	93.00	127.10	0.37
18	11.60	92.00	2.60	92.00	127.10	0.38
12	14.70	90.90	0.60	90.90	127.10	0.40
53	87.70	25.40	7.40	88.50	127.10	0.44
24	83.00	17.30	2.60	83.10	127.10	0.53
30	10.60	78.70	2.50	78.80	127.10	0.61
9	75.70	19.50	2.70	75.90	127.10	0.68
51	74.40	28.00	1.40	74.80	127.10	0.70
19	8.60	74.70	1.00	74.70	127.10	0.70
26	74.60	1.10	0.40	74.60	127.10	0.70
1	22.80	72.10	1.60	72.20	127.10	0.76
56	68.00	22.10	8.90	69.70	127.10	0.82
13	68.90	5.60	0.00	68.90	127.10	0.85
37	66.20	28.80	9.10	68.30	127.10	0.86
2	43.30	64.10	7.60	66.60	127.10	0.91
31	65.00	23.40	3.70	65.30	127.10	0.95
62	63.20	17.30	2.30	63.40	127.10	1.01
92	2.90	58.90	0.80	58.90	127.10	1.16
66	55.20	26.20	6.10	56.40	127.10	1.25
80	2.80	54.80	0.90	54.80	127.10	1.32
33	54.50	14.60	1.80	54.80	127.10	1.32
44	44.60	45.80	8.90	54.10	127.10	1.35
47	26.90	49.10	9.10	52.40	127.10	1.43
17	44.60	41.00	8.90	51.90	127.10	1.45
12	29.30	49.60	7.00	51.70	127.10	1.46
3	50.90	29.90	3.30	51.40	127.10	1.47
41	48.60	36.60	4.10	49.90	127.10	1.55
54	10.70	39.60	19.70	49.60	127.10	1.56
50	39.30	40.40	9.70	49.60	127.10	1.56
8	29.50	47.90	5.80	49.60	127.10	1.56
60	47.30	38.90	4.30	49.10	127.10	1.59
23	32.40	43.80	8.00	47.90	127.10	1.66
46	28.90	1.10	18.10	45.60	127.10	1.79
67	26.60	43.20	6.40	45.40	127.10	1.80
91	3.60	44.30	0.10	44.30	127.10	1.87
63	27.00	42.60	5.30	44.30	127.10	1.87
49	8.70	41.60	9.20	43.90	127.10	1.89

Table 11.2.12.3-8 Support Disk 3 Primary Membrane Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	2.60	30.00	3.20	33.20	89.00	1.68
49	16.00	32.70	1.00	32.80	89.00	1.71
50	32.30	29.90	0.80	32.60	89.00	1.73
48	6.10	25.20	3.10	32.00	89.00	1.78
47	18.20	30.90	0.60	30.90	89.00	1.88
22	1.40	29.90	0.80	30.00	89.00	1.97
17	29.70	8.90	0.00	29.70	89.00	2.00
28	29.00	25.20	0.90	29.20	89.00	2.04
46	3.40	19.60	9.00	29.20	89.00	2.05
25	27.40	1.30	1.20	28.90	89.00	2.08
21	28.60	3.60	0.40	28.60	89.00	2.11
29	15.40	28.30	0.90	28.40	89.00	2.13
14	28.30	13.70	0.00	28.30	89.00	2.14
30	4.60	20.80	2.90	26.00	89.00	2.42
32	25.10	20.70	1.20	25.40	89.00	2.50
30	1.40	25.20	0.90	25.20	89.00	2.53
59	0.20	10.00	10.90	24.00	89.00	2.70
42	11.20	8.90	3.70	21.40	89.00	3.15
40	3.90	11.00	10.10	21.30	89.00	3.17
33	1.40	20.80	2.90	21.20	89.00	3.20
43	12.50	21.10	0.40	21.10	89.00	3.21
39	10.00	18.20	3.00	19.20	89.00	3.63
53	18.20	5.90	3.10	19.00	89.00	3.68
19	14.00	3.70	3.40	18.90	89.00	3.71
106	18.20	1.40	0.60	18.20	89.00	3.88
37	15.50	15.70	2.50	18.20	89.00	3.90
2	17.70	7.20	2.00	18.10	89.00	3.92
56	16.00	12.80	2.50	17.40	89.00	4.11
10	17.30	0.10	0.80	17.30	89.00	4.13
6	16.90	3.60	0.10	16.90	89.00	4.27
26	7.30	3.30	3.20	16.80	89.00	4.29
23	16.00	1.20	2.60	16.40	89.00	4.42
13	2.90	12.10	3.10	16.30	89.00	4.47
107	16.00	1.40	0.90	16.00	89.00	4.55
20	8.90	5.00	4.00	16.00	89.00	4.55
101	15.50	1.40	0.90	15.50	89.00	4.73
18	12.10	15.20	0.70	15.40	89.00	4.79
58	1.30	11.60	5.70	15.30	89.00	4.81
45	9.00	4.10	4.00	15.30	89.00	4.82
27	6.00	0.30	6.90	14.90	89.00	4.96

Table 11.2.12.3-9 Support Disk 3 Primary Membrane + Bending Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	16.00	99.30	6.20	99.80	127.10	0.27
5	92.30	31.80	4.50	92.70	127.10	0.37
45	91.90	25.10	2.60	92.00	127.10	0.38
20	91.40	22.90	2.60	91.50	127.10	0.39
48	11.20	89.30	2.50	89.40	127.10	0.42
42	14.20	88.30	0.50	88.30	127.10	0.44
53	85.20	24.50	7.10	86.00	127.10	0.48
24	82.10	16.30	2.40	82.20	127.10	0.55
30	10.70	77.00	2.40	77.10	127.10	0.65
9	74.90	18.90	2.70	75.10	127.10	0.69
26	73.70	0.40	0.50	73.70	127.10	0.72
51	72.90	26.40	4.10	73.30	127.10	0.73
19	8.60	72.90	1.00	72.90	127.10	0.74
4	22.30	70.90	1.60	70.90	127.10	0.79
13	68.10	5.30	0.00	68.10	127.10	0.87
56	66.40	21.60	3.80	68.10	127.10	0.87
37	65.60	28.20	9.10	67.60	127.10	0.88
31	64.40	21.90	3.50	64.70	127.10	0.97
2	42.80	61.90	7.60	64.60	127.10	0.97
62	63.10	17.10	2.40	63.20	127.10	1.01
92	2.80	57.20	0.80	57.20	127.10	1.22
66	54.70	25.80	6.00	55.90	127.10	1.27
33	54.20	13.60	3.60	54.60	127.10	1.33
80	2.70	53.20	0.90	53.20	127.10	1.39
44	43.40	42.60	8.70	51.70	127.10	1.46
12	28.80	48.80	6.90	51.00	127.10	1.49
47	24.80	47.30	3.80	50.40	127.10	1.52
17	43.80	38.20	8.80	50.20	127.10	1.53
3	49.40	29.40	3.30	50.00	127.10	1.54
8	28.80	47.10	5.70	48.80	127.10	1.61
60	45.80	38.50	4.40	47.90	127.10	1.65
23	31.60	44.00	7.90	47.80	127.10	1.66
41	46.30	35.40	4.10	47.70	127.10	1.67
54	10.40	38.00	19.00	47.70	127.10	1.67
50	38.40	37.20	9.50	47.30	127.10	1.68
57	26.40	42.50	6.40	44.70	127.10	1.84
46	28.20	1.20	17.40	44.00	127.10	1.89
63	10.90	43.80	0.00	43.80	127.10	1.90
91	3.50	43.00	0.00	43.00	127.10	1.96
25	35.90	4.80	6.80	42.90	127.10	1.96

Table 11.2.12.3-10 Support Disk 2 Primary Membrane Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	3.90	29.20	3.20	33.70	89.00	1.64
50	32.60	29.10	0.90	32.80	89.00	1.71
49	15.90	32.30	1.10	32.30	89.00	1.75
48	6.70	24.40	3.10	31.70	89.00	1.81
28	29.70	24.30	1.00	29.90	89.00	1.98
25	27.10	2.60	1.20	29.80	89.00	1.99
17	29.60	7.50	0.10	29.60	89.00	2.00
47	16.70	29.20	0.60	29.30	89.00	2.04
92	1.40	29.20	0.90	29.20	89.00	2.05
21	28.80	2.30	0.40	28.80	89.00	2.09
46	4.10	18.30	8.80	28.50	89.00	2.13
29	16.10	28.10	1.00	28.20	89.00	2.16
44	27.70	12.30	0.10	27.70	89.00	2.21
32	25.80	19.80	1.20	26.00	89.00	2.42
30	4.50	19.90	2.90	25.10	89.00	2.55
80	1.40	24.30	1.00	24.40	89.00	2.65
59	0.10	10.40	10.60	23.70	89.00	2.75
40	3.70	10.80	9.60	20.50	89.00	3.35
83	1.40	19.90	2.80	20.30	89.00	3.39
43	12.40	20.30	0.50	20.30	89.00	3.39
42	10.90	7.60	3.70	19.90	89.00	3.47
39	10.00	18.20	2.60	19.00	89.00	3.69
2	18.10	7.10	2.00	18.40	89.00	3.82
37	16.20	15.10	2.50	18.20	89.00	3.89
53	16.80	6.10	3.10	17.60	89.00	4.04
20	9.50	6.10	4.00	17.50	89.00	4.09
6	17.30	3.60	0.00	17.30	89.00	4.15
26	7.20	8.90	3.10	17.30	89.00	4.15
10	17.20	0.00	0.70	17.20	89.00	4.17
56	16.00	12.50	2.40	17.20	89.00	4.17
19	13.30	2.40	3.40	17.10	89.00	4.20
106	16.70	1.40	0.60	16.80	89.00	4.31
101	16.10	1.40	1.00	16.20	89.00	4.49
13	2.90	11.90	3.10	16.00	89.00	4.55
107	15.90	1.40	1.00	16.00	89.00	4.56
45	8.90	5.00	3.90	16.00	89.00	4.57
24	8.40	6.00	3.50	16.00	89.00	4.57
23	15.40	2.50	2.60	15.90	89.00	4.61
58	1.40	11.90	5.60	15.40	89.00	4.78
18	12.70	14.70	0.80	14.90	89.00	4.96

Table 11.2.12.3-11 Support Disk 2 Primary Membrane + Bending Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	14.40	96.00	5.70	96.40	127.10	0.32
5	91.30	30.80	4.40	91.60	127.10	0.39
20	90.30	21.20	2.30	90.40	127.10	0.41
45	89.40	23.20	2.30	89.50	127.10	0.42
48	10.00	86.60	2.20	86.70	127.10	0.47
42	13.80	85.30	0.50	85.30	127.10	0.49
53	83.80	24.50	7.10	84.60	127.10	0.50
24	82.40	15.00	2.10	82.40	127.10	0.54
30	10.40	75.40	2.30	75.50	127.10	0.68
9	74.90	18.40	2.60	75.00	127.10	0.69
26	73.10	0.20	0.60	73.30	127.10	0.73
51	72.20	25.10	3.90	72.50	127.10	0.75
19	8.90	71.10	0.90	71.10	127.10	0.79
4	22.20	69.90	1.60	69.90	127.10	0.82
13	67.40	5.30	0.10	67.40	127.10	0.89
37	64.00	27.00	8.90	66.10	127.10	0.92
31	64.70	20.70	3.30	65.00	127.10	0.96
56	63.10	20.80	8.50	64.70	127.10	0.96
62	63.80	17.30	2.40	63.90	127.10	0.99
2	42.40	59.60	7.60	62.50	127.10	1.03
92	2.70	56.00	0.90	56.00	127.10	1.27
66	54.70	25.20	5.90	55.90	127.10	1.27
33	55.30	12.60	3.40	55.60	127.10	1.29
80	2.60	51.80	1.00	51.80	127.10	1.45
12	28.50	48.00	6.90	50.20	127.10	1.53
23	31.10	45.80	7.80	49.20	127.10	1.58
44	42.10	39.30	3.40	49.20	127.10	1.58
3	48.60	29.10	3.40	49.10	127.10	1.59
8	28.10	47.30	5.60	48.80	127.10	1.61
54	10.60	38.80	19.40	48.70	127.10	1.61
17	43.20	35.10	3.60	48.70	127.10	1.61
47	23.40	45.40	3.30	48.10	127.10	1.64
60	44.70	38.50	4.60	47.20	127.10	1.70
50	38.00	34.20	9.50	45.80	127.10	1.78
41	44.10	34.20	4.00	45.50	127.10	1.80
63	11.10	44.30	0.10	44.30	127.10	1.87
57	26.40	41.40	6.40	43.70	127.10	1.91
25	35.50	5.30	6.60	42.90	127.10	1.96
46	28.20	2.00	16.90	42.80	127.10	1.97
21	38.80	20.60	7.90	41.70	127.10	2.05

Table 11.2.12.3-12 Support Disk 1 Primary Membrane Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	6.20	28.10	3.00	34.80	89.00	1.56
50	33.50	28.00	1.00	33.70	89.00	1.64
19	16.10	31.80	1.20	31.90	89.00	1.79
18	7.70	23.10	3.00	31.30	89.00	1.84
28	30.90	23.00	1.10	31.10	89.00	1.86
25	26.00	4.10	1.10	30.20	89.00	1.95
17	29.10	5.80	0.20	29.10	89.00	2.06
21	28.70	0.70	0.40	28.70	89.00	2.10
22	1.40	28.00	1.00	28.10	89.00	2.17
29	17.10	27.60	1.10	27.80	89.00	2.21
32	27.10	18.40	1.20	27.30	89.00	2.26
16	4.50	16.30	8.50	26.90	89.00	2.31
47	14.60	26.50	0.60	26.50	89.00	2.35
44	26.40	10.40	0.20	26.40	89.00	2.36
30	4.80	18.40	2.80	24.00	89.00	2.71
30	1.40	23.00	1.10	23.10	89.00	2.86
59	0.00	10.90	10.10	23.00	89.00	2.87
20	10.40	7.50	3.80	19.50	89.00	3.57
43	12.60	19.30	0.50	19.30	89.00	3.61
2	18.80	7.20	1.80	19.10	89.00	3.67
33	1.40	18.40	2.80	18.90	89.00	3.71
40	3.40	10.50	8.70	18.90	89.00	3.72
24	9.60	7.70	3.40	18.60	89.00	3.78
37	17.10	14.40	2.30	18.50	89.00	3.82
39	9.80	17.80	1.90	18.30	89.00	3.88
5	18.10	3.60	0.10	18.10	89.00	3.93
12	9.90	5.80	3.60	17.30	89.00	4.14
45	9.00	6.50	3.70	17.20	89.00	4.17
26	6.80	9.30	3.10	17.20	89.00	4.18
101	17.10	1.40	1.10	17.20	89.00	4.18
56	16.10	11.60	2.20	17.10	89.00	4.22
10	17.00	0.10	0.80	17.00	89.00	4.23
107	16.10	1.40	1.20	16.20	89.00	4.49
53	14.70	6.90	3.20	15.80	89.00	4.62
58	1.70	12.20	5.50	15.30	89.00	4.83
13	2.60	11.20	3.10	15.10	89.00	4.88
106	14.70	1.40	0.60	14.70	89.00	5.06
18	13.60	14.00	0.80	14.60	89.00	5.09
23	13.90	4.00	2.60	14.60	89.00	5.10
61	14.40	5.50	0.10	14.40	89.00	5.16

Table 11.2.12.3-13 Support Disk 1 Primary Membrane + Bending Stresses for Tip Over Accident

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
52	11.70	90.00	4.70	90.20	127.10	0.41
5	89.10	29.10	4.20	89.40	127.10	0.42
20	87.40	18.50	1.80	87.50	127.10	0.45
45	84.50	20.00	1.70	84.50	127.10	0.50
53	82.50	24.80	7.30	83.40	127.10	0.52
48	8.00	82.60	1.80	82.70	127.10	0.54
24	81.80	12.90	1.70	81.80	127.10	0.55
42	13.60	80.70	0.50	80.70	127.10	0.58
9	74.40	17.30	2.50	74.50	127.10	0.71
30	9.50	72.70	2.00	72.70	127.10	0.75
51	71.50	22.90	3.60	71.70	127.10	0.77
26	70.50	0.50	0.70	71.10	127.10	0.79
19	9.60	68.10	0.70	68.10	127.10	0.87
4	21.50	67.60	1.60	67.70	127.10	0.88
31	65.40	18.90	3.00	65.60	127.10	0.94
13	65.50	5.50	0.20	65.50	127.10	0.94
62	64.50	17.10	2.50	64.70	127.10	0.97
37	61.00	25.20	3.80	63.00	127.10	1.02
56	57.50	18.90	3.10	59.10	127.10	1.15
2	41.50	55.60	7.70	58.90	127.10	1.16
33	57.80	10.90	3.10	58.00	127.10	1.19
66	54.60	24.10	5.70	55.60	127.10	1.29
92	2.60	54.10	1.10	54.10	127.10	1.35
54	11.10	41.10	20.40	51.40	127.10	1.47
23	29.80	48.60	7.60	51.30	127.10	1.48
30	2.50	49.70	1.10	49.70	127.10	1.56
8	26.90	47.10	5.40	48.50	127.10	1.62
12	27.90	45.60	6.80	48.00	127.10	1.65
3	46.00	28.30	3.50	46.70	127.10	1.72
17	41.70	30.20	3.20	46.00	127.10	1.77
60	42.30	38.10	4.80	45.40	127.10	1.80
63	11.30	45.10	0.20	45.10	127.10	1.82
44	39.50	33.50	7.80	44.80	127.10	1.84
47	22.00	42.10	7.50	44.60	127.10	1.85
50	37.60	28.80	9.50	43.70	127.10	1.91
67	26.20	39.10	6.40	41.70	127.10	2.05
41	39.60	32.00	3.90	41.20	127.10	2.08
25	34.30	5.00	6.20	41.20	127.10	2.09
21	38.30	17.10	7.60	40.80	127.10	2.12
46	27.60	2.90	16.00	40.40	127.10	2.15

Table 11.2.12.3-14 Buckling Evaluation Summary for Disk 5

Section Number	P (kip)	Pcr (kip)	Py (kip)	M (in-kip)	Mp (in-kip)	Mm (in-kip)	MS1	MS2
52	12.02	35.92	32.00	3.39	6.00	5.75	0.14	0.17
48	10.22	35.92	32.00	3.11	6.00	5.75	0.29	0.32
53	7.79	39.79	34.56	3.85	7.00	6.77	0.43	0.45
45	3.86	43.95	37.31	5.53	8.16	7.95	0.45	0.47
42	3.97	39.75	34.53	4.51	6.99	6.76	0.47	0.51
20	3.65	43.95	37.31	5.46	8.16	7.95	0.48	0.50
5	2.97	44.00	37.34	5.60	8.17	7.96	0.49	0.51
30	3.54	35.87	31.97	2.67	5.99	5.74	0.52	0.55
24	2.87	39.79	34.56	4.20	7.00	6.77	0.65	0.69
51	5.40	43.95	37.31	4.03	8.16	7.95	0.77	0.78
92	12.01	35.92	32.00	1.31	6.00	5.75	0.83	0.78
26	2.60	35.92	32.00	3.20	6.00	5.75	0.81	0.88
9	1.68	39.75	34.53	3.95	6.99	6.76	0.84	0.90
19	1.83	39.79	34.56	3.90	7.00	6.77	0.85	0.90
56	6.90	43.95	37.31	3.35	8.16	7.95	0.90	0.88
37	6.51	43.95	37.31	3.27	8.16	7.95	0.97	0.94
4	1.55	44.00	37.34	4.43	8.17	7.96	0.95	0.99
80	10.19	35.87	31.97	1.34	5.99	5.74	1.01	0.97
31	5.05	43.95	37.31	3.45	8.16	7.95	1.03	1.03
13	0.97	35.92	32.00	3.13	6.00	5.75	1.03	1.12
2	3.09	44.00	37.34	3.72	8.17	7.96	1.12	1.13
50	11.99	35.87	31.97	0.48	5.99	5.74	1.43	1.26
62	0.54	39.79	34.56	3.41	7.00	6.77	1.26	1.33
33	4.08	39.79	34.56	2.46	7.00	6.77	1.39	1.40
44	5.94	39.79	34.56	1.80	7.00	6.77	1.61	1.56
46	3.37	39.79	34.56	1.20	7.00	6.77	1.72	1.58
3	3.62	44.00	37.34	2.79	8.17	7.96	1.60	1.59
41	3.83	44.00	37.34	2.63	8.17	7.96	1.68	1.66
91	5.94	39.75	34.53	1.65	6.99	6.76	1.74	1.68
28	10.19	35.92	32.00	0.36	6.00	5.75	1.93	1.71
106	7.77	39.79	34.56	1.18	7.00	6.77	1.86	1.72
83	3.54	35.92	32.00	0.63	6.00	5.75	1.98	1.81
60	2.94	44.00	37.34	2.65	8.17	7.96	1.83	1.83
8	0.01	44.00	37.34	3.10	8.17	7.96	2.02	2.10
17	3.94	39.75	34.53	1.79	6.99	6.76	2.04	2.02
79	3.96	39.79	34.56	1.70	7.00	6.77	2.15	2.12
63	0.22	44.00	37.34	2.79	8.17	7.96	2.30	2.38
47	7.75	39.75	34.53	0.51	6.99	6.76	2.82	2.50
105	5.38	43.95	37.31	1.27	8.16	7.95	2.83	2.62
32	3.53	35.92	32.00	0.04	6.00	5.75	3.09	2.67

Table 11.2.12.3-15 Buckling Evaluation Summary for Disk 4

Section Number	P (kip)	Pcr (kip)	Py (kip)	M (in-kip)	Mp (in-kip)	Mm (in-kip)	MS1	MS2
52	11.70	35.92	32.00	3.35	6.00	5.75	0.16	0.19
48	9.91	35.92	32.00	3.07	6.00	5.75	0.31	0.34
53	7.69	39.79	34.56	3.76	7.00	6.77	0.46	0.48
45	3.90	43.95	37.31	5.44	8.16	7.95	0.47	0.49
20	3.72	43.95	37.31	5.38	8.16	7.95	0.49	0.52
42	3.89	39.75	34.53	4.44	6.99	6.76	0.50	0.54
5	3.03	44.00	37.34	5.54	8.17	7.96	0.50	0.53
30	3.25	35.87	31.97	2.66	5.99	5.74	0.55	0.58
24	2.93	39.79	34.56	4.15	7.00	6.77	0.66	0.70
51	5.44	43.95	37.31	3.95	8.16	7.95	0.80	0.80
26	2.67	35.92	32.00	3.17	6.00	5.75	0.82	0.89
92	11.68	35.92	32.00	1.30	6.00	5.75	0.87	0.82
9	1.74	39.75	34.53	3.90	6.99	6.76	0.85	0.91
19	1.76	39.79	34.56	3.85	7.00	6.77	0.88	0.93
56	6.95	43.95	37.31	3.32	8.16	7.95	0.91	0.88
37	6.59	43.95	37.31	3.26	8.16	7.95	0.97	0.94
4	1.59	44.00	37.34	4.37	8.17	7.96	0.98	1.01
80	9.89	35.87	31.97	1.33	5.99	5.74	1.05	1.01
31	5.13	43.95	37.31	3.39	8.16	7.95	1.05	1.04
13	1.03	35.92	32.00	3.10	6.00	5.75	1.04	1.13
2	3.13	44.00	37.34	3.64	8.17	7.96	1.15	1.17
62	0.59	39.79	34.56	3.38	7.00	6.77	1.27	1.35
50	11.66	35.87	31.97	0.43	5.99	5.74	1.53	1.35
33	4.14	39.79	34.56	2.42	7.00	6.77	1.41	1.42
46	8.25	39.79	34.56	1.17	7.00	6.77	1.77	1.63
3	3.69	44.00	37.34	2.71	8.17	7.96	1.64	1.63
44	5.85	39.79	34.56	1.72	7.00	6.77	1.71	1.65
41	3.87	44.00	37.34	2.54	8.17	7.96	1.75	1.72
91	5.85	39.75	34.53	1.63	6.99	6.76	1.79	1.72
106	7.68	39.79	34.56	1.17	7.00	6.77	1.89	1.75
28	9.88	35.92	32.00	0.32	6.00	5.75	2.07	1.82
60	3.00	44.00	37.34	2.58	8.17	7.96	1.88	1.87
83	8.25	35.92	32.00	0.63	6.00	5.75	2.04	1.88
8	0.05	44.00	37.34	3.06	8.17	7.96	2.05	2.13
17	3.86	39.75	34.53	1.72	6.99	6.76	2.15	2.13
79	3.87	39.79	34.56	1.68	7.00	6.77	2.19	2.17
63	0.28	44.00	37.34	2.76	8.17	7.96	2.32	2.40
105	5.43	43.95	37.31	1.26	8.16	7.95	2.83	2.62
47	7.66	39.75	34.53	0.44	6.99	6.76	3.00	2.64
93	3.01	44.00	37.34	1.82	8.17	7.96	2.77	2.71

Table 11.2.12.3-16 Buckling Evaluation Summary for Disk 3

Section Number	P (kip)	Pcr (kip)	Py (kip)	M (in-kip)	Mp (in-kip)	Mm (in-kip)	MS1	MS2
52	11.25	35.92	32.00	3.25	6.00	5.75	0.20	0.23
48	9.46	35.92	32.00	3.01	6.00	5.75	0.36	0.39
53	7.39	39.79	34.56	3.66	7.00	6.77	0.50	0.52
45	3.94	43.95	37.31	5.29	8.16	7.95	0.51	0.53
20	3.89	43.95	37.31	5.26	8.16	7.95	0.51	0.54
5	3.20	44.00	37.34	5.43	8.17	7.96	0.51	0.54
42	3.61	39.75	34.53	4.33	6.99	6.76	0.55	0.59
30	7.80	35.87	31.97	2.63	5.99	5.74	0.59	0.62
24	3.10	39.79	34.56	4.08	7.00	6.77	0.67	0.72
61	5.49	43.95	37.31	3.85	8.16	7.95	0.83	0.83
26	2.72	35.92	32.00	3.12	6.00	5.75	0.84	0.90
9	1.90	39.75	34.53	3.84	6.99	6.76	0.87	0.92
92	11.23	35.92	32.00	1.28	6.00	5.75	0.93	0.88
56	7.01	43.95	37.31	3.21	8.16	7.95	0.95	0.92
19	1.50	39.79	34.56	3.79	7.00	6.77	0.93	0.99
37	6.78	43.95	37.31	3.19	8.16	7.95	0.98	0.95
4	1.62	44.00	37.34	4.29	8.17	7.96	1.01	1.05
31	5.31	43.95	37.31	3.33	8.16	7.95	1.06	1.05
13	1.09	35.92	32.00	3.06	6.00	5.75	1.06	1.15
80	9.43	35.87	31.97	1.31	5.99	5.74	1.13	1.08
2	3.16	44.00	37.34	3.49	8.17	7.96	1.22	1.24
62	0.74	39.79	34.56	3.35	7.00	6.77	1.27	1.34
33	4.32	39.79	34.56	2.38	7.00	6.77	1.41	1.42
50	11.21	35.87	31.97	0.34	5.99	5.74	1.72	1.51
3	3.86	44.00	37.34	2.59	8.17	7.96	1.71	1.69
46	7.94	39.79	34.56	1.14	7.00	6.77	1.87	1.72
91	5.56	39.75	34.53	1.60	6.99	6.76	1.88	1.82
106	7.37	39.79	34.56	1.15	7.00	6.77	1.97	1.83
41	3.91	44.00	37.34	2.39	8.17	7.96	1.87	1.84
44	5.55	39.79	34.56	1.58	7.00	6.77	1.91	1.84
60	3.16	44.00	37.34	2.47	8.17	7.96	1.95	1.94
83	7.80	35.92	32.00	0.64	6.00	5.75	2.16	1.99
28	9.43	35.92	32.00	0.25	6.00	5.75	2.31	2.03
8	0.08	44.00	37.34	3.02	8.17	7.96	2.08	2.17
79	3.60	39.79	34.56	1.65	7.00	6.77	2.31	2.29
63	0.42	44.00	37.34	2.73	8.17	7.96	2.31	2.39
17	3.58	39.75	34.53	1.60	6.99	6.76	2.38	2.35
105	5.47	43.95	37.31	1.24	8.16	7.95	2.84	2.63
93	3.18	44.00	37.34	1.79	8.17	7.96	2.76	2.69
107	6.99	44.00	37.34	0.78	8.17	7.96	3.09	2.73

Table 11.2.12.3-17 Buckling Evaluation Summary for Disk 2

Section Number	P (kip)	Pcr (kip)	Py (kip)	M (in-kip)	Mp (in-kip)	Mm (in-kip)	MS1	MS2
52	10.96	35.92	32.00	3.14	6.00	5.75	0.24	0.27
48	9.13	35.92	32.00	2.92	6.00	5.75	0.40	0.43
5	8.45	44.00	37.34	5.33	8.17	7.96	0.53	0.55
20	4.16	43.95	37.31	5.15	8.16	7.95	0.53	0.55
53	6.80	39.79	34.56	3.67	7.00	6.77	0.54	0.56
45	8.91	43.95	37.31	5.13	8.16	7.95	0.55	0.57
42	3.08	39.75	34.53	4.24	6.99	6.76	0.61	0.66
30	7.45	35.87	31.97	2.60	5.99	5.74	0.63	0.66
24	3.41	39.79	34.56	4.05	7.00	6.77	0.66	0.70
51	5.46	43.95	37.31	3.81	8.16	7.95	0.85	0.85
26	2.69	35.92	32.00	3.09	6.00	5.75	0.85	0.92
9	2.19	39.75	34.53	3.79	6.99	6.76	0.86	0.91
92	10.94	35.92	32.00	1.26	6.00	5.75	0.98	0.92
37	7.08	43.95	37.31	3.05	8.16	7.95	1.01	0.97
56	6.98	43.95	37.31	3.00	8.16	7.95	1.04	1.00
19	0.98	39.79	34.56	3.76	7.00	6.77	1.00	1.07
31	5.60	43.95	37.31	3.31	8.16	7.95	1.04	1.02
4	1.59	44.00	37.34	4.23	8.17	7.96	1.04	1.08
13	1.07	35.92	32.00	3.03	6.00	5.75	1.08	1.17
80	9.11	35.87	31.97	1.29	5.99	5.74	1.19	1.14
62	1.02	39.79	34.56	3.35	7.00	6.77	1.23	1.30
2	3.13	44.00	37.34	3.35	8.17	7.96	1.31	1.32
33	4.65	39.79	34.56	2.40	7.00	6.77	1.35	1.35
50	10.92	35.87	31.97	0.24	5.99	5.74	1.92	1.67
3	4.14	44.00	37.34	2.50	8.17	7.96	1.74	1.70
46	7.41	39.79	34.56	1.11	7.00	6.77	2.02	1.87
41	3.88	44.00	37.34	2.25	8.17	7.96	2.01	1.97
106	6.78	39.79	34.56	1.16	7.00	6.77	2.12	1.98
91	5.00	39.75	34.53	1.58	6.99	6.76	2.03	1.98
60	3.42	44.00	37.34	2.36	8.17	7.96	2.00	1.98
8	0.05	44.00	37.34	3.03	8.17	7.96	2.08	2.17
83	7.45	35.92	32.00	0.64	6.00	5.75	2.25	2.09
44	4.99	39.79	34.56	1.48	7.00	6.77	2.17	2.09
63	0.64	44.00	37.34	2.74	8.17	7.96	2.25	2.32
28	9.11	35.92	32.00	0.16	6.00	5.75	2.60	2.26
79	3.06	39.79	34.56	1.63	7.00	6.77	2.51	2.50
93	3.43	44.00	37.34	1.76	8.17	7.96	2.72	2.64
105	5.44	43.95	37.31	1.23	8.16	7.95	2.87	2.65
101	7.07	44.00	37.34	0.80	8.17	7.96	3.01	2.67
17	3.05	39.75	34.53	1.50	6.99	6.76	2.72	2.70

Table 11.2.12.3-18 Buckling Evaluation Summary for Disk 1

Section Number	P (kip)	Pcr (kip)	Py (kip)	M (in-kip)	Mp (in-kip)	Mm (in-kip)	MS1	MS2
52	10.54	35.92	32.00	2.90	6.00	5.75	0.33	0.35
48	8.65	35.92	32.00	2.80	6.00	5.75	0.47	0.50
5	8.80	44.00	37.34	5.14	8.17	7.96	0.55	0.58
20	4.54	43.95	37.31	4.91	8.16	7.95	0.57	0.58
53	5.96	39.79	34.56	3.71	7.00	6.77	0.59	0.61
45	8.95	43.95	37.31	4.81	8.16	7.95	0.63	0.65
24	8.89	39.79	34.56	3.95	7.00	6.77	0.66	0.69
30	6.91	35.87	31.97	2.54	5.99	5.74	0.70	0.74
42	2.36	39.75	34.53	4.09	6.99	6.76	0.72	0.77
9	2.63	39.75	34.53	3.71	6.99	6.76	0.85	0.90
51	5.52	43.95	37.31	3.75	8.16	7.95	0.87	0.86
26	2.54	35.92	32.00	2.99	6.00	5.75	0.92	0.99
31	5.99	43.95	37.31	3.30	8.16	7.95	1.01	0.99
92	10.52	35.92	32.00	1.22	6.00	5.75	1.05	0.99
37	7.49	43.95	37.31	2.80	8.16	7.95	1.09	1.04
4	1.61	44.00	37.34	4.08	8.17	7.96	1.10	1.14
19	0.32	39.79	34.56	3.68	7.00	6.77	1.12	1.20
13	0.97	35.92	32.00	2.95	6.00	5.75	1.15	1.24
56	7.06	43.95	37.31	2.64	8.16	7.95	1.22	1.16
62	1.44	39.79	34.56	3.34	7.00	6.77	1.18	1.24
33	5.18	39.79	34.56	2.47	7.00	6.77	1.23	1.23
80	8.62	35.87	31.97	1.25	5.99	5.74	1.29	1.24
2	8.16	44.00	37.34	3.09	8.17	7.96	1.46	1.47
3	4.51	44.00	37.34	2.28	8.17	7.96	1.85	1.80
50	10.50	35.87	31.97	0.04	5.99	5.74	2.35	2.00
8	0.08	44.00	37.34	3.02	8.17	7.96	2.09	2.17
60	8.77	44.00	37.34	2.15	8.17	7.96	2.14	2.09
46	6.62	39.79	34.56	1.05	7.00	6.77	2.30	2.13
63	0.95	44.00	37.34	2.74	8.17	7.96	2.17	2.23
106	5.94	39.79	34.56	1.16	7.00	6.77	2.33	2.20
91	4.22	39.75	34.53	1.53	6.99	6.76	2.29	2.24
41	8.92	44.00	37.34	1.95	8.17	7.96	2.32	2.25
83	6.91	35.92	32.00	0.65	6.00	5.75	2.41	2.25
49	7.03	44.00	37.34	0.93	8.17	7.96	2.82	2.51
101	7.48	44.00	37.34	0.78	8.17	7.96	2.91	2.55
93	8.78	44.00	37.34	1.71	8.17	7.96	2.69	2.60
29	7.46	44.00	37.34	0.75	8.17	7.96	2.96	2.60
44	4.21	39.79	34.56	1.27	7.00	6.77	2.73	2.63
105	5.50	43.95	37.31	1.22	8.16	7.95	2.87	2.65
28	8.62	35.92	32.00	0.02	6.00	5.75	3.12	2.68

11.2.13 Tornado and Tornado Driven Missiles

This analysis evaluates the strength and stability of the concrete storage cask for a maximum tornado wind loading and for the impacts of tornado generated missiles. The design basis tornado characteristics have been selected in accordance with Regulatory Guide 1.76.

Classical techniques are used to evaluate the loading conditions. Cask stability analysis for the maximum tornado wind loading is based on NUREG-0800, Section 3.3.1, "Wind Loadings," and Section 3.3.2, "Tornado Loadings." Loads due to tornado generated missiles are based on NUREG-0800, Section 3.5.3, "Barrier Design Procedures."

11.2.13.1 Cause of Tornado Event

A tornado is a random weather event having a higher probability of occurrence at certain times of the year and in certain geographical areas.

Wind loading and tornado driven missiles have the potential for causing damage from pressure differential loading and from impact loadings.

A tornado event is expected to be visually observed. Warning of a tornado probability and of tornado sighting may be received from the National Weather Service, local radio and television, local law enforcement officials, and site personnel.

11.2.13.2 Analysis of the Tornado Event

Classical analysis is applied to the evaluation of the consequences of tornado wind and missile events.

The concrete cask stability in a maximum tornado wind is evaluated based on the design wind pressure calculated in accordance with ANSI/ASCE 7-93 and using classical free body stability analysis methods.

Local damage to the concrete shell is assessed using a formula developed by the National Defense Research Committee. This formula has been selected as the basis for predicting depth

of missile penetration and minimum concrete thickness requirements to prevent scabbing of the concrete. Penetration depths calculated using this formula have been shown to provide reasonable correlation with test results (EPRI Report NP-440).

The local shear strength of the concrete shell is evaluated based on ACI 349-85, Section 11.11.2.1, discounting the reinforcing and steel shell.

The concrete shell shear capacity and shear-friction reinforcing steel area requirements are also evaluated for missile loading using ACI 349-85, Section 11.7.

The cask has the following properties that are considered in this evaluation:

H = Height = 160 in
D_o = Outside Diameter = 128 in
D_i = Inside Diameter of concrete shell = 86 in
W_{VCC} = Weight of the storage cask with canister, basket and full fuel load = 206,100 lbs
A_c = Cross section area of concrete shell = 7,059 in^2
I_c = Moment of inertia of concrete shell = 10.49×10^6 in^4
f_c' = Compressive strength of concrete shell = 4,000 psi

11.2.13.2.1 Tornado Wind Loading (Storage Cask)

The tornado wind velocity is transformed into an effective pressure applied to the cask using procedures delineated in ANSI/ASCE 7-93 Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. The maximum pressure, q, is determined from the maximum tornado wind velocity as follows:

$$q = (0.00256)\ V^2 \text{ psf}$$

Where:

V = Maximum tornado wind speed = 360 mph

The velocity pressure exposure coefficient for local terrain effects K, Importance Factor I, and the Gust Factor G, may be taken as unity (1) for evaluating the effects of tornado wind velocity pressure.

Then:

$$q = (0.00256)(360)^2 = 331.8 \text{ psf}$$

Considering the cask is small with respect to the tornado radius, the velocity pressure is assumed uniform over the projected area of the cask.

Then the total wind loading on the projected area of the cask, F_w is then computed as:

$$F_w = q \times G \times C_f \times A_p$$

Where:

q = Effective velocity pressure (psf)

C_f = Force Coefficient = 0.50 (ASCE 7-93, Table 12 with $D\,q^{1/2} = 194$ for a moderately smooth surface, h/D = 13.33 ft /10.66 ft = 1.25)

A_f = Projected area of cask = 10.67 ft x 13.33 ft = 142.2 ft^2

$$F_w = 331.8 \times 0.50 \times 142.2 = 23{,}590 \text{ lbs}$$

The wind overturning moment, M_w, is computed as:

$M_w = F_w \times H/2$, where, H, is the cask height

$$M_w = 23{,}590 \text{ lbs} \times 160.\text{ in}/12 \times 1/2 = 157{,}267.\text{ ft-lbs}$$

The stability moment, M_s, of the cask with the canister, basket and full fuel load about an edge of the base, is:

$M_s = W_{VCC} \times D_o/2$

Where:

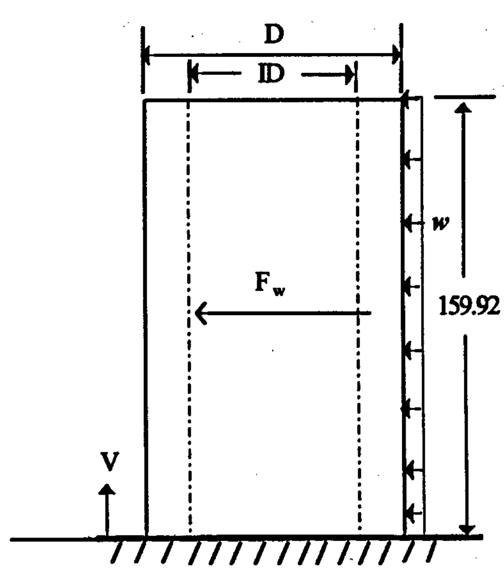
D_o = Diameter of the cask = 128 in

W_{VCC} = Weight of the cask with canister
= 206,100 lbs

M_s = 206,100 lbs x 128. In /12 x 1/2 = 1.099×10^6 ft-lbs

Thus, the cask has a Safety Factor of approximately +7 ($1.099 \times 10^6 / 1.573 \times 10^5$) against overturning with respect to the maximum tornado wind loading and requires only a coefficient of friction of about 0.12 (23.6×10^3 / $206. \times 10^3$) to be developed between the concrete cask base and ISFSI support deck to inhibit sliding via friction.

The stresses in the concrete due to the tornado wind load are conservatively calculated as below. The concrete cask is considered to be fixed at its base.



F_W	= 21,720 lb		
D	= 128 in. (concrete exterior diameter)		
ID	= 86 in. (concrete interior diameter)		

A	$= \pi (D^2 - ID^{2)} / 4$	= 7,059.2 in.^{2}	
I	$= \pi (D^4 - ID^{4)} / 64$	= 10.492 x10^6 in.^{4}	(Moment of Inertia)
S_{outer}	= 2I /D	= 163,937.5 in.^{3}	(Section Modulus for inner surface)
S_{inner}	= 2I / (ID)	= 244,000.0 in.^{3}	(Section Modulus for outer surface)
w	$= F_w / 159.92$	= 147.5 lbf / in	
M	$= w (159.92)^2 / 2$	= 1.886 x 10^6 in.-lb	(Bending Moment at the base)

Maximum stresses at the base surface:

$\sigma_{v\ outer} = M / S_{outer}$ = 11.5 psi (tension or compression)

$\sigma_{v\ inner} = M / S_{inner}$ = 7.7 psi (tension or compression)

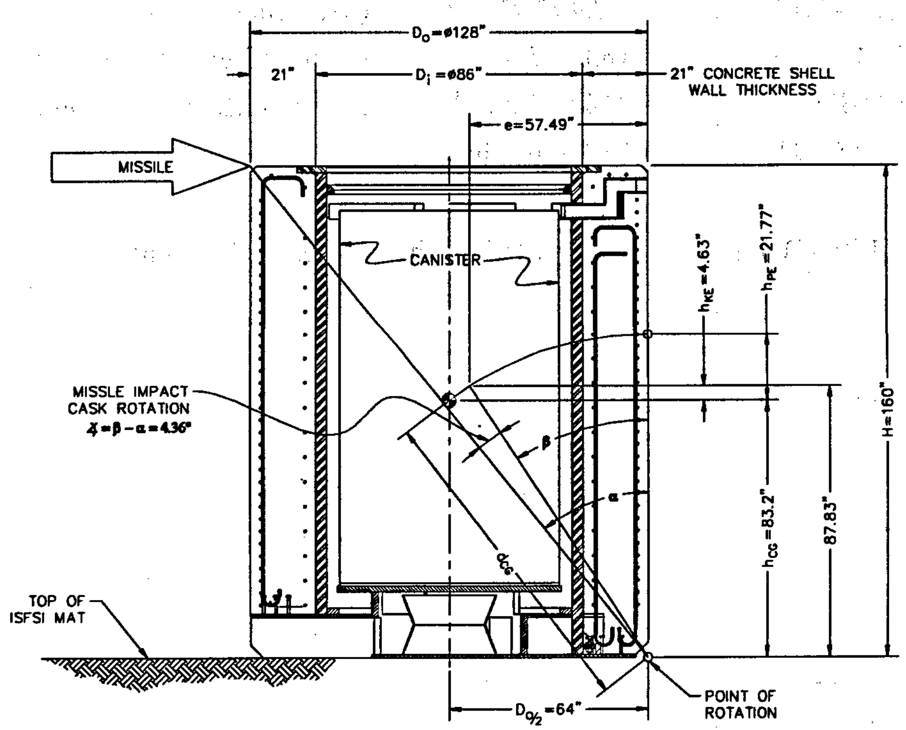
The compressive stresses are included in the load combination No. 8 in Table 3.4.4.2-1, since they are governing stresses for the load combination. As shown in Tables 3.4.4.2-1 and 3.4.4.2-2, the maximum combined stresses for the load combination of dead, live, thermal and tornado wind are below the allowable stress.

11.2.13.2.2 Tornado Missile Loading (Storage Cask)

The NAC-MPC concrete cask is designed to withstand the effects of impacts associated with postulated tornado generated missiles identified in NUREG-0800, Section 3.5.1.4.III.4, Spectrum I missiles. Consisting of: 1) a high kinetic energy missile (3,960 lb automobile, with a frontal area of 20 square feet that deforms on impact); 2) a 275 lb, 8 in diameter armor piercing artillery shell; and 3) a small 1-inch diameter solid steel sphere. All of these missiles are assumed to

impact in a manner that produces the maximum damage at a velocity of 126 mph (35 percent of the maximum tornado wind speed of 360 mph). The cask has been evaluated for impact effects associated with each of the above missiles.

The principal dimensions and moment arms used in this evaluation are shown below:



The concrete cask has no openings except for the four outlets at the top and four inlets at the bottom of the cask. These openings are configured such that a 1-inch diameter solid steel missile cannot directly enter the concrete cask interior. In addition, the canister is protected from the inlet (bottom) openings by a steel pedestal (bottom plate), and from the outlet (top) openings by the canister structural and shield lids. Therefore, a detailed analysis of the impact of a 1-inch diameter steel missile is not required.

Concrete Shell Local Damage Prediction (Penetration Missile)

Local damage to the cask body has been assessed using the National Defense Research Committee (NDRC) formula. This formula has been selected as the basis for predicting depth of penetration and minimum concrete thickness requirements to prevent scabbing. Penetration depths calculated using this formula have been shown to provide reasonable correlation with test results (EPRI Report NP-440, Section 4 "Local Response Evaluation").

Concrete shell penetration depths are calculated as follows:

For $x/2d \leq 2.0$:

Where:

x = Missile penetration depth
d = Missile diameter = 8 in
$x = [4KNWd^{-0.8}(V/1000)^{1.8}]^{0.5}$

Where:

K = Coefficient depending on concrete strength
$= 180/(f_c')^{1/2} = 180/(4000)^{1/2} = 2.846$
N = 1.14 Shape factor for sharp nosed missiles
W = Missile weight = 275 lb
V = Missile velocity = 126 mph = 185 ft/sec

$x = [(4)(2.846)(1.14)(275)(8^{-0.8})(185/1000)^{1.8}]^{0.5}$
= 5.68 inches
$x/2d = 5.68/(2)(8) = 0.355 < 2.0$

The minimum concrete shell thickness required to prevent scabbing is three times the predicted penetration depth of 5.68 inches based on the NDRC formula, or 17.04 inches. The concrete cask wall thickness includes 21 inches of concrete, which is more than the thickness required to

prevent damage due to the penetration missile. This analysis conservatively neglects the 3.5 inch steel shell at the inside face of the concrete shell.

Closure Plate Local Damage Prediction (Penetration Missile)

The concrete cask is closed with a 1.5-inch thick steel plate bolted in place. The following missile penetration analysis shows that the 1.5-inch steel closure plate is adequate to withstand the impact of the 275 lb armor piercing missile, impacting at 126 mph.

The perforation thickness of the closure steel plate is calculated by the Ballistic Research Laboratories Formula with K = 1, formula number 2-7, in Section 2.2 of Topical Report BC-TOP-9A, Revision 2.

$$T = [0.5 M_m V^2]^{2/3}/672d$$
$$= 0.516 \text{ inch}$$

Where:

T = Perforation thickness
M_m - Missile mass = W/g = 275 lbs/32.2 ft/sec^2 = 8.54 slugs
g = Acceleration of gravity = 32.2 ft/sec^2
W, V and d are as defined above

BC-TOP-9A, recommends that the plate thickness be 25 percent greater than the calculated perforation thickness T to prevent perforation.

Thus, the recommended plate thickness is: 1.25 x 0.516 in. = 0.645 in.

The closure plate is 1.5 inches thick; therefore the plate is adequate to withstand the local impingement damage due to the specified armor piercing missile.

Overall Damage Prediction for a Tornado Missile Impact (High Energy Missile)

The concrete cask is a freestanding structure. Therefore, the principal consideration in overall damage response is the potential of upsetting or overturning the cask as a result of the impact of a

high energy missile. Based on the following analysis, it is concluded that the cask can sustain an impact from the defined high energy missile and does not overturn.

From the principle of conservation of momentum, the impulse of the force from the missile impact on the cask must equal the change in angular momentum of the cask. Also, the impulse force due to the impact of the missile must equal the change in linear momentum of the missile. These relationships may be expressed as follows:

Change in momentum of the missile, during the deformation phase:

$$\int_{t_1}^{t_2} (F)(dt) = M_M (v_2 - v_1)$$

Where:

F = Impact Impulse force on missile

M_M = Mass of missile = 3960 lbs/g = 123 slugs/12 =
= 10.25 lbm (lb sec^2 /in)

t_1 = Time at missile impact

t_2 = Time at conclusion of deformation phase

v_1 = Velocity of missile at impact = 126 mph = 185 ft/sec

v_2 = Velocity of missile at time t_2

The change in angular momentum of the cask, about the bottom outside edge/rim, opposite the side of impact is:

$$\int_{t_1}^{t_2} (M_c)(dt) = \int_{t_1}^{t_2} (H)(F)\,dt = I_m(\varpi_1 - \varpi_2)$$

Thus, $\int (F)(dt) = M_M (v_2 - v_1) = I_m(\varpi_1 - \varpi_2)/H$

Where:

M_c = Moment of the impact force on the cask

I_m = Storage cask mass moment of inertia, about point of rotation on the bottom rim

ϖ_1 = Angular velocity at time t_1

ϖ_2 = Angular velocity at time t_2

M_{VCC} = Mass of the VCC cask = W_{VCC}/g

= 6,400. slugs/12 = 533.4 lbm (lb sec^2 /in)

I_{mx} = Mass moment of inertia of VCC cask about x axis through center of gravity

$\cong 1/12(M_{VCC})(3r^2 + H^2)$

$\cong (1/12)(533.4)\,[(3)(64)^2 + (160)^2] = 1.684 \times 10^6$ in^2 lbm

$I_m = I_{mx} + (M_{VCC})(d_{CG})^2$, where: d_{CG} is the distance (105 inches) between the cask CG and a rotation point on base rim

Thus, $I_m \cong 1.684 \times 10^6 + (533.4)(105)^2$

$= 7.565 \times 10^6$ in^2 lbm

Based on conservation of momentum, the impulse of the impact force on the missile is equated to the impulse of the force on the cask.

$M_M(v_2 - v_1) = I_m(\varpi_1 - \varpi_2)/H$,

at time t_1, v_1 = 185 ft/sec and ϖ_1 = 0 rad/sec

at time t_2, = v_2 = 0 ft/sec based on the following:

During the restitution phase, the final velocity of the missile will depend upon the coefficient of restitution of the missile, the geometry of the missile and target, the angle of incidence, and on the amount of energy dissipated in deforming the missile and target. It is assumed, based on tests conducted by EPRI, (Ref. EPRI Report NP-440) that the final velocity of the missile, v_f, following the impact is zero. If it is conservatively assumed that all of the missile energy is transferred to the cask:

Then: $(10.25)(v_2 - 185 \text{ ft/sec} \times 12 \text{ in/ft}) = 7.565 \times 10^6 \text{ in}^2\text{lbm}\,(0 - \varpi_2)/160$

Setting v_2 = 0 and solving for ϖ_2,

ϖ_2 = 0.481 rad/sec

and $v_2 = 205\ \varpi_2$

Then, $v_2 = (205)(0.481) = 98.6$ in/sec

Equating the impulse of the force on the missile during restitution to the impulse of the force on the cask yields:

$$-[M(v_f - v_2] = I_m(\varpi_f - \varpi_2)/H$$

With: $v_f = 0$, $v_2 = 98.6$ in/sec and $\varpi_2 = 0.481$ rad/sec

Then: $-[10.25(0 - 98.6)] = 7.565 \times 10^6\ in^2 lbm\ (\varpi_f - 0.481)/160$

$\varpi_f = 0.502$ rad/sec

Thus, the final energy of the cask following the impact, E_k, is:

$$E_k = (I_m)(\varpi_f)^2/(2)$$
$$= (7.565 \times 10^6)(0.502)^2/(2)$$
$$E_k = 9.53 \times 10^5\ in\text{-}lb_f$$

The energy required to overturn cask must be equal to or greater than its potential energy, E_p:

$$E_p = (W_{VCC})(h_{PE})$$
$$E_p = 206{,}100\ lbs \times 21.77\ in$$
$$E_p = 4.487 \times 10^6\ in\text{-}lb_f$$

The high energy tornado generated missile imparts insufficient kinetic energy to produce a cask overturning due to the missile impact.

Combined Tornado Wind and Missile Loading (High Energy Missile)

The cask rotation due to the heavy missile impact is calculated as:

$$h_{EK} = E_k / W_{VCC} = 9.53 \times 10^5\ in\text{-}lb_f / 206{,}100.\ lbs = 4.63\ in$$

Then: $\cos\beta = (h_{CG} + h_{KE}) / d_{CG}$

$\cos\beta = (83.2 + 4.63) / 104.97 = 0.8367$

$\beta = 33.21$ deg

$\cos\alpha = 83.2 / 104.97 = 0.7926$

$\alpha = 37.57$ deg

$e = d_{CG} \sin\beta$

$e = 104.97 \sin 33.21 = 57.49$ in

Thus, cask rotation after impact = $\alpha - \beta = 37.57 - 33.21 = 4.36$ deg

Available gravity restoration moment after missile impact = $(W_{VCC})(e)$

= 206,100. lb x 57.49 in / 12 =

987,391 ft-lb >> Tornado Wind Moment = 157,267. ft-lb

Therefore, the combined effects of tornado wind loading and the high energy missile impact loading will not overturn the cask.

Local Shear Strength Capacity of Concrete Shell (High Energy Missile)

This section evaluates the shear strength of the concrete at the top edge of the concrete shell due to a high energy missile impact based on ACI 349-85, Chapter 11, Section 11.11.2.1, on concrete punching shear strength.

The force developed by the missile using the methodology presented in Topical Report, BC-TOP-9A, is:

$F = 0.625(v)(W_M)$

$F = 0.625(185 \text{ ft/sec})(3960 \text{ lbs}) = 457.8$ kips

$F_u = LF \times F = 1.1 \times 457.8 = 503.6$ kips

Based on a rectangular missile contact area, having proportions of 2 horizontal to 1 vertical and the top of the area flush with the top of the concrete cask, the required missile contact area based on the concrete punching shear strength , neglecting reinforcing is:

$V_c = (2+4/\beta_c)(f_c')^{1/2} b_o\, d$, where $\beta_c = 2/1 = 2$
$V_c = 4 (f_c')^{1/2} b_o\, d$
$d = 21 \text{in} - 3 \text{ in} = 18 \text{ in}$
$(f_c')^{1/2} = 63.24$ psi, where $f_c' = 4{,}000$ psi
b_o = perimeter of punching shear area at d/2 from missile contact area
$b_o = (2b + 18) + 2(b + 9) = 4b + 36$
$V_u = \Phi(V_c + V_s)$, where $V_s = 0$, assuming no steel shear
$V_u = \Phi V_c = \Phi\, 4 (f_c')^{1/2} b_o\, d = (.85)(4)(63.24)(4b + 36)(18)$
$= 15{,}481\, b + 139{,}330.$

Setting, V_u equal to F_u and solving for b

$503.6 \times 10^3 = 15{,}481\, b + 139{,}330$
$b = 23.53$ inches (say 2.0 ft)

The implied missile impact area required = $2b \times b = 2 \times 2 \times 2 = 8.0 \text{ sq ft} < 20.0 \text{ sq ft}$

Thus, the concrete shell alone, based on the concrete conical punching strength and discounting the steel reinforcement and shell, has sufficient capacity to react to the high energy missile impact force.

The effects of tornado winds and missiles have been considered both separately and combined in accordance with NUREG-800, Section 3.3.2 II.3.d. For the case of tornado wind plus missile loading, the stability of the cask has been assessed and found to be acceptable. Equating the kinetic energy of the cask following missile impact to the potential energy yields a maximum postulated rotation of the cask, as a result of the impact, of 4.36 degrees. Applying the total tornado wind load to the cask in this configuration results in an available restoring moment considerably greater than the tornado wind overturning moment. Therefore, overturning of the cask under the combined effects of tornado winds, plus tornado-generated missiles, does not occur.

11.2.13.2.3 Tornado Effects on the Canister

The postulated tornado wind loading and missile impacts are not capable of overturning the cask, or penetrating the boundary established by the concrete cask. Consequently, there is no effect on the canister.

11.2.13.3 Radiological Consequences

This evaluation shows that there is little potential for significant damage to the concrete cask, which provides radiation shielding.

Under the worst tornado missile impact, a penetration of 5.68 inches into the concrete shield is possible. This would result in a local surface radiation dose rate at the point of penetration of 125 mrem/hr. Since the area of reduced shielding is very small, there would not be a noticeable increase in the dose rate at the site boundary. The estimated dose rate is well below the 1000 mrem/hr limit for dose rates one meter from the cask wall after an accident.

Repair of the damage would likely require two persons to form the damaged area and apply grout. This is estimated to require 30 minutes. The estimated extremity dose is 125 mrem. The whole body dose would be less. The dose rate of clearing inlets and outlets has been estimated in Section 11.1.1.3 at approximately 25 mrem per opening.

11.2.13.4 NAC-MPC Performance

The concrete cask is demonstrated to be stable in tornado wind loading in conjunction with impact from a high energy tornado missile. The performance of the NAC-MPC is not significantly affected by the tornado event.

The storage cask has a safety factor of 7.0 against overturning under the sustained maximum wind loading. The maximum concrete shell stresses under maximum tornado wind loading are 3.34 psi in shear and 11.51 psi in bending, which are well below their respective ACI 349-85 code allowables of 107.5 psi and 1904 psi, respectively.

The concrete shell of the storage cask is more than three times thicker than the calculated missile penetration depth, which is adequate to prevent significant scabbing of the concrete.

11.2.13.5 Recovery and/or Corrective Actions

A tornado event is not expected to result in the need to take any corrective action other than an inspection of the ISFSI. This inspection would be directed at ensuring that inlets and outlets had not become blocked by wind-blown debris and at checking for obvious (concrete) surface damage.

As shown in the evaluation, in the worse case, a missile could dislodge concrete to a depth of approximately 6 inches. To repair the cask surface this area would need to be filled with grout. As noted, penetration to 6 inches is unlikely, since the reinforcing bar cage is encountered at a depth of 2 to 3 inches, depending on the location on the cask surface.

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11.3 Design Basis Loading of the Transportable Storage Canister

The Transportable Storage Canister (canister) is designed to be stored in the NAC-MPC storage cask and transported in the NAC-STC Storable Transport Cask. The NAC-STC is licensed to transport spent fuel in accordance with 10CFR71, and has been issued Certificate of Compliance Number 71-9235. The NAC-STC has a design weight when loaded of 250,000 pounds, and is intended to be transported by rail.

An amendment to the Safety Analysis Report (SAR) for the NAC-STC is being requested, in conjunction with this Safety Analysis Report for storage of Yankee class fuel, to include the loaded canister as authorized contents.

The load condition imposed on the canister and its basket by the transport conditions—including the 30 foot end and side impacts and the fire accident—are more rigorous than those imposed by design basis storage normal, off-normal and accident conditions.

Sections 11.1.2 and 11.2.11 use the results of analysis performed for transport end and side impact conditions to show adequate performance of the canister in the canister off-normal handling condition (Section 11.1.2) and of the canister and basket in the 6-inch concrete cask drop accident (Section 11.2.11). This section summarizes the transport analysis upon which the results of sections 11.1.2 and 11.2.11 are based. The canister and basket are evaluated in accordance with ASME Section III, Subsection NB, and Subsection NG, respectively.

The complete evaluation of the transport normal and accident conditions loading on the canister and basket is presented in the NAC-STC SAR, Docket Number 71-9235.

11.3.1 Canister Impact Analysis

The canister is a right-circular shell fabricated from rolled 5/8-inch thick, Type 304L stainless steel plate and closed by a 1-inch thick, Type 304L stainless steel plate that is welded to one end of the shell. The canister is closed at the top end by the installation and welding of the 5-inch thick, Type 304 stainless steel shield lid and the 3-inch thick, Type 304L stainless steel structural lid.

11.3.1.1 Finite Element Model Description - Canister

A finite element model of the canister was constructed using ANSYS solid (SOLID45) elements. The model represents a one-half (180°) section of the canister and basket. The basket support discs were modeled with three-dimensional shell (SHELL63) elements. The model uses gap-spring elements to simulate contact between adjacent components. Interaction between the basket and canister were accomplished using three-dimensional gap elements (CONTACT52) along the periphery of the support disks. Contact between the canister and the cask inner shell is also modeled using CONTACT52 gap elements. Contact between the canister structural lid and shield lid is modeled using COMBIN40 combination elements in the axial degree of freedom. Simulation of the backing ring is accomplished using a ring of COMBIN40 spring gap elements connecting the shield lid and the canister in the axial direction at the lid lower outside radius. In addition, CONTACT52 elements are used to model interaction between the structural lid and canister shell and the shield lid and canister shell just below the respective lid weld joints. The size of the CONTACT52 gaps were determined from the nominal dimensions of contacting components. The COMBIN40 elements used between the structural and shield lids and for the backing ring were assigned small gap sizes of 1E-8 inches. All gap-spring elements are assigned a stiffness of 1E8 lb/in.

Boundary conditions were applied to enforce symmetry at the plane of symmetry of the model. All nodes on the cask shell side of the canister to cask spring gap elements were fixed in all degrees of freedom. In addition, the axial and inplane rotational degrees of freedom of the basket nodes were fixed.

Figure 11.3.1.1-1 is a plot of the entire canister finite element model. An isolated view of the canister shield and structural lids portion of the model is presented in Figure 11.3.1.1-2 and an enlarged view of the model in the structural lid and shield lid weld regions is shown in Figure 11.3.1.1-3. The canister bottom plate portion of the model is shown in Figure 11.3.1.1-4. Identification of the sections for evaluating the linearized stresses in the canister is shown in Figure 11.3.1.1-5.

In the bottom end impact orientation, the fuel weight as well as the basket weight are transferred to the canister bottom plate. In the finite element model, the canister content weight is represented by applying a pressure load to the surface of the canister bottom plate. The support

disks inside the canister as shown in Figure 11.3.1.1-1 are set to be in-active for the bottom end impact analysis. The canister bottom plate is considered to be fully supported.

For the side impact condition, the loads from the canister contents weight is transferred through the support disks into the canister wall, which is considered to be backed by a rigid shell support of 71.0 inside diameter. The basket, canister and the assumed support shell have different radii which implies that the contact angle between the components is dependent on the loading. Gap elements between the basket and the canister allow the interface to be dependent on the loading. The interface between the canister and the support shell is also represented by gap elements. The load due to the contents is applied to the basket via pressure acting in the plane of the disks. The weight is assumed to act over the effective width of 8.254 inches in which the disk is 0.5 inches thick. The content weight includes the 900 pounds per fuel assembly (for 36 fuel assemblies) plus the fuel tube weight (58.6 pounds/tube). This weight is distributed over the 22 support disks.

Use of the minimum size gap between the transportable storage canister structural and shield lids, $1x10^{-8}$ inch, results in the maximum stress and minimum margin of safety for the transportable storage canister impact analysis. Use of the maximum gap size (0.08 inches) results in a reduced margin of safety in some section locations, but does not result in the maximum stress / lowest margin of safety condition.

Figure 11.3.1.1-1 Canister Assembly Finite Element Model

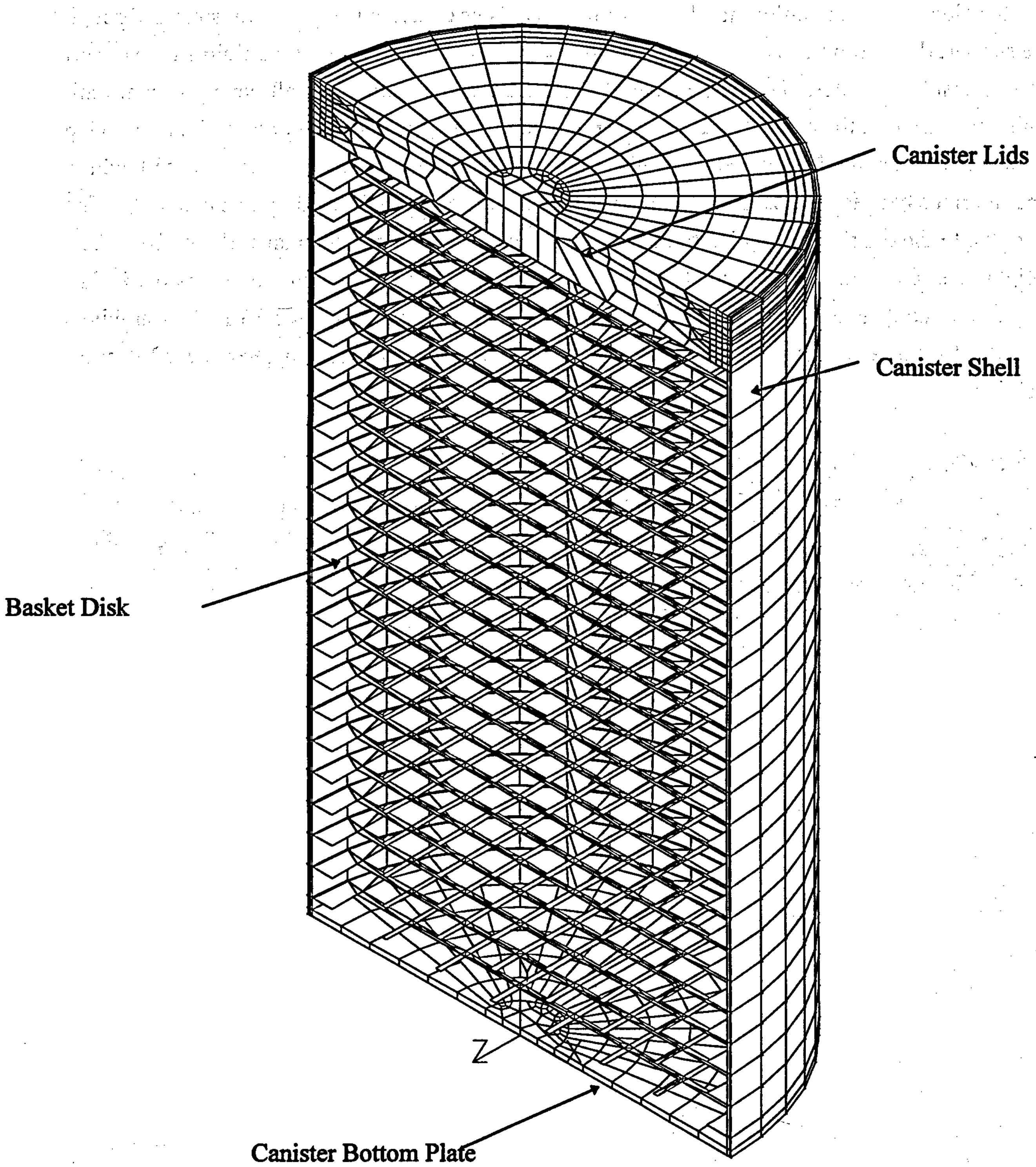


Figure 11.3.1.1-2 Canister Structural and Shield Lid Finite Element Mesh

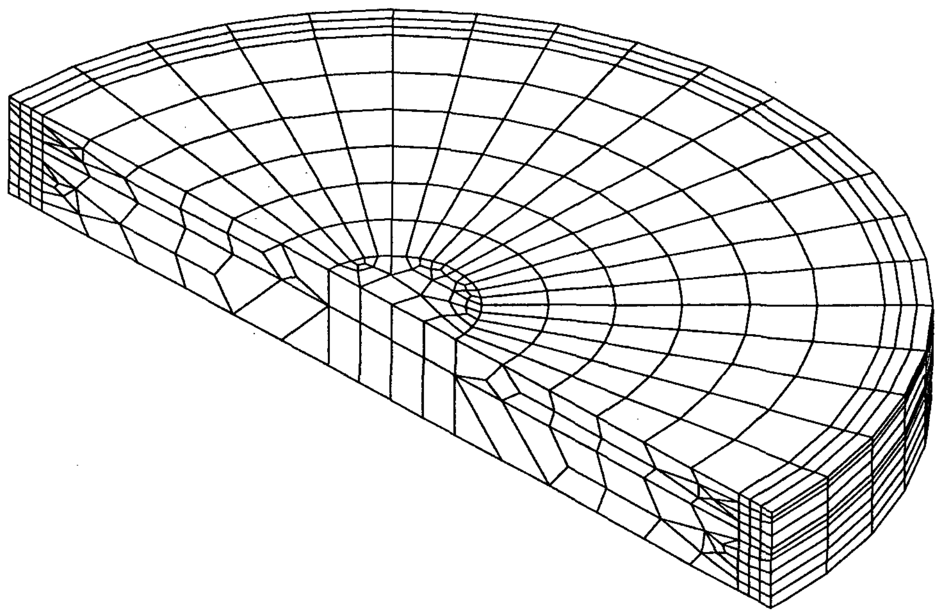


Figure 11.3.1.1-3 Structural and Shield Lid Weld Regions Finite Element Mesh

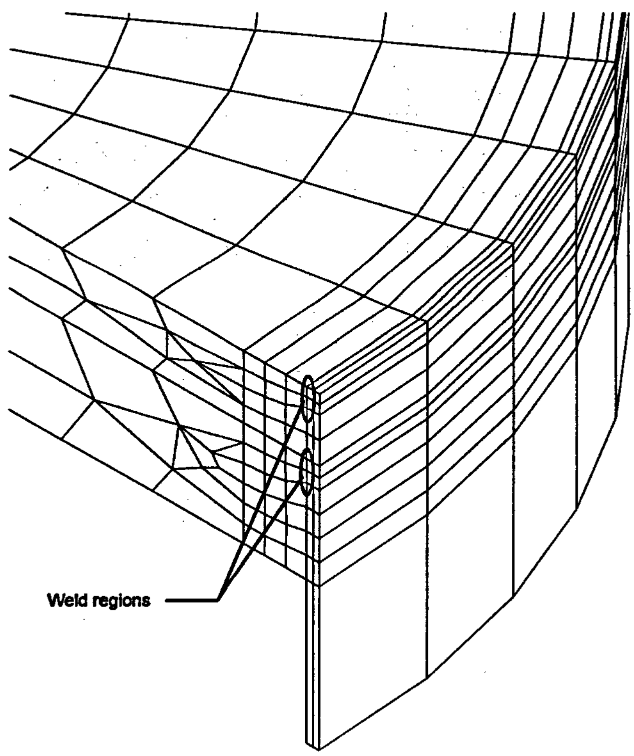


Figure 11.3.1.1-4 Canister Bottom Plate Finite Element Mesh

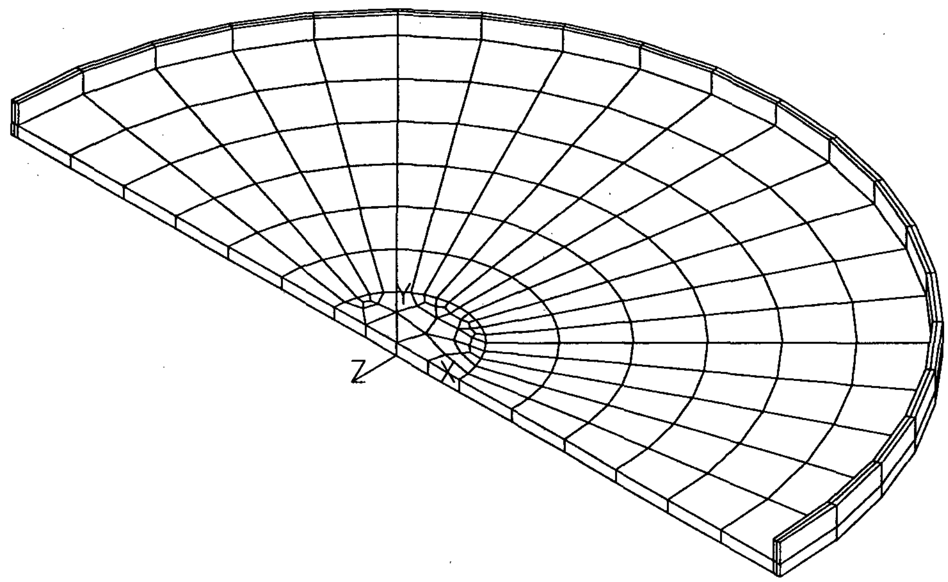
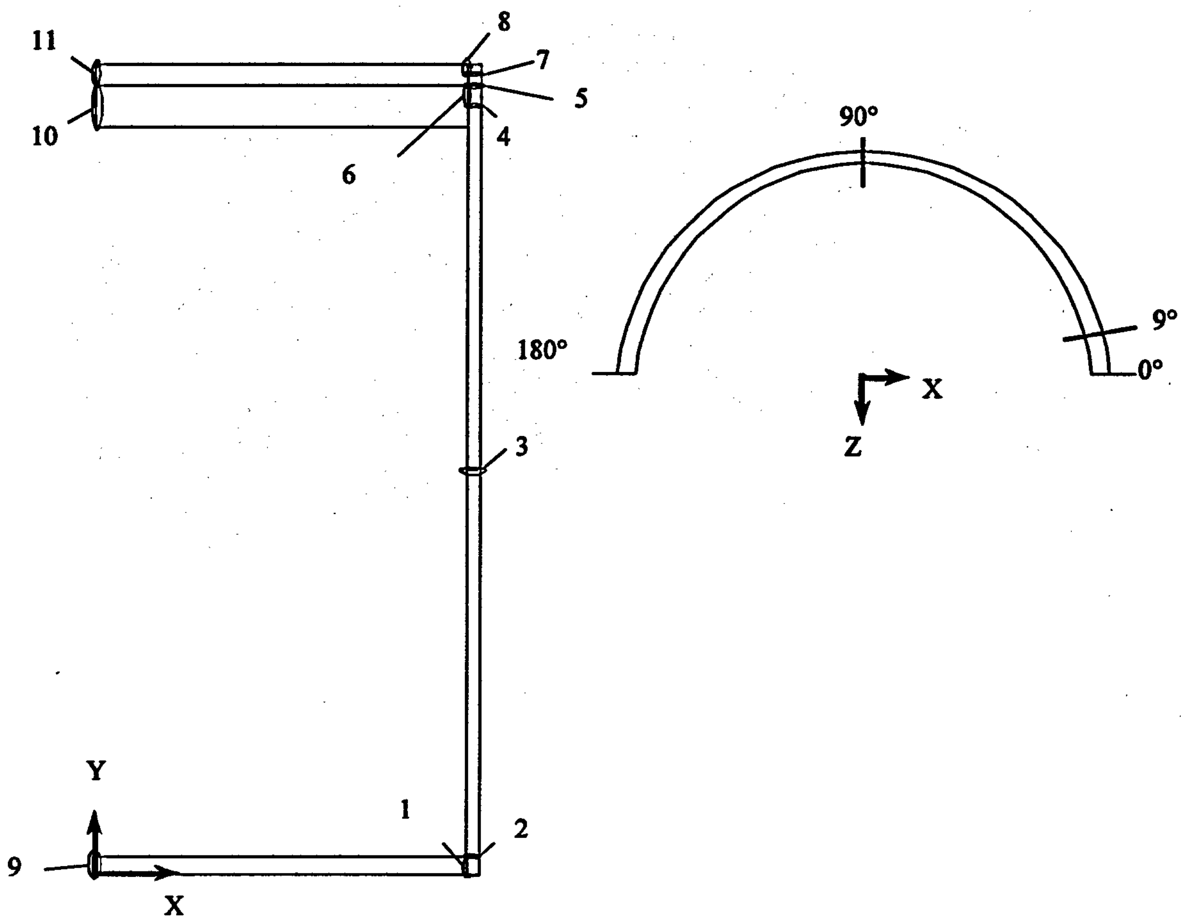


Figure 11.3.1.1-5 Identification of the Sections for Evaluating the Linearized Stresses in the Canister



Section	Node 1		Node 2	
	X (in.)	Y (in.)	X (in.)	Y (in.)
1	34.695	0.000	34.695	1.000
2	34.695	1.000	35.320	1.000
3	34.695	57.269	35.320	57.269
4	34.695	118.000	35.320	118.000
5	34.695	119.000	35.320	119.000
6	34.695	118.000	34.695	119.000
7	34.695	121.120	35.320	121.120
8	34.695	121.120	34.695	122.000
9	0.000	0.000	0.000	1.000
10	0.000	114.000	0.000	119.000
11	0.000	119.000	0.000	122.000

The actual length of the canister is 122.5 inches. There is no significant effect on the analysis results due to the 0.5-inch difference in the evaluated length and the actual canister length.

11.3.1.2 Canister Bottom and Side Impact Analysis

This section documents the evaluation of the canister for the 56.1 g bottom end impact and 55 g side impact load conditions. In addition to the impact loads, a 20 psig pressure load internal to the canister is considered. Note that the use of 20 psig is conservative since the maximum internal pressure for the canister is 11.32 psi for normal conditions of storage. To determine the effect of the 20 psig pressure load, analyses with and without the pressure load were performed. The maximum nodal stresses are summarized as:

Impact Orientation	Internal Pressure (psi)	Maximum Stress Intensity (ksi)
Bottom End	0	4.6
Bottom End	20	3.0
Side	0	24.5
Side	20	27.1

It is concluded that the impact loading without pressure is the limiting condition for the bottom end impact case. For the side impact case, the addition of pressure to the impact loading is limiting. Therefore, a 20 psig pressure is conservatively applied to the inner surface of the canister model for the side impact conditions while no internal pressure is used for the bottom end impact analyses.

The analysis results of the 56.1 g bottom impact conditions are presented in Tables 11.3.1.2-1 and 11.3.2-2. Results for the 55 g side impact condition are shown in Tables 11.3.1.2-3 and 11.3.1.2-4. The section stresses presented in the tables are identified by a section number. A cross-section of the canister showing the section numbers is presented in Figure 11.3.1.1-5. A summary of the canister minimum Margins of Safety for the evaluated impact conditions are shown in Table 11.3.1.2-5. The margins of safety are calculated as: M.S. = (allowable stress/S.I.) -1; where S.I. is the calculated stress intensity.

For the bottom end impacts, the stresses are essentially uniform around the circumference. For the side impact, the stresses vary around the circumference. Therefore, the circumferential angle at which the maximum stress occurs is noted in the table, in parentheses beside the section number. The allowable stresses presented in the tables are for Type 304L stainless steel, except

for section 10, which is for Type 304 stainless steel. These allowables are evaluated at 350°F (maximum calculated temperature in the canister is 319°F for normal conditions of storage).

Additionally, stress results for a 20 g bottom end impact and a 20 g side impact are listed in Table 11.3.1.2-6 through 11.3.1.2-9. Since the results are bounded by those of the 56.1 g bottom end impact and the 55 g side impact conditions, the stresses are listed without showing the Margin of Safety.

Table 11.3.1.2-1 Canister Analysis Results for the 56.1 g Bottom End Impact (Primary Membrane Stress)

Section No.	Component Stresses (psi)						Principal Stresses (psi)			S.I.	Allow. Stress	Margin of Safety
	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3			
1	-70.7	-1971.0	-361.1	176.2	70.3	22.4	-51.8	-360.9	-1990.0	1938.0	39000	19.12
2	289.7	-5185.0	-1182.0	91.4	54.3	94.4	297.4	-1187.0	-5187.0	5485.0	39000	6.11
3	2.1	-4867.0	0.9	0.0	0.2	0.0	2.1	0.9	-4867.0	4869.0	39000	7.01
4	-2131.0	-2251.0	-1084.0	0.0	734.3	0.0	-729.3	-2131.0	-2605.0	1876.0	39000	19.79
5	2510.0	-2096.0	-1535.0	-310.9	-0.9	278.1	2549.0	-1553.0	-2117.0	4667.0	39000	7.36
6	551.9	1897.0	-676.0	15.4	84.7	-106.6	1900.0	561.0	-688.0	2588.0	39000	14.07
7	-3028.0	979.9	-1533.0	-368.1	39.6	55.9	1014.0	-1531.0	-3063.0	4077.0	39000	8.57
8	588.3	-3496.0	-2019.0	466.6	119.6	210.4	659.5	-2031.0	-3554.0	4214.0	39000	8.25
9	82.5	-682.0	94.2	6.5	58.3	-0.5	98.5	82.5	-686.4	785.0	39000	48.68
10	183.8	-98.9	168.1	43.7	-77.1	5.7	195.2	183.5	-125.7	320.9	5640	41.22
11	-469.6	-9.4	-467.5	48.0	-75.2	-1.2	7.4	-470.1	-483.8	491.2	39000	78.40

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-2 Canister Analysis Results for the 56.1 g Bottom End Impact (Primary Membrane Plus Primary Bending Stress)

Section No.	Component Stresses (psi)						Principal Stresses (psi)			S.I.	Allow. Stress	Margin of Safety
	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3			
1	398.0	-2678.0	-380.7	125.9	67.7	37.0	405.2	-380.8	-2685.0	3090.0	58500	17.93
2	-1988.0	-7553.0	85.1	0.0	-32.4	0.0	85.2	-1988.0	-7553.0	7638.0	58500	6.66
3	2.1	-4867.0	2.9	1.1	0.4	-0.1	3.0	2.1	-4867.0	4870.0	58500	11.01
4	-2259.0	-3096.0	-704.5	0.0	805.1	0.0	-458.8	-2259.0	-3342.0	2883.0	58500	19.29
5	1450.0	-10380.0	-4379.0	304.5	3.7	410.7	1486.0	-4407.0	-10390.0	11880.0	58500	3.92
6	3324.0	5269.0	932.2	817.6	53.3	-170.6	5567.0	3041.0	917.1	4650.0	58500	11.58
7	-2361.0	8380.0	938.8	-472.4	41.6	196.1	8401.0	950.4	-2393.0	10790.0	58500	4.42
8	4403.0	-1585.0	-491.6	605.7	160.4	345.7	4490.0	-503.9	-1659.0	6149.0	58500	8.51
9	105.1	-686.4	100.3	8.1	60.4	-1.7	106.1	104.0	-691.1	797.2	58500	72.38
10	6941.0	230.8	6895.0	28.2	-72.6	35.9	6960.0	6876.0	229.9	6730.0	65200	8.69
11	-4093.0	-195.3	-4098.0	47.4	-79.5	-18.6	-193.1	-4079.0	-4115.0	3922.0	58500	13.92

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-3 Canister Analysis Results for the 55 g Side Impact + Internal Pressure (20 psi) (Primary Membrane Stress)

Section[1]	Component Stresses (psi)						Principal Stresses (psi)				Allow.	Margin of
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.	Stress	Safety
1(0°)	-14680.4	1080.1	-9311.6	-235.5	-21.1	-904.6	1083.2	-9163.7	-14827.2	15917.7	39000	1.45
2(0°)	-3395.4	62.4	-7415.7	-314.3	-438.9	-478.6	111.6	-3358.7	-7501.7	7612.8	39000	4.12
3(180°)	-4.6	-1213.2	586.7	0.1	-4.0	-45.8	590.3	-8.1	-1213.2	1802.5	39000	20.64
4(9°)	-16945.4	3043.0	-4750.2	-336.0	2851.1	2020.7	3978.4	-5329.0	-17301.9	21276.1	39000	0.83
5(0°)	-10863.5	1232.1	-7804.7	-1756.4	1333.8	92.4	1662.0	-7961.0	-11146.6	12803.4	39000	2.05
6(0°)	-23467.7	-3813.8	-11125.6	-2768.3	1168.1	38.0	-3262.2	-11293.4	23855.7	20594.5	39000	0.89
7(9)	-11503.1	654.7	-4158.7	-31.6	1865.5	961.7	1299.2	-4673.6	-11639.5	12939.7	39000	2.01
8(0°)	-19367.6	-4979.8	-8614.2	-982.6	865.8	-756.5	-4697.7	-8785.2	-19472.5	14774.8	39000	1.64
9	-2146.5	-15.3	1105.2	-2.9	-14.7	-78.0	1107.3	-15.5	-2148.6	3255.9	39000	10.98
10	-1032.3	-8.4	331.8	-59.4	-2.9	-27.1	332.3	-4.9	-1036.3	1368.4	45640	32.35
11	-1131.4	-1.3	373.3	-25.5	-5.1	-32.8	374.1	-0.7	-1132.5	1506.8	39000	24.88

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-4 Canister Analysis Results for the 55 g Side Impact + Internal Pressure (20 psi) (Primary Membrane Plus Primary Bending Stress)

Section[1]	Component Stresses (psi)						Principal Stresses (psi)				Allow.	Margin of
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.	Stress	Safety
1(0°)	-24841.3	457.1	-12761.5	-195.8	106.1	-824.5	459.5	-12709.0	-24904.3	25365.6	58500	1.31
2(0°)	-2630.9	-1326.5	-8993.8	-290.8	-641.0	-126.3	-1218.5	-2682.3	-9050.5	7832.0	58500	6.47
3(0°)	89.9	2039.5	3198.2	2.7	38.7	156.9	3207.7	2038.5	81.9	3125.9	58500	17.71
4(9°)	-13894.0	9446.8	-2019.6	93.3	2241.9	2829.1	9886.2	-1813.0	-14533.6	24421.9	58500	1.40
5(0°)	-14261.0	2077.3	-6923.9	-2052.1	1046.5	-15.1	2446.4	-7037.2	-14512.6	16966.3	58500	2.45
6(0°)	-32968.0	-7832.0	-15215.2	-4140.9	1477.5	185.3	-6920.8	-15456.4	-33639.1	26718.3	58500	1.19
7(9°)	-9079.8	4969.3	-1993.4	53.6	1402.0	1674.6	5250.3	-1894.8	-9460.5	14711.9	58500	2.98
8(0°)	-28144.4	-7245.8	-12646.1	-2107.7	1351.6	-307.9	-6716.3	-12971.2	-28354.1	21643.1	58500	1.70
9	-2172.7	-33.2	1088.4	-2.9	-14.9	-75.6	1089.5	-33.5	-2174.8	3264.3	58500	16.92
10	-1360.0	-10.9	297.9	-63.0	-2.9	-40.8	299.0	-8.0	-1364.2	1663.1	65200	38.20
11	-1344.3	-1.2	354.1	-25.6	-5.0	-39.5	355.1	-0.7	-1346.4	1700.8	58500	33.40

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-5 Summary of Minimum Margin of Safety for Canister Impact Analysis

Drop Orientation	Loading Condition	Stress Evaluated	Minimum Margin of Safety	Section No.*
bottom end	56.1 g impact	P_m	6.11	2
bottom end	56.1 g impact	$P_m + P_b$	3.92	5
side	55 g impact + internal pressure (20 psi)	P_m	0.83	4
side	55 g impact + internal pressure (20 psi)	$P_m + P_b$	1.19	6

* See Figure 11.3.1.1-5 for section locations.

Table 11.3.1.2-6 Bottom End Impact (20 g) - Primary Membrane Stresses[1]

Section	P_m Stresses (psi)						Principal Stresses (psi)			
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.
1	-25.3	-704.5	-129.2	63.1	25.1	8.0	-18.5	-129.1	-711.3	692.8
2	103.7	-1854.0	-422.7	32.7	19.4	33.8	106.4	-424.7	-1855.0	1961.0
3	0.8	-1740.0	0.3	0.0	0.1	0.0	0.8	0.3	-1740.0	1741.0
4	-760.4	-800.7	-389.0	0.0	263.2	0.0	-260.7	-760.4	-929.1	668.4
5	905.9	-756.4	-546.9	-107.1	0.2	99.9	919.5	-553.5	-763.5	1683.0
6	196.5	704.2	-233.2	5.1	30.5	-37.5	705.2	199.7	-237.4	942.6
7	-1072.0	339.2	-546.8	-127.7	13.9	19.5	350.9	-546.2	-1084.0	1435.0
8	207.7	-1240.0	-718.6	162.8	42.2	74.7	232.4	-723.0	-1260.0	1493.0
9	29.5	-243.2	33.7	2.3	20.8	-0.2	35.3	29.5	-244.7	280.0
10	70.7	23.7	69.5	16.0	-20.2	0.7	80.9	71.0	12.1	68.8
11	-161.1	50.4	-157.0	16.1	-39.4	-1.4	58.9	-161.5	-165.1	223.9

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-7 Bottom End Impact (20 g)-Primary Membrane Plus Primary Bending Stresses[1]

Section	$P_m + P_b$ Stresses (psi)						Principal Stresses (psi)			
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.
1	142.5	-957.2	-136.2	45.1	24.2	13.3	145.1	-136.2	-959.7	1105.0
2	-711.1	-2701.0	30.4	0.0	-11.5	0.0	30.5	-711.1	-2701.0	2731.0
3	0.8	-1741.0	1.0	0.4	0.1	0.0	1.053	0.8	-1741.0	1742.0
4	-808.8	-1111.0	-254.6	0.0	290.6	0.0	-165.3	-808.8	-1200.0	1035.0
5	522.1	-3735.0	-1569.0	111.2	1.6	147.5	535.4	-1580.0	-3738.0	4273.0
6	1194.0	1910.0	344.1	288.9	19.6	-60.7	2012.0	1097.0	338.7	1674.0
7	-838.6	2970.0	331.1	-166.6	14.8	69.5	2977.0	335.2	-850.0	3827.0
8	1555.0	-560.8	-178.8	213.3	56.8	122.6	1586.0	-183.1	-587.0	2173.0
9	37.6	-244.7	35.9	2.9	21.5	-0.6	38.0	37.2	-246.4	284.4
10	2529.0	140.9	2515.0	13.6	-17.2	12.0	2536.0	2508.0	140.7	2395.0
11	-1383.0	-19.4	-1389.0	14.6	-41.9	-6.1	-17.9	-1380.0	-1393.0	1375.0

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-8 Side Impact (20 g) + Internal Pressure (20 psi) - Primary Membrane Stresses[1]

Section	P_m Stresses (psi)						Principal Stresses (psi)			
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.
1	-10227.0	856.0	-4685.1	375.9	199.7	-908.3	873.9	-4543.6	-10386.4	11262.0
2	5431.7	1884.3	-732.0	-276.8	-292.7	-442.5	5481.0	1902.2	-800.0	6281.1
3	-692.7	765.9	1360.0	4.7	-5.3	114.9	1367.4	765.9	-699.1	2065.7
4	-292.6	2090.9	659.1	159.2	1019.3	427.2	2660.3	279.9	-482.3	3142.7
5	-9019.0	-32.9	-3701.6	-1049.6	954.2	-599.5	345.1	-3914.4	-9184.7	9529.7
6	-15561.2	-2614.2	-4803.6	-1996.5	811.3	-748.8	-2010.2	-5071.0	-15896.8	13883.5
7	1925.2	1097.9	814.8	69.9	485.8	-45.5	1931.5	1460.7	446.1	1484.8
8	-14051.2	-2852.2	-3555.8	-677.4	842.2	-1202.7	-2161.2	-4080.1	-14219.0	12058.9
9	-478.9	-198.6	806.7	71.4	22.0	-22.2	807.5	-181.7	-496.6	1304.5
10	-425.3	-1.7	78.9	-25.7	6.7	-10.9	79.7	-0.7	-427.1	506.8
11	-382.5	-2.7	174.5	-16.4	2.8	-13.3	174.9	-2.1	-383.6	558.5

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

Table 11.3.1.2-9 Side Impact (20 g) + Internal Pressure (20 psi) - Primary Membrane Plus Primary Bending Stresses[1]

Section	$P_m + P_b$ Stresses (psi)						Principal Stresses (psi)			
No.	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	S.I.
1	-26047.2	-2107.7	-10104.3	413.8	217.7	-1116.8	-2095.1	-10030.9	-26131.1	24044.4
2	-4429.3	-11241.0	1092.6	364.4	886.8	-75.4	1156.6	-4409.4	-11324.9	12478.3
3	-759.6	1198.5	2829.1	7.8	-5.9	227.3	2842.8	1198.5	-774.0	3617.7
4	599.0	4274.1	2236.7	208.0	755.2	1088.4	4603.4	2456.9	50.1	4553.0
5	-11146.6	26.7	-3044.1	-1644.2	728.4	-827.9	466.5	-3185.6	-11450.7	11912.1
6	-19996.8	-4548.8	-6797.0	-2643.5	1026.7	-594.2	-3707.8	-7185.0	-20447.7	16735.7
7	2385.6	321.5	419.3	86.5	664.6	-648.9	1677.8	651.1	-962.1	2639.3
8	-18046.4	-4398.9	-5819.7	-1420.9	1203.8	-864.6	-3522.2	-6506.6	-18235.2	14711.9
9	-956.6	-172.7	869.4	75.4	9.5	10.3	869.6	-165.6	-963.9	1833.0
10	-1095.8	-29.5	-493.6	-25.3	7.2	-18.4	-28.7	-493.2	-1096.8	1068.5
11	-814.4	-19.7	-190.1	-16.0	3.0	-15.9	-19.4	-189.8	-815.2	795.8

1. Sections are identified in Figure 11.3.1.1-5. Stresses are reported in a cylindrical coordinate system (X,Y,Z) corresponding to radial, circumferential and axial directions respectively.

11.3.1.3 Canister Buckling Evaluation for the Bottom End Impact

The canister shell is axially loaded by the weights of the structural lid, the shield lid, and the inertial weight of the shell during a bottom end impact. The impact load amplification factor is 56.1g's. The shell is evaluated as an unsupported, right circular cylinder using a critical buckling load per Blake, 2nd Edition, "Practical Stress Analysis in Engineering Design."

$$S_{cr} = \frac{E\left(0.605 - 10^{-7} M^2\right)}{M\left(1 + 0.004\phi\right)}$$

$$= 40.3 \text{ ksi}$$

The canister material is Type 304L stainless steel. Conservatively assume the material temperature to be at 400°F for this impact condition.

$E = 26.5E+03$ ksi $R = (69.39 + 0.625)/2$

$= 35.01$ inches (mid-radius of the canister shell)

$S_y = 17.5$ ksi $t = 0.625$ inches. (thickness of the canister)

$\phi = E/S_y$ and $m = R/t$

$= 1514.3$ $= 56.0$

The axial compression load in the canister shell is

$$P_a = [(\pi /4) (69.03^2) (8)(0.291) + (\pi /4)(70.64^2 - 69.39^2)(121.5)(0.291)] (56.1)$$

$P_a = 761{,}457$ pounds

and the axial compression stress is

$$S_a = \frac{P_A}{\left(\pi/4\right)\left(70.64^2 - 69.39^2\right)}$$

$S_a = 5{,}540$ psi

The margin of safety is:

$(S_{cr}/S_a) - 1 = +\ 6.3$

11.3.2 Canister Fuel Basket End Impact Analysis

Section 11.2.11 uses the results of analysis performed for transport end and side impact conditions to show adequate performance of the basket in the 6-inch concrete cask drop accident. This section presents the transport end impact analysis upon which the results of Section 11.2.11 are based.

The fuel basket in the transportable storage canister is designed to contain up to 36 Yankee class fuel assemblies. The basket structure has a right circular cylinder configuration and consists of 36 square tubes supported by 22 circular support disks, and a circular top and bottom plate, which are retained by eight axial tie rods. The support disks and top and bottom plates are seperated and supported by split spacers at the tie rods. The configuration of the basket is shown in Figure 11.3.2-1.

Each fuel tube has an 7.8-inch square inside dimension, a 0.048-inch thick wall, and can hold one intact fuel assembly. The fuel assemblies together with the tubes are laterally supported in square holes in the stainless steel support disks. Each circular support disk is 0.5 inches thick and 69.15 inches in diameter. There are three different web widths in the support disks. One web width is 0.750 inches between the holes, one web width is 0.810 inches between the holes, and one web width is 0.875 inches between holes. The top and bottom plates are both 0.5 inch thick and have the same diameter as the support disks. The disks are spaced and retained by tie rods and split spacers (spacers) at eight locations near the periphery of each disk to form an integral basket assembly. The fuel basket contains the fuel and is enclosed by the canister. The canister has a 70.64 inch outer diameter and 5/8 inch thick walls. The overall length of the canister cavity is 122.5 inches, which encompasses the entire fuel assembly length and the thickness of the shield lid and structural lid. The canister shell is fabricated from Type 304L stainless steel.

The material of the support disks is 17-4 PH stainless steel. The top plate and the bottom plate are fabricated from Type 304 stainless steel. The fuel tubes are made from Type 304 stainless steel, which also encases the BORAL neutron absorbing material. The tie rods and spacers are fabricated from Type 304 stainless steel. The fuel tubes are not structural components; and are not considered in the basket evaluation. The tie rods and spacers locate and structurally assemble the circular support disks, heat transfer disks, and the top and bottom plates to form an integral assembly. The spacers carry the weight of the support disks, heat transfer disks, endplate and

their own weight in the end impact loading condition. The end impact analysis uses classical closed form methods that are evaluated independent of the finite element basket model. The support disk structural evaluation is performed using a finite element model of a single disk.

The structural analysis of the basket components is in accordance with ASME Code, Section III, Division 1, Subsection NG, "Core Support Structures." In addition, the stainless steel/BORAL composite fuel tube has been evaluated for a postulated impact load.

11.3.2.1 Stress Evaluation of Support Disk in the End Impact

To determine the structural adequacy of the support disks in the end drop event, a load equal to the weight of the fuel and tubes multiplied by an amplification factor is applied to the support disk structure to simulate an end impact. For accident conditions, the amplification factor for the end impact is 56.1 g.

A finite element analysis is performed, utilizing the ANSYS computer code, to calculate the stresses in a support disk in accordance with ASME Code Section III, Subsection NG. In this subsection, linearized stresses of cross sections of the structure are compared to the allowable stresses. The maximum primary membrane stress intensity calculated in the support disk is compared to the allowable stress limits for accident conditions is, 0.7 S_u or 2.4 S_m, whichever is less.

11.3.2.1.1 Finite Element Model Description

A finite element model is used to evaluate the basket support disk for the end impact accident condition in which the loads are perpendicular to the plane of the disk.

The model for the end drop condition is constructed using ANSYS SHELL63 elements. It consists of a single support disk with a thickness of 0.5 inches. The shell elements accommodate the out-of-plane bending, which is present in the end-drop condition. In the end drop, the support disk is restrained by the split spacers on the eight tie rods. The nodes corresponding to the location of the tie rods are restrained in the out of plane direction (the cask axial direction). Four additional in-plane transitional restraints are specified at the outer edge of the model (located 90° apart from each other) in the tangential direction to prohibit rigid body

displacements. The only loading is the inertial weight (56.1 g) of the support disk in the out-of-plane direction. The finite element model is shown in Figure 11.3.2-2.

Three thermal conditions are considered:

Thermal Condition	Ambient Temperature	Solar Insolence Applied to Cask Surface	12.5 kW Fuel Load
1	100°F	yes	yes
2	-40°F	no	yes
3	-40°F	no	no

The temperature distribution of the support disk for these Thermal Conditions are determined by the thermal analysis. The bounding thermal conditions (2 and 3) are used in the analysis to determine the material properties. Allowable stresses are determined based on conservative temperatures of 539° F for Thermal Condition 2 and -40° F for Thermal Condition 3.

To determine the most critical regions, a series of cross sections are considered. The section locations are identified in Figure 11.3.2-3. Table 11.3.2-1 shows the coordinate location of the cross section end points.

11.3.2.1.2 Support Disk End Impact Analysis Results

A structural analysis is performed using ANSYS to evaluate the effect of a 56.1 g end impact which corresponds to the most severe out-of-plane loading. Linearized stresses at the cross sections identified in Figure 11.3.2-3 are compared to stress allowables in accordance with the ASME Code, Section III, Subsection NG.

The stress evaluation results for the 56.1 g end impact condition are:

Thermal Condition	P_m Stress Intensity (ksi)	M.S.	P_m+P_b Stress Intensity (ksi)	M.S.
2	0	N/A	52.9	1.42
3	0	N/A	53.9	1.51

The margin of safety (M.S.) is:

M.S. = (Allowable Stress/Stress Intensity) –1,

where the allowable stress is 1.0 S_u for 17-4PH Type 630 stainless steel.

The minimum margin of safety is +1.42. The P_m stresses in the support disk for end drop conditions are essentially zero because there is no in-plane loading. Tables 11.3.2-2 and 11.3.2-3 list the 40 highest P_m+P_b stress intensities for thermal conditions 2 and 3 respectively.

11.3.2.2 Evaluation of Tie Rods and Spacers for an End Impact Condition

The design end impact loading for the [redacted] basket is 56.1 g. The structural capacity of the spacers supporting the basket is evaluated using classical analysis. Accident loading due to the 56.1 g impact of the fuel basket was compared to the stress limit of 0.7 S_u in accordance with Subarticle NF 1440 of the ASME Code.

No detailed evaluation of the tie rods is required. The tie rods serve basket assembly purposes and are not part of the load path for the condition evaluated. The tie rods are loaded during fabrication by a 190 ft-lbs preload. Under impact conditions, the preload will be reduced. The tie rod design is, therefore, acceptable by inspection.

During the end impact, the spacers are loaded with the weight of 22 support disks, the aluminum heat transfer disks, one end plate, and the weight of the spacers. The load is resisted by the effective area of 8 spacers. The compressive stresses are calculated on the effective area of the spacer.

The material allowable stress is conservatively selected at a temperature of 500°F. The analysis input is [redacted]:

stress limits	=	0.7 S_u (accident condition) (more limiting than 2.4 S_m)
loading criteria (g)	=	56.1g (accident condition)
evaluation temperature	=	500°F

Canister Basket Parameters

fuel basket weight	=	9,530 lbs
bottom weldment weight	=	438 lbs
fuel tube weight (36 tubes)	=	2,164 lbs
rod diameter	=	1.13 in
spacer outer diameter	=	2.50 in

Materials

tie rod	=	SA 479 Type 304 Stainless Steel
spacer	=	A511 Type 304 Stainless Steel

Material Allowable

Type 304 SS	=	S_m = 17,500 psi (500°F)
	=	S_u = 63,500 psi (500°F)

The spacer load is calculated as follows:

Total weight of basket	=	9,530 lbs
Less weight of bottom weldment	=	-438 lbs
Less weight of fuel tubes	=	-2,164 lbs
Therefore,		
1 g load on spacers	=	6,928 lbs
Applied g level	=	56.1g
End impact load on spacers	=	6,928 x 56.1
	=	388,661 lbs

The effective area of one spacer at each of eight locations supporting the weight of the support disks is equal to the net area of the spacer and is calculated as:

$$A = \frac{3.14 \times \left(2.5^2 - 1.25^2\right)}{4}$$

$$= 3.68 \text{ in}^2$$

The average compressive stress, S_c, in the spacer is:

$$S_c = \frac{388,661}{8 \times 3.68}$$

$$= 13,202 \text{ psi}$$

The allowable stress for Type 304 SS under accident conditions is 0.7 S_u.

S_u = 63,500 psi

0.7 S_u = 0.7 x 63,500

= 44,500 psi

The margin of safety (MS), which is defined as $\frac{0.7S_u}{S_c} - 1$, is calculated as:

$$\frac{44,450}{13,202} - 1 = 2.37$$

Therefore, the spacers are structurally adequate for a 56.1g end impact under accident conditions.

Figure 11.3.2-1 Canistered Yankee Class Fuel Basket Assembly

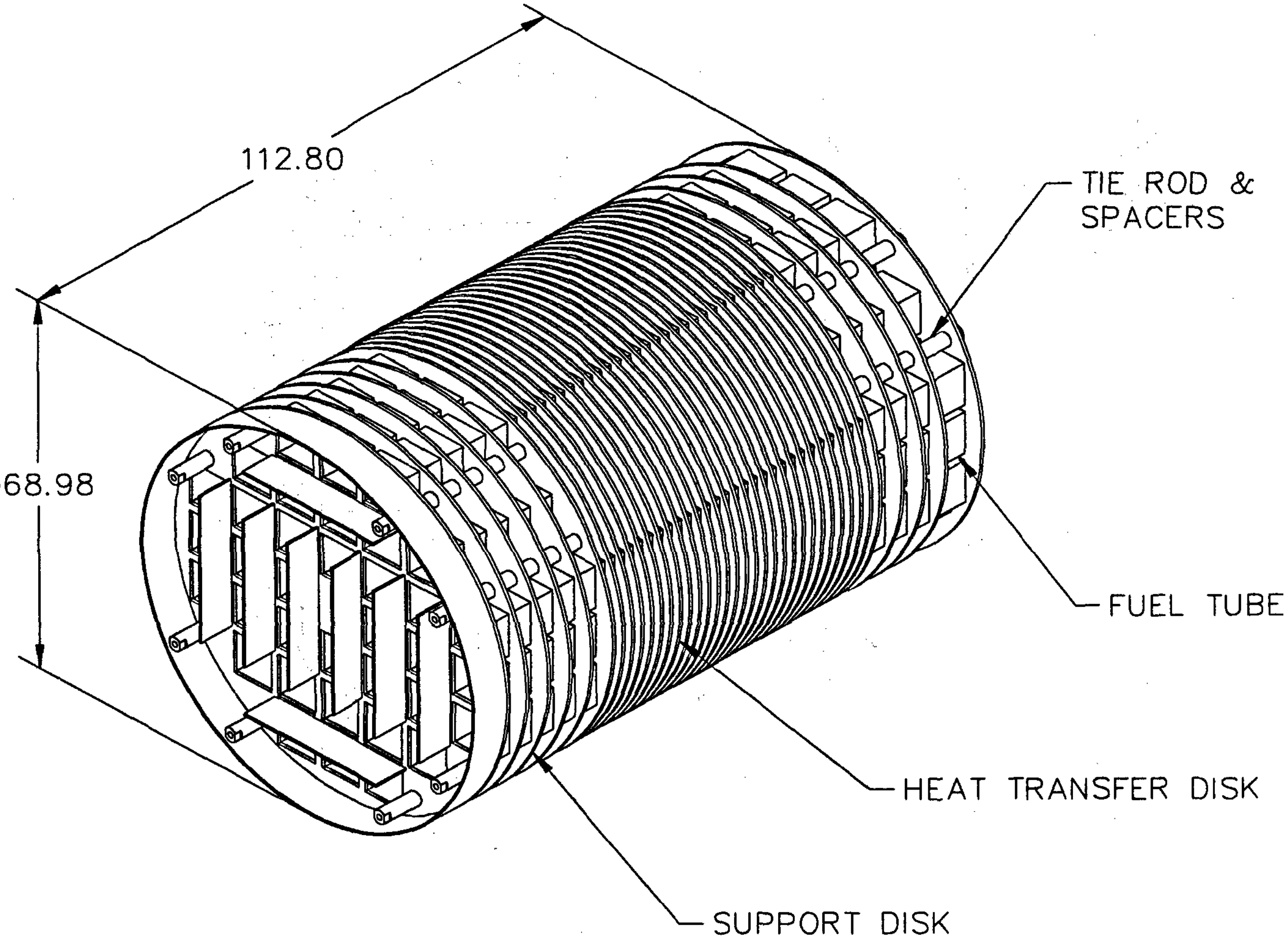


Figure 11.3.2-2 Fuel Basket Support Disk Finite Element Model

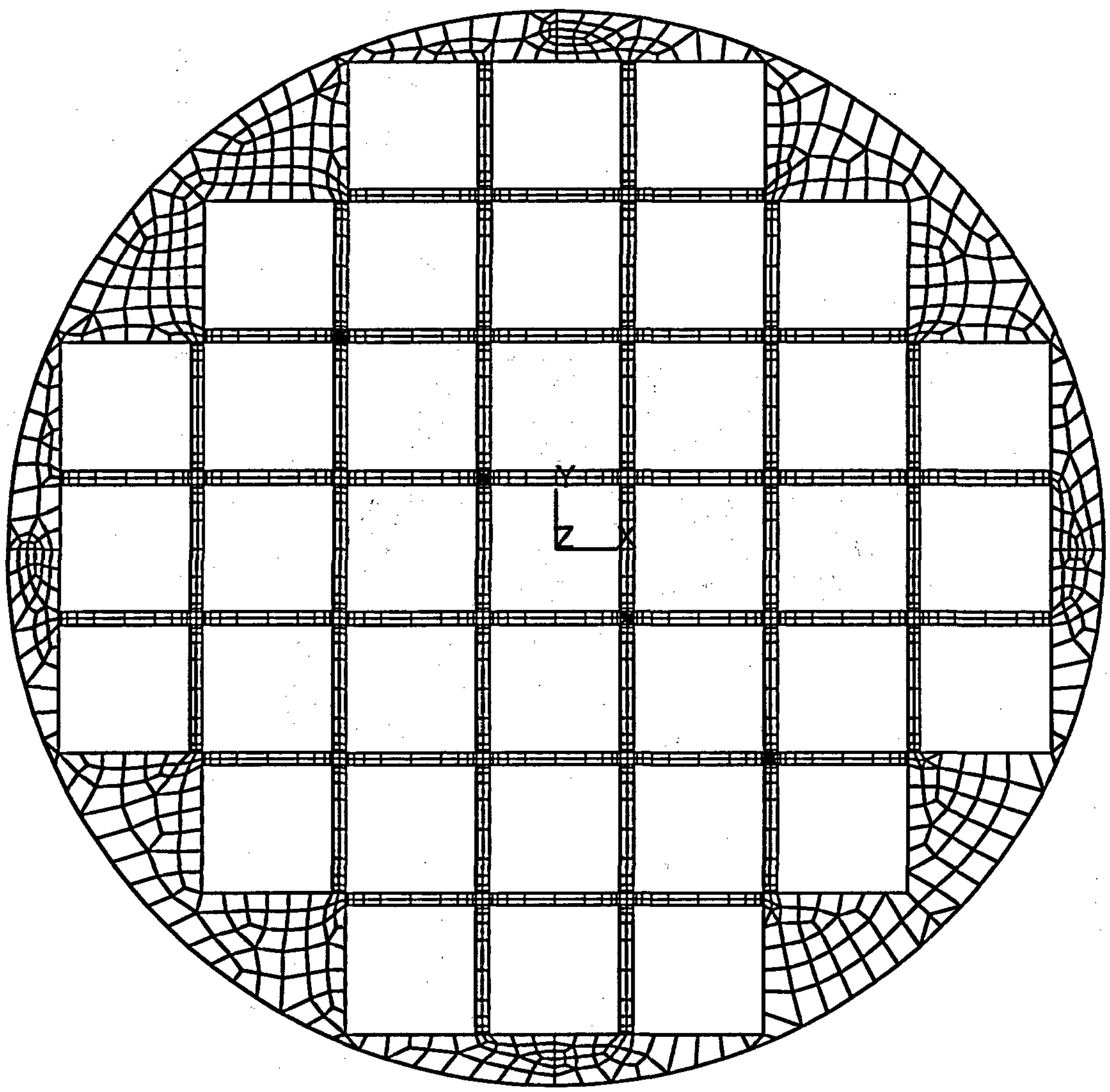


Figure 11.3.2-3 Location of the Support Disk Sections to Obtain Linearized Stresses

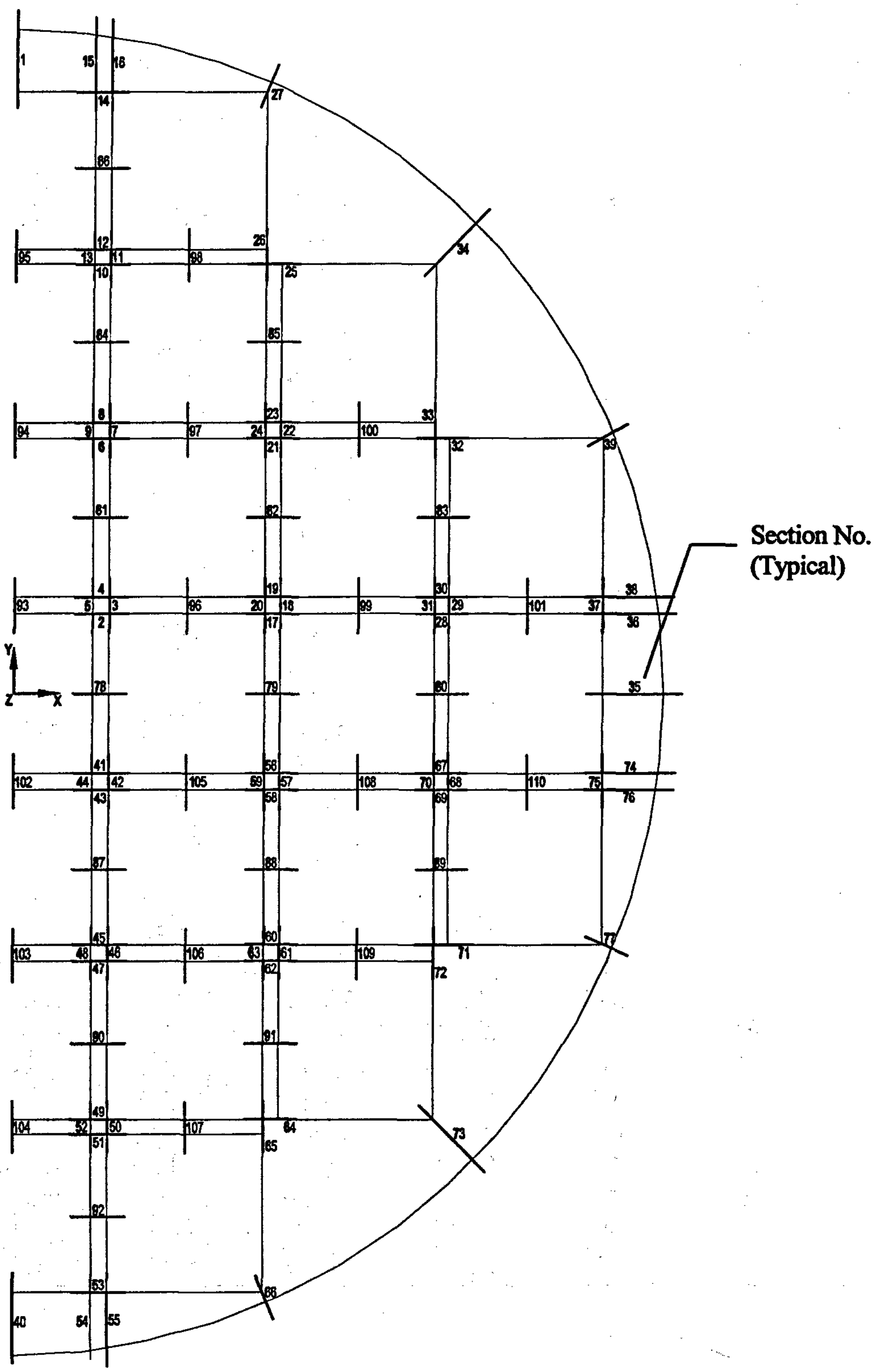


Table 11.3.2-1 Listing of Cross Sections for Stress Evaluation of the Support Disk (0° Basket Drop Orientation)

Section Number	Point 1	Point 2	Coordinates (in.) Point 1 X	Point 1 Y	Point 2 X	Point 2 Y
1	1	2	0.00	31.32	0.00	34.49
2	3	4	4.13	4.13	5.00	4.13
3	5	6	5.00	4.13	5.00	5.00
4	7	8	5.00	5.00	4.13	5.00
5	9	10	4.13	5.00	4.13	4.13
6	11	12	4.13	13.26	5.00	13.26
7	13	14	5.00	13.26	5.00	14.07
8	15	16	5.00	14.07	4.13	14.07
9	17	18	4.13	14.07	4.13	13.26
10	19	20	4.13	22.32	5.00	22.32
11	21	22	5.00	22.32	5.00	23.07
12	23	24	5.00	23.07	4.13	23.07
13	25	26	4.13	23.07	4.13	22.32
14	27	28	4.13	31.32	5.00	31.32
15	29	30	4.13	31.32	4.13	34.24
16	31	32	5.00	31.32	5.00	34.13
17	33	34	13.26	4.13	14.07	4.13
18	35	36	14.07	4.13	14.07	5.00
19	37	38	14.07	5.00	13.26	5.00
20	39	40	13.26	5.00	13.26	4.13
21	41	42	13.26	13.26	14.07	13.26
22	43	44	14.07	13.26	14.07	14.07
23	45	46	14.07	14.07	13.26	14.07
24	47	48	13.26	14.07	13.26	13.26
25	49	50	13.26	22.32	14.07	22.32
26	51	52	13.26	22.32	13.26	23.07
27	53	54	13.26	31.32	13.44	31.76
28	55	56	22.32	4.13	23.07	4.13
29	57	58	23.07	4.13	23.07	5.00
30	59	60	23.07	5.00	22.32	5.00
31	61	62	22.32	5.00	22.32	4.13
32	63	64	22.32	13.26	23.07	13.26
33	65	66	22.32	13.26	22.32	14.07
34	67	68	22.32	22.32	24.39	24.39
35	69	70	31.32	0.00	34.49	0.00

Table 11.3.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk (0° Basket Drop Orientation) (Continued)

			Coordinates (in.)			
Section	Point	Point	Point 1		Point 2	
Number	1	2	X	Y	X	Y
36	71	72	31.32	4.13	34.24	4.13
37	73	74	31.32	4.13	31.32	5.00
38	75	76	31.32	5.00	34.13	5.00
39	77	78	31.32	13.26	31.71	13.47
40	79	80	0.00	31.32	0.00	34.49
41	81	82	4.13	4.13	5.00	4.13
42	83	84	5.00	4.13	5.00	5.00
43	85	86	5.00	5.00	4.13	5.00
44	87	88	4.13	5.00	4.13	4.13
45	89	90	4.13	13.26	5.00	13.26
46	91	92	5.00	13.26	5.00	14.07
47	93	94	5.00	14.07	4.13	14.07
48	95	96	4.13	14.07	4.13	13.26
49	97	98	4.13	22.32	5.00	22.32
50	99	100	5.00	22.32	5.00	23.07
51	101	102	5.00	23.07	4.13	23.07
52	103	104	4.13	23.07	4.13	22.32
53	105	106	4.13	31.32	5.00	31.32
54	107	108	4.13	31.32	4.13	34.24
55	109	110	5.00	31.32	5.00	34.13
56	111	112	13.26	4.13	14.07	4.13
57	113	114	14.07	4.13	14.07	5.00
58	115	116	14.07	5.00	13.26	5.00
59	117	118	13.26	5.00	13.26	4.13
60	119	120	13.26	13.26	14.07	13.26
61	121	122	14.07	13.26	14.07	14.07
62	123	124	14.07	14.07	13.26	14.07
63	125	126	13.26	14.07	13.26	13.26
64	127	128	13.26	22.32	14.07	22.32
65	129	130	13.26	22.32	13.26	23.07
66	131	132	13.26	31.32	13.44	31.76
67	133	134	22.32	4.13	23.07	4.13

Table 11.3.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk (0° Basket Drop Orientation) (Continued)

			Coordinates (in.)			
Section	Point	Point	Point 1		Point 2	
Number	1	2	X	Y	X	Y
68	135	136	23.07	4.13	23.07	5.00
69	137	138	23.07	5.00	22.32	5.00
70	139	140	22.32	5.00	22.32	4.13
71	141	142	22.32	13.26	23.07	13.26
72	143	144	22.32	13.26	22.32	14.07
73	145	146	22.32	22.32	24.39	24.39
74	147	148	31.32	4.13	34.24	4.13
75	149	150	31.32	4.13	31.32	5.00
76	151	152	31.32	5.00	34.13	5.00
77	153	154	31.32	13.26	31.76	13.44
78	155	156	4.13	0.00	5.00	0.00
79	157	158	13.26	0.00	14.07	0.00
80	159	160	22.32	0.00	23.07	0.00
81	161	162	4.13	9.13	5.00	9.13
82	163	164	13.26	9.13	14.07	9.13
83	165	166	22.32	9.13	23.07	9.13
84	167	168	4.13	18.19	5.00	18.19
85	169	170	13.26	18.19	14.07	18.19
86	171	172	4.13	27.20	5.00	27.20
87	173	174	4.13	9.13	5.00	9.13
88	175	176	13.26	9.13	14.07	9.13
89	177	178	22.32	9.13	23.07	9.13
90	179	180	4.13	18.19	5.00	18.19
91	181	182	13.26	18.19	14.07	18.19
92	183	184	4.13	27.20	5.00	27.20
93	185	186	0.00	4.13	0.00	5.00
94	187	188	0.00	13.26	0.00	14.07
95	189	190	0.00	22.32	0.00	23.07
96	191	192	9.13	4.13	9.13	5.00
97	193	194	9.13	13.26	9.13	14.07
98	195	196	9.13	22.32	9.13	23.07
99	197	198	18.19	4.13	18.19	5.00
100	199	200	18.19	13.26	18.19	14.07

Table 11.3.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk (0° Basket Drop Orientation) (Continued)

			Coordinates (in.)			
			Point 1		Point 2	
Section Number	Point 1	Point 2	X	Y	X	Y
101	201	202	27.20	4.13	27.20	5.00
102	203	204	0.00	4.13	0.00	5.00
103	205	206	0.00	13.26	0.00	14.07
104	207	208	0.00	22.32	0.00	23.07
105	209	210	9.13	4.13	9.13	5.00
106	211	212	9.13	13.26	9.13	14.07
107	213	214	9.13	22.32	9.13	23.07
108	215	216	18.19	4.13	18.19	5.00
109	217	218	18.19	13.26	18.19	14.07
110	219	220	27.20	4.13	27.20	5.00
105	209	210	10.02	16.16	11.52	16.16
106	211	212	20.29	10.02	20.29	11.52
107	213	214	10.02	31.18	10.02	30.44
108	215	216	31.18	10.02	30.44	10.02
109	217	218	5.39	11.02	5.39	10.02
110	219	220	5.39	20.29	5.39	21.17

Table 11.3.2-2 P_m+P_b Stresses for Support Disk—56.1 g End Impact Thermal Condition 2

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
50	52.7	5.6	3.3	52.9	127.8	1.42
46	52.6	17.9	1.3	52.6	127.8	1.43
19	18.3	52.5	0.3	52.5	127.8	1.44
5	52.4	27.8	0.1	52.4	127.8	1.44
30	6.1	51.5	2.9	51.7	127.8	1.47
56	18.3	51.6	0.5	51.6	127.8	1.48
9	51.3	19.0	0.1	51.3	127.8	1.49
7	51.2	18.8	0.6	51.3	127.8	1.49
4	27.4	51.2	0.2	51.2	127.8	1.49
42	50.8	27.6	1.0	50.9	127.8	1.51
11	50.6	5.9	2.7	50.8	127.8	1.52
3	50.3	27.8	0.2	50.3	127.8	1.54
67	6.4	46.7	1.8	46.8	127.8	1.73
79	0.1	46.5	0.3	46.5	127.8	1.75
103	46.4	0.0	0.3	46.4	127.8	1.75
13	45.7	6.6	1.3	45.8	127.8	1.79
94	45.6	0.1	0.1	45.6	127.8	1.80
80	0.1	45.5	0.2	45.5	127.8	1.81
104	45.5	0.1	0.2	45.5	127.8	1.81
95	44.5	0.1	0.2	44.5	127.8	1.87
78	0.1	44.0	0.3	44.0	127.8	1.90
102	44.0	0.1	0.3	44.0	127.8	1.90
93	43.8	0.1	0.1	43.8	127.8	1.92
77	6.3	35.1	10.2	38.3	127.8	2.34
66	35.1	6.3	10.2	38.3	127.8	2.34
89	0.6	37.7	3.3	38.0	127.8	2.36
88	0.5	37.5	1.4	37.5	127.8	2.41
20	37.2	28.2	0.0	37.2	127.8	2.43
45	28.1	36.9	1.0	37.0	127.8	2.46
87	0.3	36.0	0.8	36.0	127.8	2.55
82	0.3	35.7	0.5	36.0	127.8	2.55
37	8.8	25.9	3.9	35.5	127.8	2.60
81	0.2	35.2	0.3	35.4	127.8	2.61
53	26.3	8.1	4.3	35.4	127.8	2.61
106	34.8	0.4	1.4	35.3	127.8	2.62
107	34.0	0.5	3.3	35.1	127.8	2.64
83	0.5	33.9	2.9	34.9	127.8	2.66
97	34.4	0.3	0.7	34.7	127.8	2.68
105	34.4	0.2	0.8	34.6	127.8	2.69
96	34.4	0.2	0.2	34.6	127.8	2.69

Note: See Figure 11.3.2-3 for section locations and definition of coordinate system.

Table 11.3.2-3 P_m+P_b Stresses for Support Disk—56.1 g End Impact Thermal Condition 3

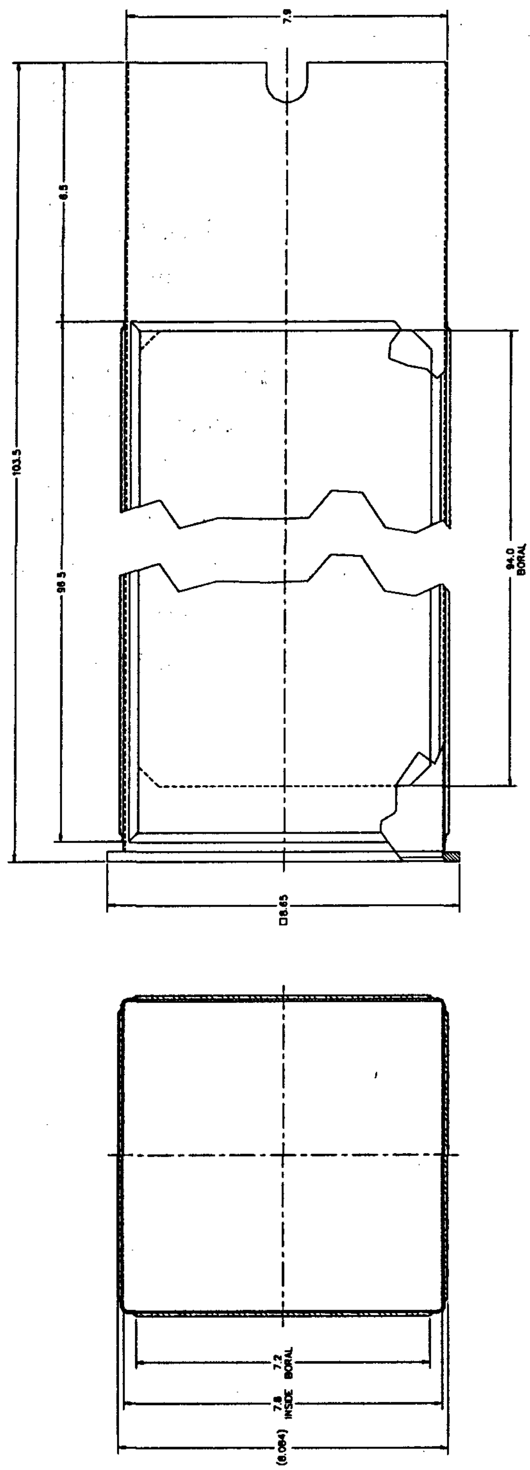
Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
5	53.9	28.5	0.0	53.9	135.0	1.51
46	53.1	18.3	1.6	53.1	135.0	1.54
19	18.8	52.9	0.6	52.9	135.0	1.55
50	52.6	5.8	3.1	52.8	135.0	1.56
4	28.1	52.4	0.4	52.4	135.0	1.58
42	52.0	28.3	1.2	52.1	135.0	1.59
56	18.7	52.0	0.6	52.0	135.0	1.60
9	51.7	19.5	0.2	51.7	135.0	1.61
7	51.7	19.2	0.9	51.7	135.0	1.61
30	6.3	51.4	2.7	51.6	135.0	1.62
3	51.5	28.5	0.3	51.5	135.0	1.62
11	50.5	6.1	2.5	50.7	135.0	1.66
79	0.1	46.7	0.3	46.7	135.0	1.89
103	46.7	0.0	0.3	46.7	135.0	1.89
67	6.6	46.5	1.7	46.6	135.0	1.90
94	45.8	0.1	0.1	45.8	135.0	1.95
13	45.6	6.8	1.2	45.6	135.0	1.96
80	0.1	45.3	0.2	45.3	135.0	1.98
78	0.1	45.3	0.3	45.3	135.0	1.98
104	45.3	0.1	0.2	45.3	135.0	1.98
102	45.3	0.1	0.3	45.3	135.0	1.98
93	45.0	0.1	0.1	45.0	135.0	2.00
95	44.3	0.1	0.2	44.3	135.0	2.05
20	38.2	28.4	0.2	38.2	135.0	2.53
45	28.3	37.9	1.2	38.0	135.0	2.55
88	0.5	37.7	1.7	37.8	135.0	2.57
89	0.6	37.5	3.1	37.8	135.0	2.57
77	6.1	34.3	9.9	37.4	135.0	2.61
66	34.3	6.1	9.9	37.4	135.0	2.61
87	0.3	36.9	1.0	36.9	135.0	2.66
81	0.2	36.1	0.5	36.3	135.0	2.72
82	0.3	36.0	0.7	36.3	135.0	2.72
106	35.1	0.3	1.7	35.6	135.0	2.79
105	35.3	0.2	1.0	35.5	135.0	2.80
96	35.3	0.2	0.3	35.5	135.0	2.80
37	8.7	25.6	3.8	35.1	135.0	2.85
8	27.5	35.0	0.4	35.0	135.0	2.85
97	34.7	0.3	0.9	35.0	135.0	2.86
53	26.0	7.9	4.2	35.0	135.0	2.86
107	33.8	0.5	3.1	34.9	135.0	2.87

Note: See Figure 11.3.2-3 for section locations and definition of coordinate system.

11.3.2.[redacted] Fuel Tube Analysis

The BORAL neutron poison plates are supported by the fuel tubes within the canister basket. The fuel tube must preserve the geometry of the BORAL in the 6 inch drop and tip over accident events of the storage cask. The fuel tube has been evaluated for an end drop of 56.1 g and a side drop of 55 g for the hypothetical accident events for transport. That analysis is presented in the Safety Analysis Report for the NAC-STC, docket 71-9235. That analysis shows that the BORAL neutron poison remains in place in the end and side drop conditions. The fuel tube configuration is shown in Figure 11.3.2.[redacted]-1.

Figure 11.3.2.3-1 Yankee Class Fuel Basket Tube Configuration



11.3.2.[redacted] Fuel Basket Weldment Analysis for End Impact Conditions

The response of the top and the bottom weldment plates of the fuel basket assembly to a 56.1g accident impact load are examined. The top and bottom weldment are 0.5-inch thick plates constructed of SA240, Type 304 stainless steel. The weldments support their own weight plus the weight of 36 fuel assembly tubes.

A finite element analysis is performed for both plates, since the support for each weldment is different due to the location of the welded ribs for each. Eight structural ribs, eight tie-rod ends, and a circumferential ring support the top weldment and its loads during a top end drop. These structural components are modeled as zero-translation restraints in the direction of the end drop. The load from the fuel tube (2108 pounds) are represented as point forces applied to the nodes at the periphery of the fuel assembly slots. An average point force is applied. The application of the nodal loads at the slot periphery is accurate since the tube weight is transmitted to the edge of the slot, which provides support to the fuel tubes in the end drop condition. Both models use the SHELL63 element which permits out of plane loading. The finite element models represent one-quarter sections of the weldments. Figures 11.3.2.[redacted]-1 through 11.3.2.[redacted]-4 show the finite element models for the weldments.

Figure 11.3.2.4-1 Top Weldment Finite Element Model with Structural Boundary Conditions

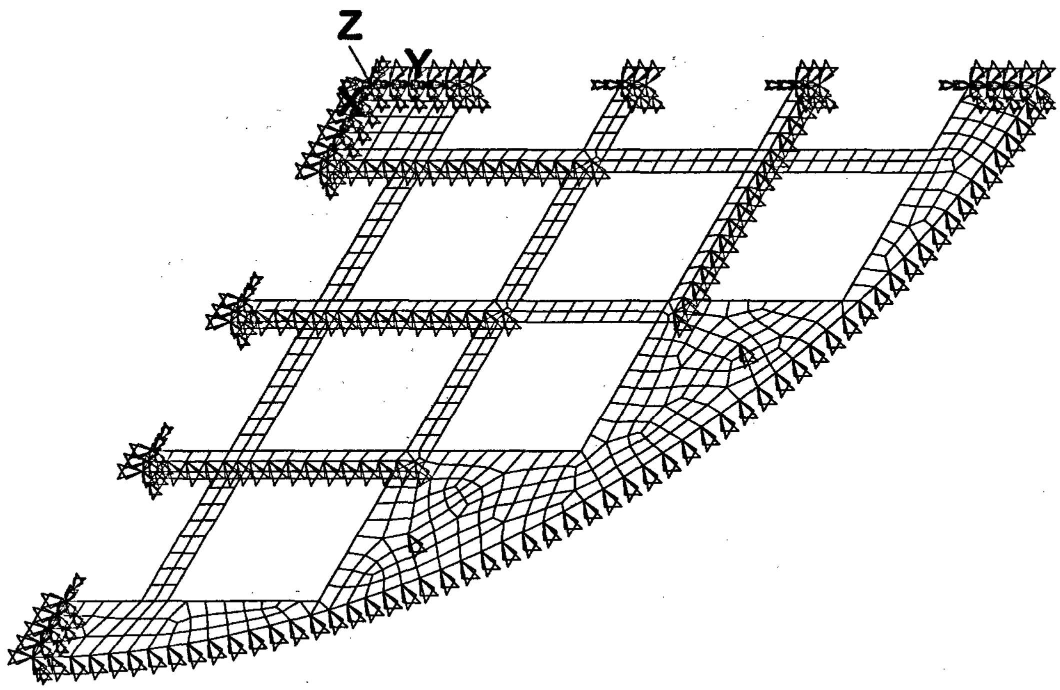
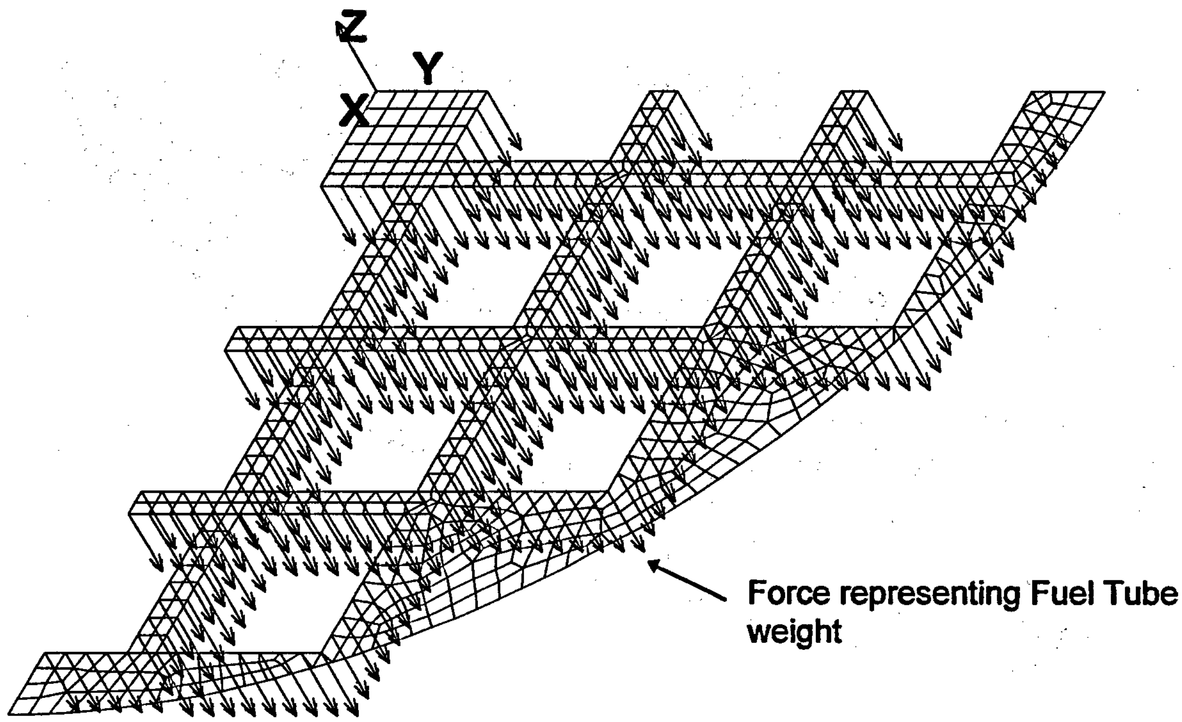


Figure 11.3.2.4-2 Top Weldment Finite Element Model with Structural Applied Loads[1]



1. Displacement conditions not shown.

Figure 11.3.2.[redacted]-3 Bottom Weldment Finite Element Model with Structural Boundary Conditions

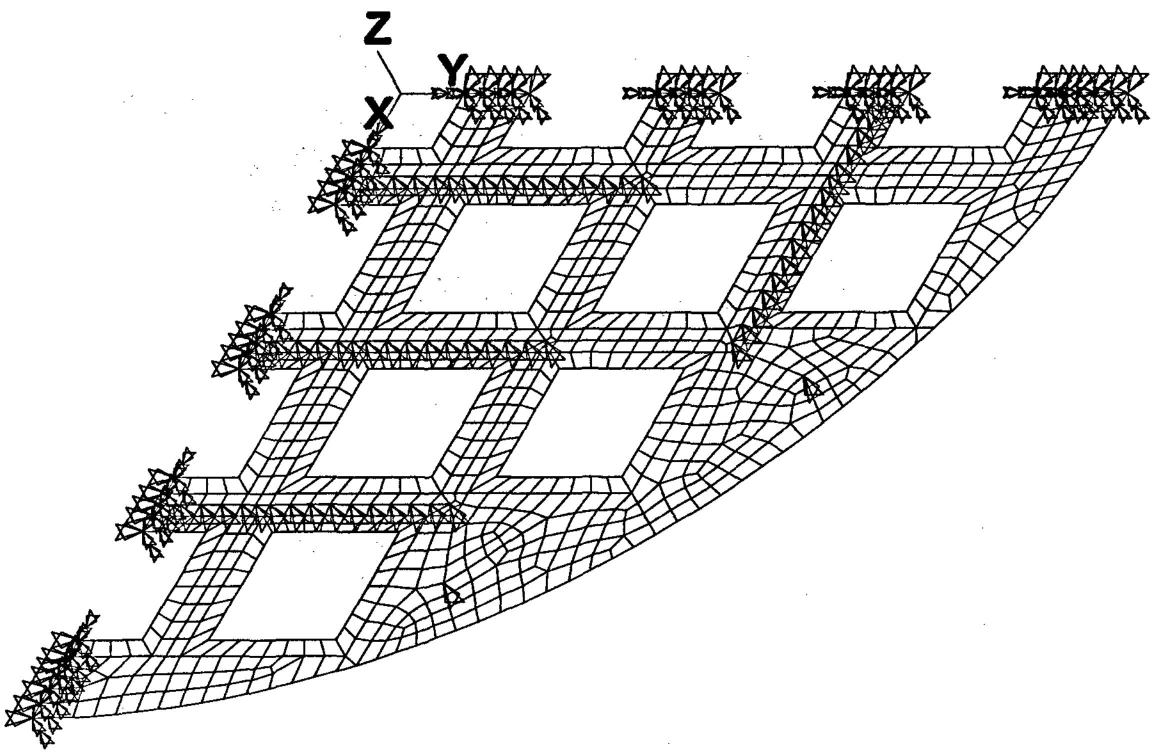
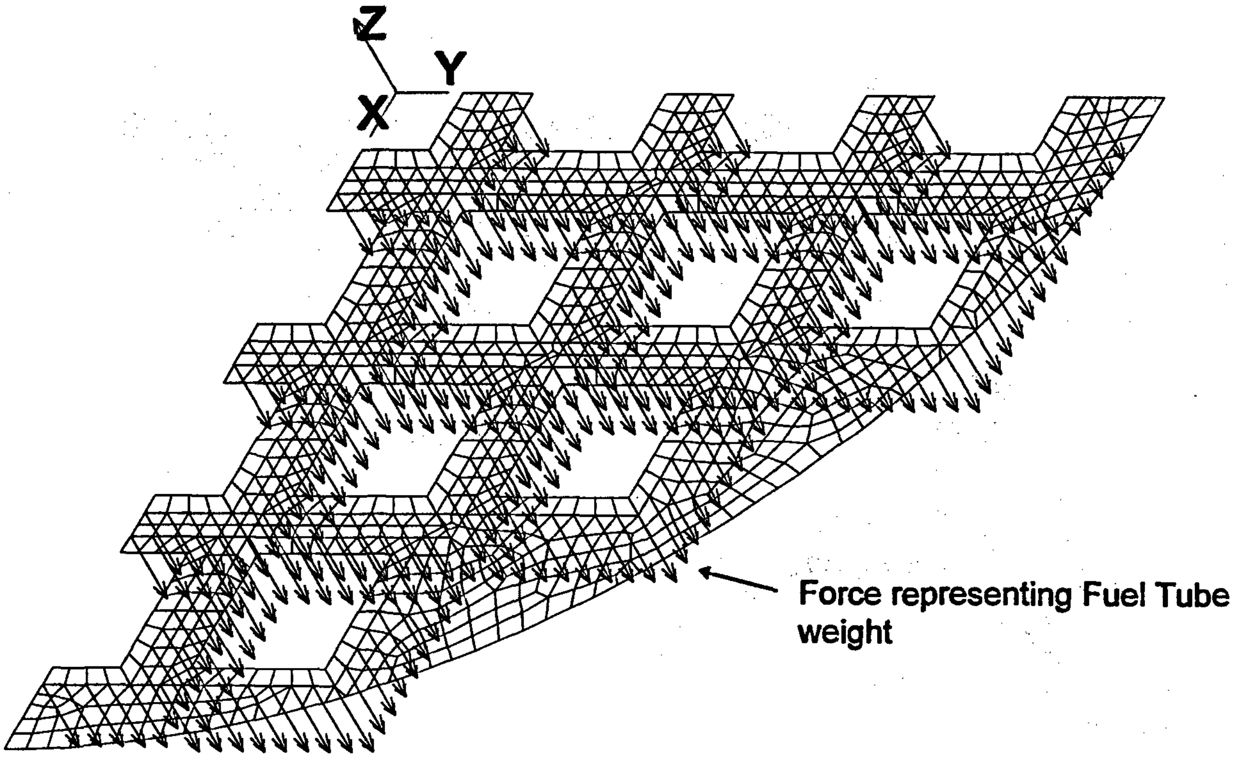


Figure 11.3.2.[redacted]-4 Bottom Weldment Finite Element Model with Structural Applied Conditions[1]



1. Displacement conditions not shown.

11.3.2.4.1 Results of Fuel Basket Weldment Analyses

The analysis using the applied nodal forces demonstrates that the weldment design satisfies the primary membrane (P_m) and the primary membrane plus bending ($P_m + P_b$) stress criteria in ASME Code, Section III Division I, Subsection NG. Conservatively, nodal stresses, in lieu of sectional stresses, are used to compare with the stress allowable. For the end impact conditions, the P_m stresses are essentially zero since the weldments are subjected to bending load only. Hence, the following criteria for the $P_m + P_b$ stresses was used in the evaluation:

$P_m + P_b < 3.6S_m$ or S_u, whichever is less.

(Note: For Type 304 stainless steel in these temperature ranges, S_u is smaller than $3.6S_m$.)

The margin of (MS) was calculated as:

$$M.S. = \frac{\text{Allowable Stress}}{\text{Nodal Stress Intensity}} - 1$$

The minimum margins of safety for each weldment for the end drop condition are shown in the table below. The allowable stress is determined based on a temperature of 530°F. This temperature is established by using the maximum temperature of the support disk for normal conditions of storage. The minimum Margins of Safety for the top/bottom weldments for the 56.1 g end impact are:

Component	$P_m + P_b$ (ksi)	Allowable (ksi)	M.S.
Top Weldment	58.0	62.2	+0.1
Bottom Weldment	48.1	62.2	+0.3

11.3.2.[redacted].2 Top Weldment Structural Rib Buckling Evaluation

The structural ribs on the top weldment are subjected to axial loads during a top end drop. End constraints on the ribs during a top end drop consist of fixed at the end welded to the top weldment, and free at the other end. Because there are no closed solutions readily available for evaluating a plate for buckling loads with end constraints matching those of the top weldment ribs, a closed-form solution for the buckling of a column was used to analyze a 1-inch section of one of the ribs.

For a column under axial loading with one end fixed and the other end free, the critical load (P_{cr}) is determined by:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

where,

- I = moment of inertia,
- E = modulus of elasticity,
- L = length of the column, and
- K = effective length factor (K = 2 for a column with one end fixed and the other free).

Evaluating a 1-inch section of one of the ribs at the temperature of 540°F yields:

$$P_{cr} = \frac{\pi^2 (25.576 \times 10^6 \text{lbf/in}^2) \frac{1}{12} (1.0\text{in})(0.38\text{in})^3}{(2 \times 6.80\text{in})^2} = 6{,}241\text{lb}$$

For the 30-foot top end drop, the sum of the forces on the nodes representing the ribs was a maximum of 3,681 lb. Thus, the maximum load (P) on a 1-inch section of one of the structural ribs is:

$$P = \frac{3{,}681\text{ lb}}{27.5\text{ in}/2}(1\text{ in}) = 268\text{ lb}$$

Thus, the margin of safety (MS) for buckling of one of the structural ribs of the top weldment during a 30-foot top end drop is:

$$\text{M.S.} = \frac{6{,}241\text{ lb}}{268\text{ lb}} - 1 = 22.3$$

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11.4 Canister Overpack

As discussed in Section 1.2.4, a canister overpack (overpack) has been designed to accommodate a transportable storage canister. The overpack configuration is provided to allow the confinement of a loaded canister in the event that either the reactor spent fuel pool is not available for unloading a designated canister or the NAC-STC transport cask is not available to transport the canister to a facility where the contents could be placed in a new canister. The recovery from the event that requires the use of an overpack is considered to be an accident event. There are no design basis normal, off-normal, or accident events that are expected to result in the use of a canister overpack. However, the thermal and structural performance of the vertical concrete cask is evaluated in this section based on the assumed use of the loaded overpack for all of the normal, off-normal and accident conditions of storage.

11.4.1 Structural Evaluation

This section presents the structural evaluation of the canister overpack and the effects of the use of the overpack on the vertical concrete cask.

11.4.1.1 Structural Evaluation of the Canister Overpack

A finite element model of the canister overpack (See Figure 11.4-1 through Figure 11.4-3) is constructed using ANSYS solid elements (SOLID45) for structural analysis of storage conditions. The finite element model represents a one-half (180°) section of the canister overpack and consists of the overpack shell, bottom plate, outer lid, and inner lid (including the lid weld regions). The model uses gap/spring elements to simulate contact between adjacent components. Contact between the overpack outer and inner lids is modeled using COMBIN40 gap/spring elements in the axial (UY) degree of freedom. Simulation of the lid support ring uses a ring of COMBIN40 gap/spring elements connecting the inner lid and the overpack in the axial direction at the lid lower outside radius. CONTAC52 elements are used to model the interaction between the outer lid and overpack shell and the inner lid and overpack shell just below the respective lid weld joints. The size of the CONTAC52 gaps is determined from nominal dimensions of contacting components, except that COMBIN40 elements used to model the interaction of the inner and outer lids have a gap size of 0.08 inches, based on the flatness tolerances of the lid. The COMBIN40 elements used to simulate the lid support ring are assigned small gap sizes of 1×10^{-8} inches. All gap/spring elements are assigned a stiffness of 1×10^{6} lb/in.

A central hole is modeled in the inner and outer lids and bottom plate. These holes are then filled with solid elements. This technique is used to avoid a small hole, which can cause a stress concentration, or a series of degenerate solid elements which can produce a region of excessive stiffness.

Contact between the inner surfaces of the vertical concrete cask and the external surfaces of the canister overpack is modeled using CONTAC52 gap elements. These elements are assigned sizes based on differences in nominal dimensions of the components and a gap stiffness of 1×10^6 lb/in. Spring elements (COMBIN14) are inserted over the gap elements located on the model symmetry plane to help stabilize the model during solutions phases. The springs are given a low stiffness of 100 lb/in. so their presence will not adversely affect the accuracy of the solutions.

Symmetry boundary conditions are applied to the plane of symmetry of the model. All nodes on the concrete liner side of the gap elements that represent the interface between the canister overpack shell and the concrete liner are fixed for all degrees of freedom (UX, UY, and UZ).

Storage conditions consist of dead load, handling load, increased internal pressure (normal, off-normal, and accident), thermal stresses, and accident conditions (drop, seismic, flood, and tornado). The overpack is designed in accordance with ASME, Section III, Subsection NB for Class 1 components. Table 11.4-1 presents the load combinations for the evaluation of the canister overpack for normal, off-normal, and accident conditions and corresponding ASME service levels. Table 11.4-2 presents the allowable stress criteria for the stress intensities generated by the combined pressure, thermal expansion, and mechanical loads per ASME, Section III.

As shown below, the overpack maintains positive margins of safety for the normal, off-normal, and accident storage conditions evaluated.

11.4.1.1.1 Normal Storage Conditions

The normal storage conditions consist of dead load, handling load, increased internal pressure, and thermal expansion. The dead load condition is defined as a 1g acceleration applied to the overpack and contents. The handling load is defined as a 1.1g acceleration (1g dead load plus a 10% dynamic load factor). In the analyses performed for normal storage conditions, the dead load and handling load are evaluated using a 1.1g acceleration.

The internal pressure load used for normal storage conditions is 14.0 psig. This is conservative compared to the value calculated in Section 11.4.2.2. A bounding temperature distribution is used for all evaluations of the storage conditions (normal, off-normal, and accident) presented in Section 11.4.1.1.1 through Section 11.4.1.1.3. This temperature distribution envelopes the temperature gradients experienced by the overpack for all storage conditions (normal, off-normal, and accident). The temperature distribution is calculated by performing a steady-state thermal analysis on the overpack model with the temperatures at key locations specified as shown:

Location	Fixed Temperature (°F)
Top of outer lid at center	140
Bottom of inner lid at center	150
Top of shell	100
Shell at mid elevation	350
Bottom of bottom plate at center	200
Bottom of bottom plate at outer	100

All allowable stress values for 304L stainless steel are evaluated at a temperature of 350°F for all of the storage conditions (normal, off-normal, and accident) analyses presented in Section 11.4.1.1.1 through Section 11.4.1.1.3.

The results of the stress evaluation for normal storage conditions are presented in Table 11.4-3 through Table 11.4-5. The locations of the stress sections presented in these tables are shown in Figure 11.4-4. The overpack maintains positive margins of safety for the normal storage conditions evaluated

11.4.1.1.2 Off-Normal Storage Conditions

The off-normal storage conditions consist of dead load, handling load, increased internal pressure, and thermal expansion. The dead load, and the handling load, condition is defined to be the same as those for normal conditions (1.1g acceleration). The internal pressure load used for off-normal storage conditions is 16.0 psig. This is conservative compared to the value calculated in Section 11.4.2.2.

The results of the stress evaluation for off-normal storage conditions are presented in Table 11.4-6 through Table 11.4-8. The locations of the stress sections presented in these tables are shown

in Figure 11.4-4. The overpack maintains positive margins of safety for the off-normal storage conditions evaluated.

11.4.1.1.3 Accident Storage Conditions

The accident storage conditions consist of dead load, increased internal pressure, 6-inch bottom end drop, seismic tip-over, seismic, flood, and tornado.

The accident internal pressure load used in the evaluations is 35.0 psig. This is conservative compared to the accident internal pressure value calculated in Section 11.4.2.2.

An axial acceleration of 20g is used to simulate the end impact for the 6-inch bottom drop condition. This is conservative compared to the acceleration value calculated in Section 11.4.1.2.3. Additionally, no internal pressure is used for this load combination because it results in larger stress intensities than if the normal internal pressure load is used.

Evaluation for the seismic condition (0.25g in the horizontal and vertical directions) is bounded by the tip over and 6-inch bottom end drop conditions.

An external pressure of 22 psi is used to simulate flood conditions. This is based on the pressure exerted on an object by a 50 ft water head. An internal pressure of 0 psig is conservatively assumed when applying the 22 psi external pressure load. No inertial load is applied to the model for the increased external pressure condition so that stresses in the bottom plate/shell juncture will be maximized.

The reduced external pressure of 3.5 psi resulting from tornado conditions is enveloped by the loading combination with the accident internal pressure (35.0 psig), and is, therefore, not specifically evaluated.

The stresses resulting in the overpack during the non-mechanistic tip-over of the vertical concrete cask are evaluated by applying a conservative 45g side impact load and the normal conditions internal pressure of 14.0 psig to the overpack model. The g-load for the canister overpack lids in the tip over event is calculated using the method applied in Section 11.2.12.3 to determine the g-load for the canister lids. The g-load for the canister overpack lids is found to be 34.7g by applying a dynamic load factor (DLF) of 1.07 to the g-load of the steel liner (32.4g) at the shield

plug location (Section 11.2.12.2.5). 45g is conservatively applied to the entire canister overpack model. The loading from the overpack contents (loaded canister) during this tip-over condition are modeled by applying the weight of the contents multiplied by the 45g loading as a pressure load with a cosine distribution over a total angle of 36° (18° in the one-half model) to the inner surface of the overpack shell. The contact angle of 18 degrees is determined based on the canister shell deformation for the tip-over event as evaluated in Section 11.2.12.3.

The results of the stress evaluation for accident storage conditions are presented in Table 11.4-9 through Table 11.4-16. The locations of the stress sections presented in these tables are shown in Figure 11.4-4.

During the tip-over accident, the overpack shell at the inner and outer lids is subjected to the inertial load of the lids which results in highly localized bearing stresses (Sections 9 and 11 at angular locations of 0 and 4.5 degrees). These stresses are predominant because the weights of the lids are transferred to the overpack shell through the thickness of the welds (5/8-in. welds for both lids). According to ASME Section III, Appendix F, bearing stresses are not evaluated for Level D service (accident) conditions. Therefore, Pm stresses are not presented for the region local to the impact (angular locations of 0 and 4.5 degrees) for section 9 in Table 11.4-15. Conservative stresses, which include bearing stresses, are presented for sections 10, 11, 12, and 13 in Table 11.4-15.

Additionally, during the tip-over accident, the inertial load of the inner lid results in localized bending stresses in the overpack shell (at the inner lid weld, i.e., section 9). This scenario is similar to the case of a cylindrical shell at the junction with a head, as shown in Table NB-3217-1 of the ASME Code, Section III, Subsection NB. The localized bending stress at the structural discontinuity is classified as a secondary (Q) stress. Per ASME Section III, Appendix F, secondary stresses are not considered for the stress evaluation for Level D (accident) conditions. Therefore, the $P_m + P_b$ stresses are not presented for the region local to the impact for section 9 (at angular locations of 0° and 4.5°) in Table 11.4-16.

The overpack maintains positive margins of safety for the accident storage conditions evaluated.

11.4.1.1.4 Overpack Buckling Evaluation

The overpack shell is axially loaded by the self-weight of the lids and the shell during storage conditions. Considering the handling load as 10% of the dead load, the applied load is the self-

weight with a factor of 1.1. The overpack shell is evaluated as an unsupported, right circular cylinder using a critical buckling load (Blake):

$$S_{cr} = \frac{E\left(0.605 - 10^{-7} m^2\right)}{m\left(1 + 0.004\phi\right)}$$

$= 162.8$ ksi

Where the canister material is Type 304L stainless steel, conservatively assumed to be at 400°F for normal conditions, and

$E = 26.5 \times 10^3$ ksi, modulus of elasticity
$R = (71.64 + 0.5)/2 = 36.07$ in., mean radius of overpack shell
$S_y = 17.5$ ksi, yield stress
$t = 0.5$ in., overpack shell thickness
$\phi = \frac{E}{S_y} = 1514.3$, inverse strain parameter
$m = R/t = 72.14$, mean radius-to-thickness ratio

The axial compression load in the canister overpack shell is:

$$P_A = [(\pi/4)(72.62)^2(5.0)(0.288) + (\pi/4)(72.64^2 - 71.64^2)(133.0)(0.288)](1.1)$$

$= 11{,}160$ pounds

and the axial compression stress is:

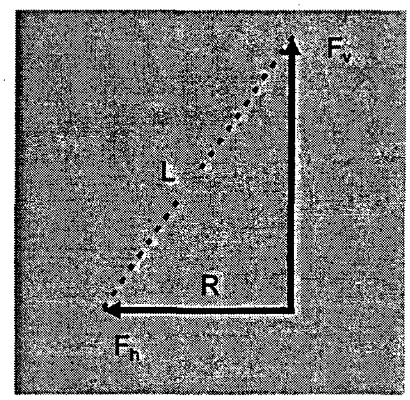
$$S_A = \frac{P_A}{\left(\pi/4\right)\left(72.64^2 - 71.64^2\right)} = 0.1 \text{ ksi}$$

Therefore, the margin of safety for canister shell buckling is:

$M.S. = S_{cr} / S_A - 1 = 162.8 / 0.1 - 1 = +$ Large

11.4.1.1.5 Canister Overpack Empty Lift Evaluation

This section evaluates the handling of an empty overpack (without lids). The overpack is lifted with four slings/hoist rings at four locations (equally spaced 90° apart) at the top edge of the overpack shell. The length of each sling is 10 ft. Four hoist rings are used, each having a rated load of at least 10,000 pounds and a minimum thread engagement length of 1.29 inches. Using the weight of the overpack shell and bottom plate (5,937 lbs.) with a dynamic load factor of 1.1, the vertical force (F_v) at each lifting location is 1,633 lbs ($1.1 \times 5937/4$). The horizontal force (F_h) can be calculated as:



L = 120 in., sling length

R = 72.64/2 + 1 = 37.32 in., radius to hoist ring

$F_h = F_v / \tan[\cos^{-1}(R/L)] = 534$ lbs.

The overpack shell is evaluated for the handling condition in which the forces F_v and F_h are applied at four lifting locations. A finite element analysis is performed to determine the stresses and the results are evaluated in accordance with ASME Section III, Subsection NB. A classical evaluation is performed to determine the adequacy of the weld at the lift locations.

Because of symmetry, the finite element model contains one quarter of the overpack shell and bottom plate, as shown in Figure 11.4-5. ANSYS (SOLID45) 3-D solid elements are used to construct the model. Symmetry boundary conditions are applied at the planes of symmetry (0° and 90°). A horizontal force, F_h, is applied at the lift location as a nodal (concentrated) force in the radial direction. A conservative force of 550 lbs is applied. The vertical force, F_v, is simulated by applying a displacement restraint (in the canister axial direction), while an inertial force is applied to all elements to represent the weight of the overpack (without lids) with a dynamic load factor of 1.1. The forces are actually spread over a 2.5-in. by 2.0-in. area, therefore, it is conservative to consider the concentrated forces (F_h and F_v) in the model. The maximum calculated nodal stress intensity, which occurs at the lift location, is 8,134 psi and is conservatively considered to be the P_m and P_m+P_b stresses for stress evaluation as shown in the

table below. The margins of safety are calculated as: M.S. = (Allowable Stress/Maximum Stress Intensity) - 1.

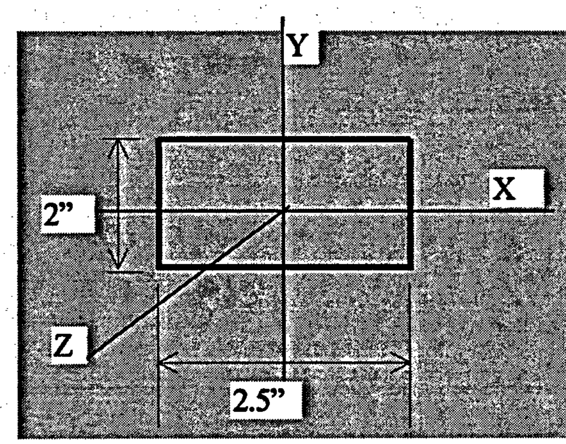
	Max. stress intensity (psi)	Allowable stress[1] (psi)	Margin of safety
P_m	8,134	16,700	1.1
$P_m + P_b$	8,134	25,050	2.1

[1] Material temperature at 250°F

Weld Evaluation

The welds at the lift locations are evaluated for the vertical force, F_v, and horizontal force, F_h. The weld size conservatively considered to be 1/4 inch at all four sides (actual size at the top side is 5/16 inch).

Weld properties (welds are treated as lines) are:



$A = 2.0 \times 2 + 2.5 \times 2 = 9.0 \text{ in.}^2$

$Sw = (2.5 \times 2) + 2.0^2 / 3 = 6.3 \text{ in.}$

(Section modulus, Blodgett)

The calculated forces are:

$F_y = 1633 \text{ lbs.}$

$F_z = 550 \text{ lbs.}$

$M_x = 550 \times 3 + 1633 \times 1 = 3{,}283 \text{ in.-lb.}$

The eccentricities of the force application point to the centroid of the weld are 3 inches and 1 inch.

The unit forces at the welds are:

$f_y = 1633 / 9 = 181 \text{ lbs/in.}$

$f_z = 550/ 9 + 3283/6.3 = 582 \text{ lbs/in.}$

$f_R = (f_y^2 + f_z^2)^{1/2} = 609 \text{ lbs/in.}$

The allowable shear stress for the base metal (SA 240, Type 304L stainless steel) is:

$F_w = 0.4F_y = 0.4 \times 20{,}300 = 8{,}120$ psi

where F_y is the yield stress taken at 250°F.

The required weld size is:

$F_R / F_w = 609 / 8120 = 0.08$ in. < 1/4 in. (provided)

The margin of safety, M.S., for the weld is:

M.S. = 0.25/0.08 -1 = +2.1

Therefore, the weld is adequate.

11.4.1.2 Effect of the Overpack on the Vertical Concrete Cask Structural Evaluation

11.4.1.2.1 Concrete Cask Normal Storage Conditions

The calculated weight of the overpack is 11,726 lb. The storage cask shield plug (5,490 lbs) is not required when the overpack is used. However, the storage cask lid that is used in the overpack configuration results in an increase in lid weight of 683 lbs. Therefore, the net increase in the loaded storage cask weight is 6,919 lbs.

As shown in Section 11.4.2.2, use of the canister overpack slightly reduces the storage cask temperatures which results in a slight reduction of thermal stress in the concrete. Therefore, no further evaluation is required for the storage cask concrete region. The addition of the overpack increases the load on the pedestal and the air inlet system during the bottom lift of the storage cask. The evaluation of the bottom lift (without the overpack) is presented in Section 3.4.3.1.

Based on the calculations in Section 3.4.3.1, and considering the additional weight of the overpack, the following conclusions were reached regarding storage cask components:

1. The 4 1/8-in. hydraulic cylinder diameter remains adequate to limit the concrete bearing stress below the allowable stress.

2. The Nelson studs are adequate to bond the base plate of the storage cask to the concrete.

3. The pedestal of the storage cask remains structurally adequate to support the loaded canister with the overpack.

11.4.1.2.2 Concrete Cask Off-Normal Storage Conditions

The evaluated off-normal storage conditions include blockage of one-half of the air inlets and severe environmental conditions as described in Section 11.1. The thermal evaluation for the overpack configuration is presented in Section 11.4.2. The thermal evaluation results, summarized in Table 11.4-17, demonstrate that critical component temperatures remain below allowable temperatures for the condition of half of the concrete cask air inlets blocked, and the off-normal environmental conditions (ambient temperatures of 100°F and -40°F).

11.4.1.2.3 Concrete Cask Accident Storage Conditions

This section evaluates the effects on a concrete cask containing a canister overpack in the event of a design basis storage accident condition.

Earthquake

Use of the overpack increases the overall mass and slightly raises the loaded concrete cask center of gravity. Using the method demonstrated in Section 11.2.2, the vertical and horizontal seismic accelerations required to tip the cask over are determined to be greater than 0.34g. The margin of safety against tip over under design basis vertical and horizontal seismic accelerations, 0.25g, is +0.38.

Flood

In Section 11.2.6, the concrete cask is demonstrated to be stable against overturning and sliding for flood loads from a 50-ft water head and a 15 ft/sec water velocity. The increased overall mass with the overpack in place increases the restoring moment opposing overturning and increases the force on the surface upon which the cask sits. Therefore, adding the overpack makes the VCC even more stable against both overturning and sliding.

Full Blockage of Air Inlets and Outlets

The use of a canister overpack has no impact on the thermal performance of the concrete cask, based on the computational fluid dynamic analysis performed in Section 11.4.2.3. As shown in Section 11.2.8, the concrete temperature will not exceed the thermal design criteria temperature of 350°F until 45.7 hours after the start of full blockage of air inlets and outlets event.

The maximum fuel cladding temperatures for normal condition of storage (steady state) with and without the canister overpack are 640°F (Sec.11.4.2-1) and 563°F (Table 4.1-4), respectively. The maximum fuel cladding temperature at 45.7 hours after the start of the blockage event for the configuration without canister overpack is conservatively determined to be 786°F (Section 11.2.8). The maximum fuel cladding temperature at 45.7 hours after the blockage is 863°F [786 + (640-563)], which is less than the short term allowable temperature of 1058°F.

Note that the concrete cask with the canister overpack is inspected every 12 hours. Based on the above discussion, the concrete temperature and the fuel cladding temperature, at 12 hours after the blockage event, are well below their allowable temperatures of short term accident conditions.

6-Inch Bottom Drop

The increased weight added by the overpack will increase the calculated deformation of the steel plate above the air inlet vents from 0.35 inch, as calculated in Section 11.2.11.2.2, to 0.43 inch. The reduction of the inlet area is bounded by the loss of half the inlet vents as evaluated in Section 11.1.1.

In a bottom-end impact of the concrete storage cask on the storage pad, the loaded overpack produces a force on the stand/inlet system located near the bottom of the storage cask. It is expected that the steel plate above the air inlet channels will yield. The flow stress, σ_f, for the material is calculated as:

$$\sigma_f = \frac{\sigma_y + \sigma_u}{2}$$

$$= 45{,}400 \text{ psi}$$

where,

σ_u = 58,000 psi, A36 carbon steel ultimate strength at 200 °F,
σ_y = 32,800 psi, A36 carbon steel yield strength at 200 °F.

The flow stress results in the deformation of the steel plate above the air inlet vents, and produces a force through the section. The total force is:

$$F = 8(\sigma_f bt)$$

$$= 1.092 \times 10^6 \text{ lb.}$$

where,

b = 1.5 in., the width of the load bearing area,
t = 2.0 in, the thickness of the stand.

This force results in an acceleration to the loaded overpack (weight, w_c = 66,530 lb) of:

$$g = \frac{F}{w_c} = \frac{1.092 \times 10^6}{6.653 \times 10^4} = 16.41 \text{ g}$$

which is bounded by the 56.1 g loading evaluated in Section 11.3, for the canister and basket. It is also bounded by the 20g loading evaluated in Section 11.4.1.1.3 for the canister overpack.

Tornado and Tornado Missile

The postulated tornado wind loading and missile impacts are not capable of overturning the cask, or penetrating the boundary established by the concrete cask as demonstrated in Section 11.2.13. Use of the overpack increases the overall cask mass. The increased mass makes the cask less likely to be overturned by tornado wind loading or missile impact.

Explosion

The overpack shell is evaluated in Section 11.4.1.1.3 for the effects of a flood having a depth of 50 feet. The water exerts an external hydrostatic pressure of 22 psig on the overpack that results in stresses in the overpack shell. The margin of safety for the flood external pressure is found to be positive for both primary membrane and primary membrane plus bending stresses as shown in

Table 11.4-13 and Table 11.4-14, respectively. Consequently, there is no adverse consequence to the canister overpack as a result of the 22 psig external pressure. This pressure conservatively bounds an explosion event.

11.4.1.3 Effect of the Overpack on the Canister and Basket Structural Evaluation

Due to the overpack, the temperatures of the canister and basket are increased, which may affect the determination of thermal stress and material allowables. The structural evaluation of the canister and the basket are documented in Section 3.4.4.1. Conservative temperatures are used for the thermal stress analysis for the canister, with an assumed minimum ΔT of 370°F (500° - 130°) in the axial direction of the shell. This temperature difference envelopes the ΔT within the shell for the overpack condition. The increased temperature inside the canister enhances the radiant heat transfer. Hence, the thermal gradients for all basket components are expected to be reduced, which results in reduced thermally induced stress. Therefore, the thermal stress calculation for the canister and basket, as presented in Section 3.4.4.1, bounds the overpack conditions. The material allowable stresses decrease with increasing temperature. However, the temperatures used to determine material allowables in the evaluations presented in Section 3.4.4.1 bound the maximum temperatures for all canister and basket components. No further evaluation is required for the canister and the basket for the overpack configuration.

11.4.2 Thermal Evaluation

11.4.2.1 Overpack Thermal Evaluation

For normal storage conditions, a 3-D ANSYS thermal model is generated for the canister and overpack. Steady-state thermal analysis is performed for the normal design condition and the analysis results are summarized in Table 11.4-17. The results indicate that maximum temperatures of the fuel cladding and all safety related components are below allowables.

The ANSYS program is used to generate the 3-D ANSYS thermal model and perform analyses for the normal storage condition using the characteristics of the design basis fuel as described in Section 4.1. The normal storage condition is defined as 75°F environmental temperature, insolation is present, and all of the concrete cask air vents are open.

The 3-D canister model is shown in Figures 11.4-1, 11.4-2, and 11.4-3. ANSYS 3-D SOLID70 conduction elements and LINK31 radiation elements are used. The model includes fuel assemblies, fuel tubes, stainless steel support disks, heat transfer disks, the canister shell, lids and the bottom plate, and the canister overpack. Because of symmetry, only half of the system is modeled. This model is based on the 3-D Canister model described in Section 4.4.1.2 with the overpack portion added (gaps between the canister and the overpack are considered to be filled with helium). The top surface of the overpack outer lid and the bottom surface of the overpack bottom plate in the model are considered to be adiabatic. The overpack shell temperatures obtained from the computational fluid dynamic analysis presented in Section 11.4.2.3 are applied at the overpack shell surface in the model as boundary conditions.

The maximum calculated temperatures (with the overpack) and the allowable temperatures for the overpack, fuel cladding and safety related components for the normal conditions of storage are:

Maximum Temperature (°F)	Aluminum Heat Transfer Disks	Stainless Steel Support Disks	Canister	Overpack	Fuel Cladding
Calculated	608	609	420	321	640
Allowable	650	650	800	800	644

The temperature differences, ΔT, between the components for the normal conditions with and without the overpack are added to the component temperatures without the overpack (determined in Chapter 4.0) for various operating conditions and the results are presented in Table 11.4-17.

Temperatures of the fuel cladding and all the safety related components are less than the allowable temperatures.

11.4.2.2 Overpack Internal Pressurization

The overpack is back-filled with helium to atmospheric pressure (0.0 psig) and closed by welding. Normal condition pressure comprises the pressure due to the heating of the back filled helium, plus the pressure due to the postulated failure of the canister. Conservatively, all of the gases initially contained in the canister (see Section 4.4.1) are considered to remain in the

overpack. The internal pressure is calculated using the ideal gas law. The gas constant, R, is 0.0821 (atm × liters)/(Mole °K) (Lamarsh).

The four gases that contribute to the overpack internal pressure are:

1) Fuel rod back-fill gas
2) Fuel rod fission gas
3) Canister back-fill gas
4) Overpack back-fill gas

The moles of back-fill gases are calculated using the ideal gas law.

$$Pv = NRT$$

where

P = pressure in atmospheres
v = volume, liters
N = number of moles
R = gas constant, 0.0821 liter-atmospheres/°K/mole
T = temperature in degrees K

The average gas temperature for normal and accident conditions is conservatively taken as 520°F (544.3°K) and for off-normal conditions the temperature is 550°F (560.9°K). The calculated canister average gas temperature is 512°F with the overpack. The overpack average gas temperature is calculated to be 227°F.

The overpack free gas volume, V_{free} = 496.5 liters, is the overpack internal volume, V_1, minus the caster external volume, V_2, calculated as:
The internal overpack volume, V_1, is

$$V_1 = \frac{\frac{\pi}{4}\left(D_1^2\right)\left(h_1\right)}{61.02} = \frac{\frac{\pi}{4}\left(71.64^2\right)(126.62)}{61.02} = \frac{510{,}391.40}{61.02} = 8{,}364.33 \text{ liters}$$

where,

D = overpack internal diameter, 71.64 in.
h = overpack internal height (133.0 - 5.0 - 1.38) =126.62 in.
(5.0 in. = lid thickness; 1.38 in. = bottom thickness)
1/61.02 converts $in.^3$ to liters

The external volume of the canister, V_2, is:

$$V_2 = \frac{\frac{\pi}{4}\left(D_2^2\right)\left(h_2\right)}{61.02} = \frac{\frac{\pi}{4}\left(70.64^2\right)(122.50)}{61.02} = \frac{480{,}095.19}{61.02} = 7{,}867.83\,\text{liters}$$

where,

D_2 = canister external diameter, 70.64 in.
h_2 = canister external height (122.50 in)

Calculating the moles of overpack back-fill gas (the overpack is pressurized to 1 atm with helium at 75°F):

$$N = \frac{Pv}{RT} = \frac{1\,\text{atm} \times 496.5\,\text{liters}}{0.0821\frac{\text{atm liter}}{\text{mole K}} \times 297\,\text{K}} = 20.36\,\text{moles}$$

From Sections 4.4.1 and 11.2.1, the number of moles, N, in the canister for the indicated conditions are:

Normal conditions
N = 181.41 moles
Off-normal conditions
N = 195.76 moles

100% rod failure hypothetical accident
N = 380.24 moles

The normal storage temperature with overpack (bulk gas temperature) is 520°F.

The canister free volume, V_{TSC}, is 4,877.93 liters, from Section 4.4.1. The overpack free volume, V_{free}, is 496.5 liters.

Using the ideal gas law, (Pv = NRT), the pressure is calculated for normal conditions:

$$P = \frac{(181.41\text{ moles} + 20.36\text{ moles})\left(0.0821\frac{\text{atm liter}}{\text{mole K}}\right)\times 544.3\text{ K}}{4{,}877.93 + 496.5\text{ liters}} = 1.68\text{ atm}$$

P = 1.68 atm ≈ 24.7 psia ≈ 10.0 psig

For off-normal conditions, the pressure is:

$$P = \frac{(195.76\text{ moles} + 20.36\text{ moles})\left(0.0821\frac{\text{atm liter}}{\text{mole K}}\right)\times 560.9\text{ K}}{4{,}877.93 + 496.5\text{ liters}} = 1.85\text{ atm}$$

P = 1.85 atm ≈ 27.2 psia ≈ 12.5 psig

100% rod failure accident conditions result in a pressure of:

$$P = \frac{(380.24\text{ moles} + 20.36\text{ moles})\left(0.0821\frac{\text{atm liter}}{\text{mole K}}\right)\times 544.3\text{ K}}{4{,}877.93 + 496.5\text{ liters}} = 3.3\text{ atm}$$

P = 3.3 atm ≈ 48.5 psia ≈ 33.8 psig

11.4.2.3 Evaluation of Thermal Performance of the Concrete Cask

The addition of the canister overpack results in a reduction of the size of the air annulus inside the vertical concrete cask. The radial air gap between the shell of the overpack and the concrete cask steel liner is reduced by 1 inch. A computational fluid dynamic and thermal

analysis was performed to determine the effect on concrete and canister shell temperature. This analysis was done using the air flow and concrete cask model presented in Section 4.4.1.1. The steady state normal condition of storage (75°F ambient temperature) was assumed. The analysis results show that the concrete temperatures decreased slightly (less than 1°F in concrete bulk temperature and less than 4°F for local temperature). It can be concluded that the overpack has no impact on concrete temperature for long term (normal) and short term (off-normal and accident) thermal design conditions. ■

Figure 11.4-1 Canister Overpack Three-Dimensional Finite Element Model

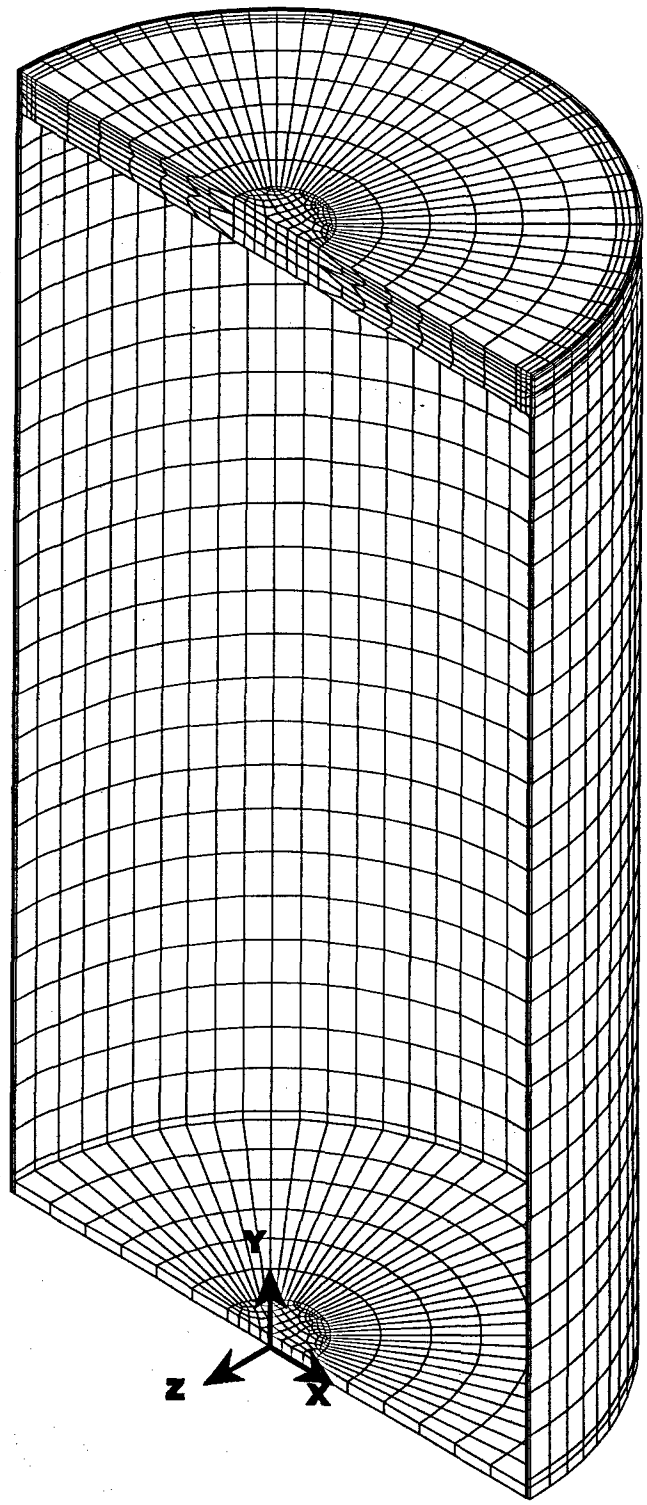


Figure 11.4-2 Overpack Inner and Outer Lids with Upper Portion of Overpack Shell

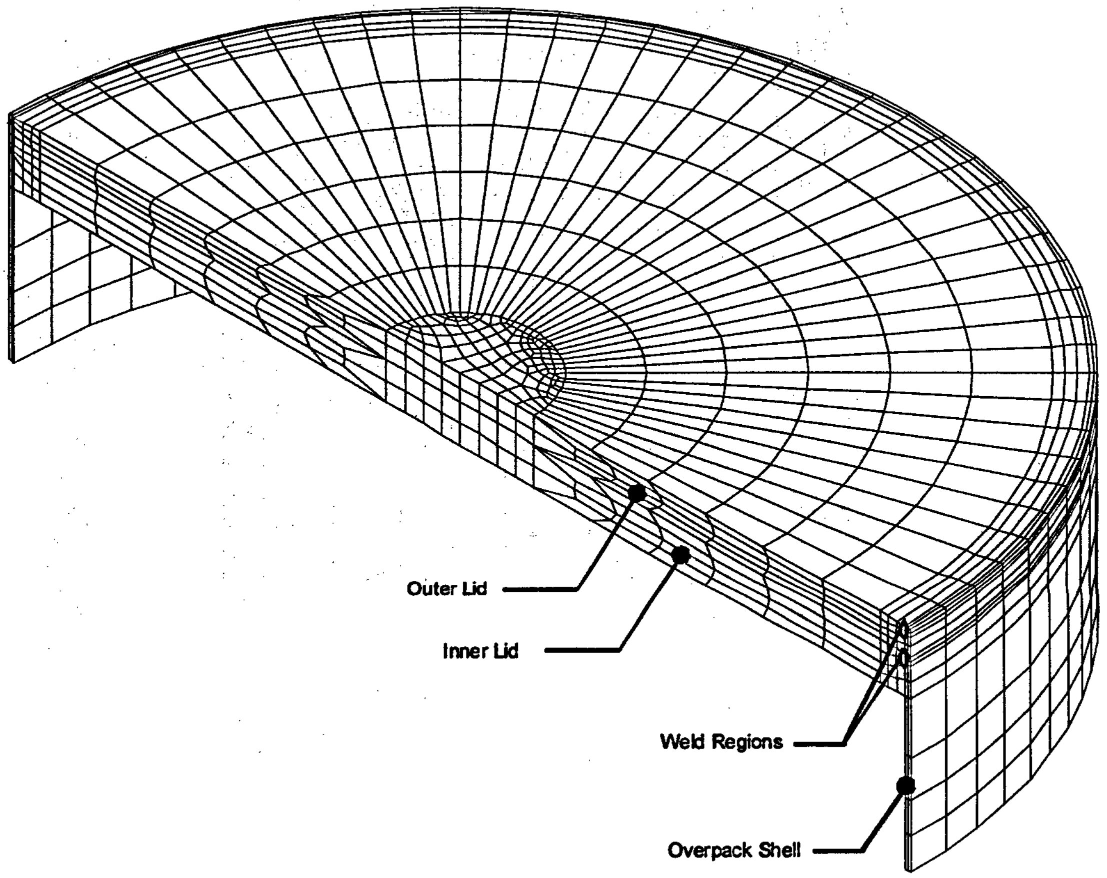


Figure 11.4-3 Overpack Bottom Plate and Lower Portion of the Overpack Shell

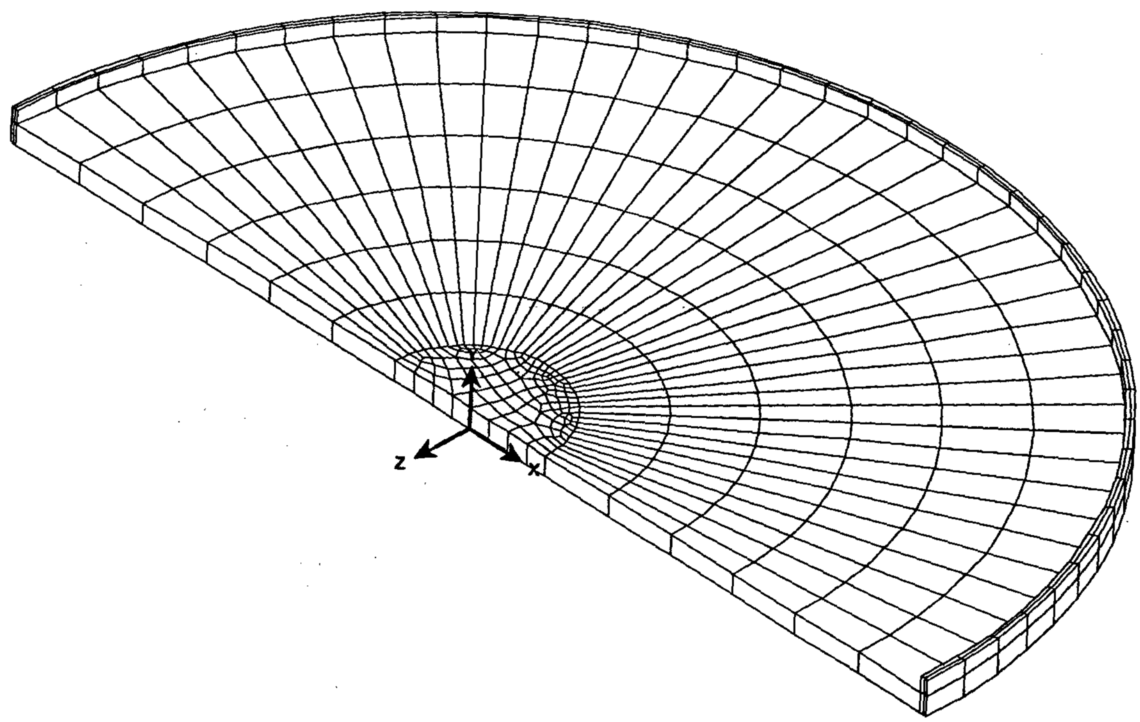
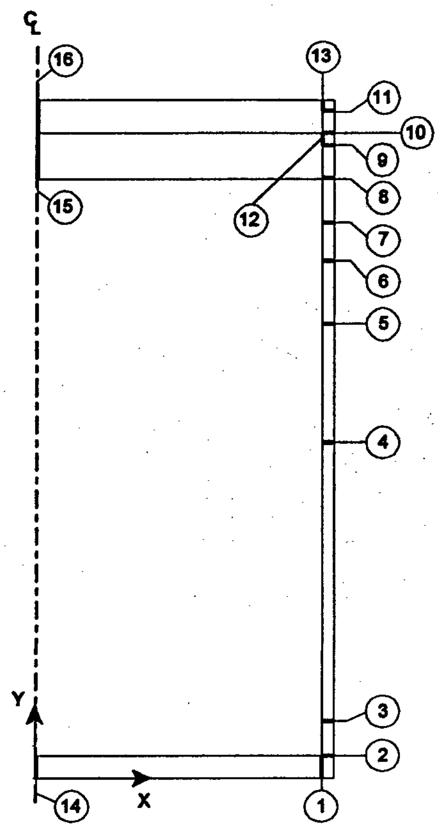
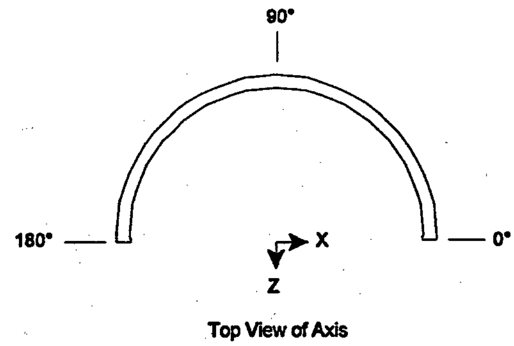


Figure 11.4-4 Locations of Stress Sections for the Overpack Finite Element Model





Notes:

1) There are 41 sections taken at each location from 0° to 180° (total = 656 sections).
2) Location 7 at top of canister structural lid.
3) Location 6 at canister structural/shield lid interface.
4) Location 5 at bottom of canister shield lid.
5) Location 3 at top of canister bottom plate

Section Coordinates at Z=0 and X>0

Location	Point 1		Point 2	
	X	Y	X	Y
1	35.82	0	35.82	1.38
2	35.82	1.38	36.32	1.38
3	35.82	2.38	36.32	2.38
4	35.82	64.69	36.32	64.69
5	35.82	115.88	36.32	115.88
6	35.82	120.88	36.32	120.88
7	35.82	123.88	36.32	123.88
8	35.82	128	36.32	128
9	35.82	130.375	36.32	130.375
10	35.82	131	36.32	131
11	35.82	132.375	36.32	132.375
12	35.82	130.375	35.82	131
13	35.82	132.375	35.82	133
14	0.1	0	0.1	1.38
15	0.1	128	0.1	130.8
16	0.1	131	0.1	133

Figure 11.4-5 ANSYS Model for the Overpack (Without Lid)

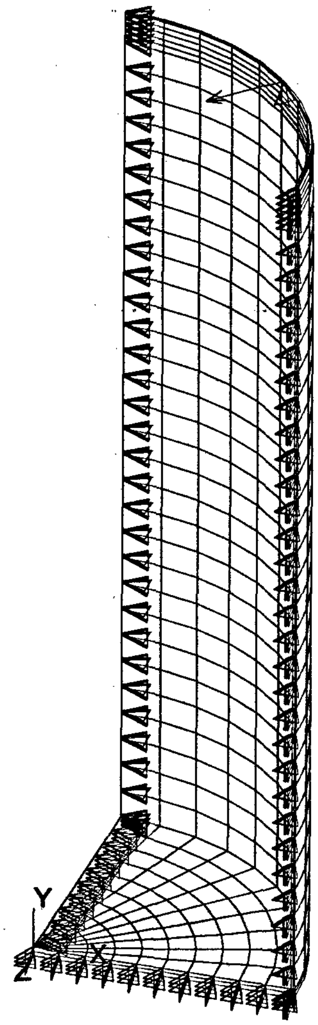


Table 11.4-1 Load Combinations for the Overpack Storage Conditions

LOAD		NORMAL		OFF-NORMAL		ACCIDENT				
ASME Service Level		A		B		D				
Load Combinations		1	2	1	2	1	2	3	4	5
Dead Weight	(including loaded canister)	X	X	X	X	X	X	X	X	X
Thermal	Inside VCC: 75° ambient	X	X			X	X	X	X	X
	Inside VCC: -40°F or 100°F ambient			X	X					
Internal Pressure	Normal	X	X			X	X	X	X	
	Off-Normal			X	X					
	Accident									X
Handling	Normal		X		X					
Drop/Impact	6-in. bottom-end drop or tip over					X				
Seismic	0.25g acceleration (horizontal and vertical)						X			
Flood	50-foot water head							X		
Tornado	Pressure drop of 3.0 psi, 290 mph rotational and 70 mph maximum translational wind speed								X	

Note: This table is based on Table 2.2-3 with the transfer cask thermal conditions and the off-normal handling load removed. The canister overpack is not handled while loaded and is not used with the transfer cask.

Table 11.4-2 Structural Design Criteria for Overpack Components

ASME Service Level	Stress Criteria)
Normal conditions: Service Level A	$P_m \leq S_m$ $P_L + P_b \leq 1.5\ S_m$ $P_L + P_b + Q \leq 3\ S_m$
Off-normal operation: Service Level B	$P_m < 1.1\ S_m$ $P_L + P_b < 1.65\ S_m$
Accident conditions: Service Level D	$P_m \leq 2.4\ S_m$ or $0.7\ S_u$ (whichever is less) $P_L + P_b \leq 3.6\ S_m$ or S_u (whichever is less)

Table 11.4-3 Canister Overpack Dead/Handling Load + Internal Pressure (Normal), P_m (ksi).

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0	0.4	0.1	0	0	0	0.33	16.25	47.84
2	0.1	0.2	0.1	0	0	0	0.1	16.25	167.64
3	0	0.4	0.1	0.1	0	0	0.43	16.25	36.77
4	0	0.4	1	0	0	0	1.01	16.25	15.09
5	0	0.4	1	0	0	0	1.04	16.25	14.63
6	0	0.4	1	0	0	0	1.03	16.25	14.72
7	0	0.4	0.8	0	0	0	0.81	16.25	19.09
8	0	0.4	0.4	0	0	0	0.41	16.25	38.84
9	0.7	0.5	0.6	-0.6	0	0	1.19	16.25	12.70
10	-1.4	0.6	0.2	0	0	0.1	2.05	16.25	6.93
11	0.9	-0.1	0.3	-0.1	0	0	1.02	16.25	14.92
12	-0.4	-0.7	0.1	0.2	0	0	0.86	16.25	17.99
13	0	0.7	0.2	0.1	0	0	0.74	16.25	21.08
14	0	0	0	0	0	0	0.06	16.25	282.60
15	-0.1	0	-0.1	0	0	0	0.12	16.25	137.18
16	0.2	0	0.2	0	0	0	0.16	16.25	98.21

Table 11.4-4 Canister Overpack Dead/Handling Load + Internal Pressure (Normal), $P_m + P_b$ (ksi).

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0	0.7	0.2	0	0	0	0.64	24.38	37.22
2	0.1	0.7	0.2	0	0	0	0.7	24.38	34.01
3	0	1.1	0.3	0.1	0	0.1	1.1	24.38	21.24
4	0	0.4	1	0	0	0	1.02	24.38	22.80
5	0	0.4	1	0	0	0	1.06	24.38	22.08
6	0	0.7	1.1	0	0	0	1.1	24.38	21.20
7	0	0.5	0.8	0	0	0	0.83	24.38	28.45
8	0	0.9	0.5	0	0	0	0.81	24.38	28.96
9	0.4	-0.1	0.4	0.5	-0.2	0	1.23	24.38	18.9
10	-0.6	4.4	1.5	0.4	0	0.1	5.05	24.38	3.82
11	0.6	-1	0	-0.1	0	0	1.67	24.38	13.60
12	-2.2	-2.6	-0.9	-0.3	0	0	1.94	24.38	11.55
13	-1.2	0.5	-0.2	0.1	0	0	1.62	24.38	14.04
14	0	0	0.1	0	0	0	0.09	24.38	260.09
15	-1.9	0	-1.9	0	0	0	1.91	24.38	11.80
16	0.4	0	0.4	0	0	0	0.45	24.38	53.74

Table 11.4-5 Canister Overpack Dead/Handling Load + Internal Pressure (Normal), P + Q (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.2	0.1	1.2	-0.1	0.1	0.7	1.85	48.75	25.37
2	0.1	-2.8	0.2	-0.1	0.1	0.2	3.1	48.75	14.72
3	0.1	3.6	1.4	0.1	-0.1	0.3	3.59	48.75	12.58
4	0.1	2.2	0.2	0	0	0.2	2.29	48.75	20.28
5	0	0.4	1.1	0	0	0	1.14	48.75	41.91
6	0.2	0.8	0.9	0	0	0.5	1.16	48.75	40.95
7	0.1	0.5	0.5	0	0	0.2	0.66	48.75	72.65
8	0.2	1.6	0.2	0	0.1	0.1	1.42	48.75	33.28
9	0.6	-1.2	0.5	0.8	-0.7	-0.4	2.97	48.75	15.39
10	-1.7	7.7	2.1	0.4	-0.1	0.3	9.46	48.75	4.15
11	1.7	-5.1	-0.4	0.1	0	-0.1	6.85	48.75	6.12
12	-5.2	-4.7	-2.3	-1	0	0.1	3.68	48.75	12.25
13	-3.4	1.2	-0.3	0.3	0	0.3	4.69	48.75	9.39
14	-21.5	-13.5	-20.3	-0.1	-0.8	0.4	8.29	48.75	4.88
15	-10.3	-6.5	-9.7	0	-0.5	0.2	3.91	48.75	11.46
16	-8.3	-5.3	-7.8	0	0.5	0.1	3.06	48.75	14.91

Table 11.4-6 Canister Overpack Dead/Handling Load + Internal Pressure (Off-Normal), P_m (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.1	0.8	0.3	0	0	0	0.66	17.88	26.01
2	-0.1	-0.1	-0.1	0	0	-0.1	0.28	17.88	63.72
3	-0.1	0.5	-0.2	0.1	-0.1	-0.1	0.74	17.88	23.24
4	0	0.5	1.1	0	0	0	1.15	17.88	14.49
5	0	0.5	1.2	0	0	0	1.19	17.88	14.06
6	0	0.5	1.2	0	0	0	1.19	17.88	14.07
7	0	0.5	0.9	0	0	0	0.94	17.88	18.04
8	0.2	0.5	0.3	0	0	-0.2	0.5	17.88	34.94
9	0.8	0.6	0.7	0.7	0	0	1.34	17.88	12.35
10	-1.6	0.8	0.3	0	0	0.1	2.36	17.88	6.57
11	1.1	-0.1	0.4	-0.1	0	0	1.2	17.88	13.87
12	-0.5	-0.8	0.1	0.2	0	0	0.99	17.88	17.14
13	-0.1	0.8	0.3	-0.1	0	0	0.88	17.88	19.42
14	0.1	0	0.1	0	0	0	0.09	17.88	204.34
15	-0.1	0	-0.1	0	0	0	0.14	17.88	129.28
16	0.2	0	0.2	0	0	0	0.19	17.88	92.49

Table 11.4-7 Canister Overpack Dead/Handling Load + Internal Pressure (Off-Normal), $P_m + P_b$ (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	-0.2	1.5	0.1	0.1	0	0	1.61	26.81	15.61
2	-0.1	-1.7	-0.3	-0.1	0	-0.4	1.92	26.81	12.96
3	0.1	2.4	0.2	0.1	-0.1	0.1	2.39	26.81	10.22
4	0	0.5	1.2	0	0	0	1.17	26.81	21.92
5	0	0.5	1.2	0	0	0	1.21	26.81	21.25
6	0	0.8	1.2	0	0	0	1.26	26.81	20.36
7	0	0.6	0.9	0	0	0	0.97	26.81	26.75
8	0.1	1	0.6	0	0	0	0.98	26.81	26.32
9	0.5	0	0.5	0.5	-0.4	0	1.38	26.81	18.37
10	-0.6	5.1	1.7	0.4	-0.1	0.4	5.84	26.81	3.59
11	0.7	-1.2	0	-0.2	0	0	1.99	26.81	12.47
12	-2.5	-3	-1	-0.4	0	0.1	2.26	26.81	10.88
13	-1.4	0.5	-0.2	-0.1	0	0	1.91	26.81	13.05
14	0.1	0	0.1	0	0	0	0.13	26.81	213.16
15	-2.2	0	-2.2	0	0	0	2.2	26.81	11.2
16	0.5	0	0.5	0	0	0	0.48	26.81	54.85

Table 11.4-8 Canister Overpack Dead/Handling Load + Internal Pressure (Off-Normal), P + Q (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.7	2.5	1.3	0	0	0.9	2.49	48.75	18.56
2	0	-3.8	-0.1	-0.1	0.1	-0.1	3.85	48.75	11.67
3	0.5	4.7	1	0.2	-0.1	0.7	4.68	48.75	9.41
4	0.2	2.3	0.3	0	0	0.3	2.37	48.75	19.60
5	0	0.5	1.3	0	0	0.1	1.29	48.75	36.85
6	0.2	0.9	1	0	0	0.5	1.32	48.75	35.99
7	0.1	0.6	0.6	0	0	0.3	0.78	48.75	61.40
8	0.3	1.7	0.2	0	0.1	0.1	1.55	48.75	30.37
9	0.7	-1.2	0.5	0.8	-0.7	-0.4	3.14	48.75	14.54
10	-1.8	8.4	2.3	0.4	-0.1	0.3	10.29	48.75	3.74
11	1.8	-5.3	-0.4	0.1	0	-0.1	7.17	48.75	5.80
12	-5.5	-5.1	-2.5	-1.1	0	0.1	4	48.75	11.20
13	-3.6	1.3	-0.3	0.4	0	0.3	4.95	48.75	8.85
14	-21.3	-13.4	-20.1	-0.1	-0.8	0.4	8.05	48.75	5.06
15	-10.6	-6.5	-10	0	-0.5	0.2	4.2	48.75	10.61
16	-8.3	-5.3	-7.8	0	0.5	0.1	3.05	48.75	15.00

Table 11.4-9 Canister Overpack Dead Load + Internal Pressure (Accident), P_m (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.3	5.2	1.8	-0.3	0	0	4.98	39	6.83
2	1	-1.7	-2.6	0.3	0	0.1	3.64	39	9.71
3	-0.1	1.2	-4.2	0.7	0	-0.1	5.64	39	5.91
4	0	1.2	2.5	0	0	0.1	2.52	39	14.48
5	0	1.2	2.6	0	0	0.1	2.59	39	14.06
6	0	1.2	2.6	0	0	0.1	2.59	39	14.06
7	0	1.2	2	0	0	0.1	2.05	39	18.02
8	0.6	1.2	0.4	0	0.1	0.4	1.15	39	32.91
9	1.9	1.4	1.7	1.5	-0.1	0	2.99	39	12.04
10	-2.5	1.7	-0.6	0	0	1.9	5.31	39	6.34
11	2.5	-0.4	0.9	-0.1	0	0	2.9	39	12.45
12	-1.1	-1.8	0.2	0.4	-0.1	0.1	2.19	39	16.81
13	-0.2	2	0.7	-0.2	0	0	2.17	39	16.97
14	0.3	0	0.3	0	0	0	0.38	39	101.63
15	-0.3	0	-0.3	0	0	0	0.31	39	124.81
16	0.4	0	0.4	0	0	0	0.45	39	85.67

Table 11.4-10 Canister Overpack Dead Load + Internal Pressure (Accident), $P_m + P_b$ (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	1.3	9.7	0.6	0.1	0	0	9.07	58.5	5.45
2	0.7	-14	-5.8	-0.6	0.1	-1.1	14.89	58.5	2.93
3	0.4	15.7	-0.1	1	0	0	15.88	58.5	2.68
4	0	1.2	2.5	0	0	0.1	2.56	58.5	21.85
5	0	1.2	2.6	0	0	0.1	2.64	58.5	21.16
6	0	1.7	2.7	0	0	-0.1	2.74	58.5	20.35
7	0	1.5	2.1	0	0	-0.1	2.1	58.5	26.86
8	0.2	2.4	1.3	0.1	0	-0.1	2.24	58.5	25.12
9	1.1	0	1.1	1.4	-0.1	0	3.08	58.5	17.99
10	-1.4	11.4	3.7	0.9	-0.2	0.8	13	58.5	3.50
11	1.7	-3.2	-0.1	-0.3	0	0	5	58.5	10.70
12	-5.6	-6.8	-2.2	-0.9	-0.1	0.1	5.07	58.5	10.54
13	-3.3	1.2	-0.5	0.3	0	0.2	4.57	58.5	11.80
14	0.4	0	0.4	0	0	0	0.44	58.5	131.95
15	-5	-0.1	-5	0	0	0	4.98	58.5	10.75
16	0.8	0	0.8	0	0	0	0.86	58.5	67.02

Table 11.4-11 Canister Overpack Accident 6-in. Bottom-End Drop Loading (no internal pressure), P_m (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.1	-0.2	0.1	-0.1	-0.1	0	0.38	39	102.92
2	-0.2	-1.9	-0.5	0.1	0	-0.2	1.85	39	20.13
3	0	-1.8	-0.6	0	0	0	1.77	39	21.02
4	0	-1.4	0	0	0	0	1.42	39	26.50
5	0	-1.1	0	0	0	0	1.13	39	33.61
6	0	-1.1	0	0	0	0	1.15	39	32.94
7	0.1	-1.1	0.1	0	0	0.1	1.23	39	30.73
8	0	-1	0	0	0	0	1.02	39	37.35
9	-0.5	-1	-0.7	0.4	0	0	0.98	39	38.66
10	1.5	-0.8	-0.3	-0.5	0	0.1	2.5	39	14.58
11	-1.8	0.9	-2.5	0.3	0.5	-0.6	3.96	39	8.86
12	0.6	0	-0.2	-0.1	0	0	0.87	39	44.00
13	0.6	-3.4	-2	0.5	0.1	0.1	4.18	39	8.33
14	0	-0.2	0	0	0	0	0.28	39	137.84
15	0.2	0	0.2	0	0	0	0.24	39	160.83
16	-0.4	0	-0.4	0	0	0	0.37	39	103.17

Table 11.4-12 Canister Overpack Accident 6-in. Bottom-End Drop Loading (no internal pressure), $P_m + P_b$ (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0.5	-0.2	0.5	-0.1	-0.1	0.1	0.78	58.5	74.31
2	0.1	-3.6	-1	-0.1	0	0.2	3.73	58.5	14.69
3	-0.1	-2.6	-0.9	0	0	0	2.56	58.5	21.81
4	0	-1.4	0	0	0	0	1.42	58.5	40.26
5	0	-1.2	0	0	0	0	1.15	58.5	49.87
6	0	-1.1	0	0	0	0	1.18	58.5	48.45
7	0.1	-1.3	0	0	0	0	1.38	58.5	41.48
8	-0.1	-1.6	-0.1	0	0	-0.1	1.53	58.5	37.21
9	-0.3	-1	-0.7	0.4	0	0	1.1	58.5	52.04
10	0.6	-2.3	-0.9	0.3	0	-0.2	3.04	58.5	18.25
11	0.8	8.2	-1.8	-0.1	0.6	0.4	10.17	58.5	4.75
12	2.3	0.9	0.4	0.7	0	-0.1	2.25	58.5	25.02
13	4.8	-1.4	-0.7	0.5	0.1	0.2	6.24	58.5	8.37
14	0.2	-0.2	0.4	0	0	0	0.62	58.5	93.69
15	2.6	0	2.6	0	0	0	2.56	58.5	21.88
16	-4.7	0	-4.7	0	0	0	4.71	58.5	11.42

Table 11.4-13 Canister Overpack Increased External Pressure (Flood), P_m (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	-0.2	-6.6	-2.2	-0.6	0	0.1	6.54	39	4.96
2	-1.6	2.6	3.6	-0.5	0	-0.2	5.24	39	6.44
3	2.2	-0.9	4	0.7	0.5	-2.9	7.44	39	4.24
4	0	-0.8	-1.6	0	0	-0.1	1.58	39	23.64
5	0	-0.8	-1.6	0	0	0.1	1.62	39	23.13
6	0	-0.8	-1.7	0	0	-0.1	1.68	39	22.24
7	0	-0.8	-1.4	0	0	-0.1	1.45	39	25.99
8	0	-0.8	-0.6	0	0	0	0.76	39	50.37
9	0	-0.2	0	0	-0.2	0	0.48	39	79.75
10	0	0.1	-0.1	0.4	-0.6	0.1	1.4	39	26.86
11	-2	1.2	-2.5	0.5	0.8	-0.5	4.51	39	7.64
12	-0.4	-2.4	0.1	0.1	-0.3	-0.3	2.76	39	13.13
13	0.9	-4.2	-2.9	0.6	0.1	0.2	5.24	39	6.45
14	-0.5	0	-0.5	0	-0.1	0	0.57	39	67.35
15	0.1	-0.3	0.1	0	0	0	0.33	39	116.36
16	-0.3	-0.3	-0.3	0	0.1	0	0.22	39	178.72

Table 11.4-14 Canister Overpack Increased External Pressure (Flood), $P_m + P_b$ (ksi)

Section No.	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	-1.9	-12.3	-1.3	0	0	-0.8	11.56	58.5	4.06
2	-0.7	18.6	7.9	-0.9	-0.1	-1.4	19.62	58.5	1.98
3	-0.4	-19.9	0.7	1.2	0.3	-0.3	20.73	58.5	1.82
4	0	-0.8	-1.6	0	0	-0.1	1.61	58.5	35.45
5	0	-0.8	-1.7	0	0	-0.1	1.65	58.5	34.54
6	0	-1.1	-1.8	0	0	0.1	1.75	58.5	32.51
7	0	-1.2	-1.5	0	0	0.1	1.53	58.5	37.24
8	0	-0.8	-0.6	-0.1	0	0	0.8	58.5	72.4
9	-0.2	-1.5	0	0.1	-0.2	-0.2	1.72	58.5	33.11
10	1.6	5.7	0	0.2	1	0.2	6.07	58.5	8.64
11	1.3	11.2	-1.7	-0.2	1.3	0.5	13.19	58.5	3.44
12	-1.1	-4.3	0	0.1	-0.4	-0.2	4.46	58.5	12.11
13	5.3	-1.3	-1.6	0.6	0.2	0.2	7.06	58.5	7.28
14	-13	-0.2	-13	0	-0.1	0.1	12.9	58.5	3.53
15	1.3	-0.1	1.3	0	0	0	1.44	58.5	39.77
16	-5.7	-0.2	-5.6	0	0.1	0	5.52	58.5	9.6

Table 11.4-15 Canister Overpack Accident Tip-Over Loading + Internal Pressure (Normal), P_m (ksi)

Section No.	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0	-19.2	2.7	-13.6	-1.8	-0.2	0	16.89	39	1.31
2	0	-14.2	2.2	-13.9	-2.9	0	1.3	18.35	39	1.13
3	0	-2.5	-2.3	-9.9	-2.3	-0.4	2.9	11.28	39	2.46
4	9	-1.7	3.9	1.7	0	0.1	0	5.68	39	5.87
5	4.5	-2.6	3.9	6	0.2	-0.3	0.8	8.81	39	3.43
6	4.5	-4.8	3.2	10	0	-0.4	-0.1	14.84	39	1.63
7	27	0.5	-0.2	2.4	2.6	-4.5	1.3	10.87	39	2.59
8	0	-1	4.7	-10.5	0.9	1.4	-2.6	16.27	39	1.40
9*	9	1.9	0.9	-1.4	0.7	1.8	-1.9	6.03	39	5.47
10	0	-20.7	5.8	-11.8	-10.6	1.6	0.5	34.04	39	0.15
11	0	-34.4	3.7	-15.9	0.2	1.9	0.2	38.38	39	0.02
12	0	-29.7	-27.6	-19.1	-8.6	1.8	-0.2	19.43	39	1.01
13	0	-32.9	-10.1	-14.9	-3.6	1.1	-1.7	24.37	39	0.60
14	0	-1.7	0	0.8	0	0	0	2.46	39	14.83
15	0	-1	0	0.2	0	0	0	1.2	39	31.45
16	0	-1.1	0	0.5	0	0	0	1.66	39	22.56

Note: * Stresses are not presented for the region with localized bearing stress. Per ASME Section III, Appendix F, bearing stresses need not be evaluated for Level D service (accident) conditions.

Table 11.4-16 Canister Overpack Accident Tip-Over Loading + Internal Pressure (Normal), $P_m + P_b$ (ksi)

Section No.	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable	Margin of Safety
1	0	-20	-1.6	-14	0.5	0.3	0.1	18.39	58.5	2.18
2	0	-10.2	9	-14.5	-1.3	1.1	2.3	24.67	58.5	1.37
3	13.5	0.3	17.5	-3.9	0.2	-3.6	-2.8	23.85	58.5	1.45
4	4.5	-1.9	8.5	18.3	0	0	1.8	20.54	58.5	1.85
5	18	3.1	12.3	25.1	-1.2	-2.3	8.1	27.79	58.5	1.11
6	13.5	2.5	21.3	30.1	-0.5	-4	8.2	33.43	58.5	0.75
7	13.5	1.7	11.9	20.7	-2	-3.1	4.3	22.11	58.5	1.65
8	0	-1	42.6	12.9	0.7	3.3	-1.7	44.18	58.5	0.32
9**	9	0.8	1.4	0.2	0.6	-1.6	0.3	13.4	58.5	3.37
10	0	-14.9	23.1	-9.4	-8.9	2	1	42.32	58.5	0.38
11	0	-27.1	19.3	-13	2.3	1.9	1.1	46.77	58.5	0.25
12	0	-21.7	-17.7	-14.1	-12	0.9	-0.7	24.43	58.5	1.39
13	0	-36.2	-12.5	-17.5	-3.2	1.7	-1.1	25.19	58.5	1.32
14	0	-1.7	0	0.8	0	0	0	2.49	58.5	22.48
15	18	-2.5	0	-1.3	0	0	0	2.5	58.5	22.41
16	0	-0.5	0	1.3	0	0	0	1.8	58.5	31.45

Note: **Stresses are not presented for the region with bearing stress (membrane) and secondary (Q) stress (bending). Per ASME Section III, Appendix F, both bearing stresses and secondary stresses are not required for evaluation for Level D service (accident) conditions.

Table 11.4-17 Canister Overpack Thermal Evaluation Summary

Long-Term Condition:

Design Condition (F°)	Aluminum Disks	Support Disks	Canister	Overpack	Fuel Cladding
Normal (75° ambient)	608	609	420	321	640
Allowable	650	650	800	800	644

Short-Term Condition:

Design Condition (F°)	Aluminum Disks	Support Disks	Canister	Overpack	Fuel Cladding
Off-Normal Half Inlets Blocked (75°F ambient)	610	611	419	320	642
Off-Normal Severe Heat (100°F ambient)	633	634	448	349	664
Off-Normal Severe Cold (-40°F ambient)	492	492	288	189	530
Accident Extreme Heat (125°F)	655	655	473	374	684
Allowable	700	800	800	800	1058

11.5 Reconfigured Fuel Assembly Evaluation

The reconfigured fuel assembly is evaluated at the off-normal (Service Level B) and accident (Service Level D) conditions which are the bounding conditions. The accelerations for Service Level B are 20g for both the side impact and the end impact. The accelerations for Service Level D are 55g for the side impact condition and 57g for the end impact condition. The results for the off-normal condition are conservatively compared to the allowables for the normal (Service Level A) condition. Material properties are taken at 750°F, which envelopes all operating condition temperatures.

11.5.1 Shell Casing Weldment Evaluation

The section evaluates the reconfigured fuel assembly shell casing weldment for the side and end impact events.

11.5.1.1 Shell Casing Side Impact

The shell weldment is analyzed for bending stress resulting from horizontal-side bending in the longitudinal direction as a simple span with distributed load using material properties at a temperature of 750°F. Because the assembly is supported within the basket tube the maximum deflection at the weldment center, δ, is limited to 0.099 in. at which time the remaining energy will be transferred into the basket fuel tube assembly.

In accordance with ASME Section III, Subsection NF, NF-3322.2(d), members that are subjected to axial compression or compression due to bending are considered to be fully effective if the width-thickness ratio, b/t, meets the following criterion:

$$\frac{b}{t} \le \frac{238}{\sqrt{S_y}}$$

Since, for the shell casing:

$$\frac{b}{t} = \frac{7.125-(2)(0.128)}{0.128} = 53.7 < \frac{238}{\sqrt{S_y}} = \frac{238}{\sqrt{17.3}} = 57.2$$

The shell casing meets the criteria and no reduction in allowable stress is applied.

The maximum bending stress, f_{bL}, is determined as:

$$\delta = \frac{5wL^4}{384EI} = 0.099 \text{ in., from which}$$

$$w = \frac{384EI\delta}{5L^4}$$

$$\text{Maximum moment, } M = \frac{wL^2}{8}$$

$$\text{Maximum bending stress, } f_{bL} = \frac{Mc}{I} = \frac{wL^2}{8} \times \frac{c}{I} = \frac{384E\delta c}{40L^2} = 8.73 \text{ksi}$$

where,

E = modulus of elasticity for SA240, 304 stainless steel (24.4×10^3 ksi at 750°F)
c = 7.381/2 = 3.69 in.
L = 99.03 in. distance between supports (top end fitting and bottom end fitting)

The horizontal sides (top and bottom) are evaluated for transverse bending stress, f_{bt}, as follows.

w = 0.128 in. × 0.29 lb/in.^{3} × 1.0 = 0.037 lb/in for a 1-in.-wide strip
w_{20g} = 0.037(20 + 1) = 0.78 lb/in. (Service Level B)

$$S = \frac{1.0 \times 0.128^2}{6} = 2.731 \times 10^{-3} \text{ in.}^3$$

$$I = \frac{bt^3}{12} = \frac{1.0\left(0.128^3\right)}{12} = 0.175 \times 10^{-3} \text{ in.}^4$$

$$M = \frac{wL^2}{12} \text{ (conservative)}$$

$$f_{bt} = \frac{M}{S} = \frac{wL^2}{12S} = \frac{0.78(7.25^2)}{12(2.731\times10^{-3})} = 1.25 \text{ ksi}$$

$$f_b = \sqrt{f_{bL}^2 + f_{bt}^2} = \sqrt{8.73^2 + 1.25^2} = 8.82 \text{ ksi}$$

The margin of safety is:

$$M.S. = \frac{S_m}{f_b} - 1 = \frac{15.6\text{ksi}}{8.82\text{ksi}} - 1 = +0.76 \text{ (Service Level B)}$$

For Service Level D:

$w_{ssg} = 0.037(55+1) = 2.079$ lb/in. (Service Level D)

$$f_{bt} = \frac{wL^2}{12S} = \frac{2.079(7.25^2)}{12(2.73\times10^{-3})} = 3.33 \text{ ksi}$$

$$f_b = \sqrt{f_{bl}^2 + f_{bt}^2} = \sqrt{8.73^2 + 3.33^2} = 9.34 \text{ ksi}$$

The margin of safety is:

$$M.S. = \frac{2.4S_m}{f_b} - 1 = \frac{37.4\text{ksi}}{9.34\text{ksi}} - 1 = +\text{large (Service Level D)}$$

Combined axial compression and bending of vertical sides

$$\frac{KL}{r} = \frac{1\times7.25}{0.037} = 196 \qquad \text{(NUREG/CR-6322)}$$

where,

$K = 1$, effective length factor
$L = 7.25$ in.

$$r = \frac{t}{\sqrt{12}} = \frac{0.128}{\sqrt{12}} = 0.037, \text{ radius of gyration}$$

$$F_a = S_y\left(0.40 - \frac{KL/r}{600}\right) = 127 \text{ ksi}$$

For Service Level B:

$$f_a \max = \frac{0.78\left(7.25/2\right)}{0.128} + \frac{0.78(7.25)}{0.128} = 66.27 \text{ psi}$$

$$\frac{f_a}{F_a} = \frac{0.066}{127} = 0.05 < 0.15$$

$f_{bx} = 1.25$ ksi; $f_{by} = 8.73$ ksi

$F_b = 1.5\ S_m = 1.5 \times 15.6 \text{ ksi} = 23.4 \text{ ksi}$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_b} + \frac{f_{by}}{F_b} = 0.05 + \frac{1.25}{23.4} + \frac{8.73}{23.4} = 0.48$$

Since 0.48 < 1.0, the shell casing meets the NUREG/CR-6322 acceptance criteria.

For Service Level D:

$$f_a = \frac{2.079\left(7.25/2\right)}{0.128} + \frac{2.079(7.25)}{0.128} = 177 \text{ psi}$$

$$\frac{f_a}{F_a} = \frac{0.177}{127} = 0.14 < 0.15$$

$F_B = 1.0 \times S_y = 63.1$ ksi

$$\left(\frac{f_a}{F_a} + \frac{f_{bx}}{F_b} + \frac{f_{by}}{F_b}\right) = \left(0.14 + \frac{3.33}{63.1} + \frac{8.73}{63.1}\right) = 0.33$$

Since 0.33 < 1.0, the shell casing meets the NUREG/CR-6322 acceptance criteria.

Welds, top and bottom fittings to shell casing

The shear force on the top-ring-to-casing and the bottom-fitting-to-casing welds is equal to 1/2 casing weight + 1/2 basket weight + 1/2 fuel weight = 261.3 lb; use 265 lb for evaluation. The top fitting design provides a shear key preventing the bolts from being loaded in shear.

The weld shear area = 7.25 in. × 0.128 in. × 4 = 3.712 in.^{2} and the dead load shear stress, τ_{DL}, is:

$$\tau_{DL} = \frac{265}{3.712} = 71.4 \text{ psi}$$

At Service Level B, the shear stress in the weld in the 20g acceleration, τ_{20g}, is:

$$\tau_{20g} = 71.4 \times (20 + 1) = 1.5 \text{ ksi}$$

$$F_v = (\text{greater of } 0.6\, S_m \text{ or } 0.6\, S_y) \times \text{weld quality factor}$$

$$= 0.6 \times 17.3 \times 0.50 = 5.19 \text{ ksi}$$

The margin of safety is:

$$M.S. = \frac{5.19}{1.5} - 1 = +2.46$$

At service level D, the shear stress in the weld in the 55g acceleration, τ_{55g}, is:

$$\tau_{55g} = 71.4 \times (55 + 1) = 4.0 \text{ ksi}$$

$$F_v = 0.42\, S_u \times \text{weld quality factor}$$

$$= 0.42 \times 63.1 \times 0.50 = 13.25 \text{ ksi}$$

The margin of safety is:

$$M.S. = \frac{13.25}{4.0} - 1 = +2.31$$

11.5.1.2 Shell Casing End Impact

For the bottom end impact, the top fitting and casing act against the bottom fitting assembly. For the top end impact, the bottom fitting and casing act against the top fitting assembly. Because the top fitting is heavier, the bottom end impact is the governing case.

K = 1
L = 99.03 in.

$$r = \sqrt{\frac{(b+t)^4 - (b-t)^4}{12A}} = 2.73$$

$$\frac{KL}{r} = \frac{1(99.03)}{2.73} = 36.3 < 120$$

$$\text{Therefore, use } F_a = S_y\left(0.47 - \frac{KL/r}{444}\right) = 6.72 \text{ ksi}$$

The axial stress in the shell casing wall is:

$$f_a = \frac{P_T}{A} = \frac{124(20+1)}{3.71} = 0.73 \text{ ksi (For Service Level B)}$$

$$f_a = \frac{P_T}{A} = \frac{124(57+1)}{3.71} = 1.94 \text{ ksi (For Service Level D)}$$

where,

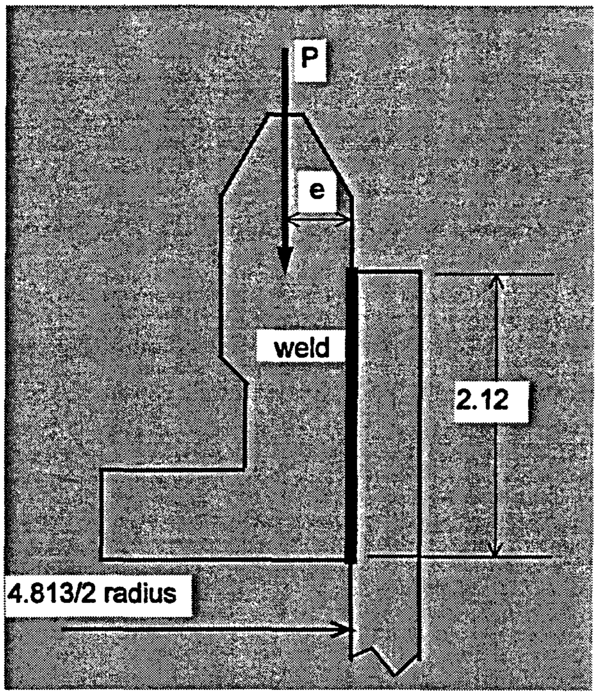
P_T = (total weight of top fitting + shell = 124 lb.)×(g + 1)
A = cross-sectional area = 2 x [(7.125 x 0.128)+(7.381x0.128)] = 3.71 in.^{2}

The margin of safety is:

$$MS = \frac{F_a}{f_a} - 1 = \frac{6.72 \text{ ksi}}{0.702 \text{ ksi}} - 1 = +8.57 \text{ (For Service Level B)}$$

$$MS = \frac{F_a}{f_a} - 1 = \frac{6.72\ \text{ksi}}{1.94\ \text{ksi}} - 1 = +2.46\ \text{(For Service Level D)}$$

11.5.1.3 Lifting Tab Welds



The lifting tabs will be subjected to bending and shear loads in the end impact condition.

For the Service Level B condition, the bending stress, f_b, on the weld is:

$$f_b = \frac{M}{S} = 6.52\ \text{ksi}$$

where,

$$M = \frac{Pe}{4} = \frac{0.555 \times (20+1)(0.53)}{4} = 1.5\ \text{in} \cdot \text{kips}$$

For the Service Level D condition, the bending stress, f_b, on the weld is:

$$f_b = \frac{M}{S} = 18.57\ \text{ksi}$$

where,

$$M = \frac{Pe}{4} = \frac{0.555 \times (57+1)(0.53)}{4} = 4.27\ \text{in} \cdot \text{kips}$$

$$P = \text{total weight} \times (g+1)$$

$$e = \frac{4.813}{2} - \left(\frac{2.0+1.75}{2}\right) = 0.53\ \text{in.}$$

$$S = \frac{bd^2}{6} = \frac{3/8 \times \left(2.12 - 3/16\right)^2}{6} = 0.23\ \text{in}^3$$

For Service Level B conditions, the shear stress, f_v, on the weld is:

$$f_v = \frac{P/4}{A_w} = \frac{0.555(20+1)}{4(0.72)} = 4.04 \text{ ksi}$$

For Service Level D conditions, the shear stress, f_v, on the weld is:

$$f_v = \frac{P/4}{A_w} = \frac{0.555(57+1)}{4(0.72)} = 11.18 \text{ ksi}$$

where,

$$A_w = \left(2.12 - 3/16\right)(0.375) = 0.72 \text{ in.}^2 \text{, the weld area.}$$

For Service Level B, the total stress, f, on the weld is:

$$f = \sqrt{f_b^2 + f_v^2} = \sqrt{6.52^2 + 4.04^2} = 7.67 \text{ ksi (Service Level B)}$$

The allowable stress, F_a, for Service Level B is $1.5 \times S_m \times$ weld quality factor.

$F_a = 1.5 \times 15.6 \times 0.5 = 11.7$ ksi

The margin of safety is:

$$MS = \frac{F_a}{f} - 1 = \frac{11.7 \text{ ksi}}{7.67 \text{ ksi}} - 1 = +0.53 \text{ (Service Level B)}$$

For Service Level D, the total stress, f, on the weld is:

$$f = \sqrt{f_b^2 + f_v^2} = \sqrt{18.57^2 + 11.18^2} = 21.68 \text{ ksi (Service Level D)}$$

The allowable stress, F_a, for Service Level D is $1.0 \times S_u \times$ weld factor.

$F_a = 1.0 \times 63.1 \times 0.5 = 31.55 \text{ ksi}$

The margin of safety, MS, for the Service Level D condition is:

$$MS = \frac{F_A}{f} - 1 = \frac{31.55}{21.68} - 1 = +0.46$$

11.5.2 Basket Assembly and Fuel Tube Evaluation

11.5.2.1 Corner Angle Side Impact

The side impact load will be shared by two corner leg angles. The maximum deflection, δ, that a corner leg angle can achieve is 0.102 in.

$$W = \frac{384EI\delta}{5L^3}$$

$$\text{Max moment, } M = \frac{WL}{8}$$

$$\text{The bending stress, } f_b = \frac{Mc}{I} = \frac{384\,E\delta c}{40L^2} = \frac{384(24.4 \times 10^3)(0.102)(0.077)}{40(97.4^2)(0.091)} = 2.13 \text{ ksi}$$

where,

$$c = \frac{I}{S} = \frac{0.077}{0.091}$$

The margin of safety is:

$$MS = \frac{1.5 \times S_m}{f_b} - 1 = \frac{23.4}{2.13} = \text{large}$$

11.5.2.2 Corner Angle End Impact

In the end impact, the load from the tie plates will be shared by four corner leg angles. Because the fuel tubes are not attached to the tie plates, their load will not be transferred to the corner leg angles in the end impact condition.

$$\frac{KL}{r} = \frac{1(15)}{0.369} = 40.6 < 120$$

where,

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.077}{0.563}} = 0.369.$$

$$KL/r < 120 \text{ and } \frac{b}{t} = \frac{125}{0.25} = 5.0 < \frac{76}{\sqrt{S_y}} = \frac{76}{\sqrt{19.4}} = 17.25$$

Therefore, in accordance with NUREG/CR-6322,

$$F_a = S_y\left(0.47 - \frac{KL/r}{444}\right) = 6.57 \text{ ksi}$$

The dead load, P_{DL}, on one corner leg angle = (7 × spacer plate weight)/4 +angle weight = 22 lb.

P_{20g} = 22 × (20 + 1) = 0.462 kips at 20g acceleration
P_{57g} = 22 × (57 + 1) = 1.28 kips at 57g acceleration

For the 20 g acceleration,

f_a = 0.462 kips/0.56 in.^{2} = 0.825 ksi

The margin of safety is:

$$M.S. = \frac{6.57\,\text{ksi}}{0.825\,\text{ksi}} - 1 = +7.0$$

For the 57 g acceleration:

$f_a = 1.28 \text{ kips}/0.56 \text{ in.}^2 = 2.29 \text{ ksi}$

The margin of safety is:

$$M.S. = \frac{6.57 \text{ ksi}}{2.29 \text{ ksi}} - 1 = +1.87$$

11.5.2.3 Fuel Tube Side Impact

The fuel tube is evaluated for bending as a continuous beam with a uniform load and six equal spans at 15.0-in. on center.

$$M_{max} = -\left(0.106 \times wL^2\right)$$ (Manual of Steel Construction)

$$f_b = \frac{Mc}{I}$$

For Service Level B:

$w = 0.0527 \text{ lb/in.} \times (20 + 1)g = 1.11 \text{ lb/in.}$

$$f_b = \frac{Mc}{I} = 5.7 \text{ ksi}$$

For Service Level D:

$w = 0.0527 \text{ lb/in.} \times (55 + 1)g = 2.95 \text{ lb/in.}$

$$f_b = \frac{Mc}{I} = 15.2 \text{ ksi}$$

where,

w	= 0.0527 lb/in.
L	= 15.0 in.
c	= 0.50/2 = 0.25 in.
I	$= \frac{\pi}{64}\left(D^4 - d^4\right) = 1.16 \times 10^{-3}\ \text{in.}^4$
D	= tube outside diameter, 0.50 in.
d	= tube inside diameter, 0.444 in.

The margin of safety at Service Level B is:

$$M.S. = \frac{1.5S_m}{f_b} - 1 = \frac{1.5(15.6)}{5.7} - 1 = +3.10$$

The margin of safety at Service Level D is:

$$M.S. = \frac{1.0S_u}{f_b} - 1 = \frac{1.0(63.1)}{15.2} - 1 = +3.15$$

11.5.2.4 Fuel Tube End Impact

For Service Level B, the fuel tubes are evaluated for axial compression in accordance with NUREG/CR-6322.

For Service Level B, the allowable stress, F_a, is:

$$F_a = S_y\left(0.47 - \frac{KL/r}{444}\right) = 4.70\ \text{ksi}$$

where,

$$r = \sqrt{\frac{I}{A}} = 0.17\ \text{in.}$$

$$\frac{KL}{r} = \frac{(1)(15.0)}{0.17} = 88 < 120$$

$$f_a = \frac{P}{A} = \frac{5.14(20+1)}{.04} = 2.70 \text{ ksi}$$

where,

L = 15.0 in.

$$I = \frac{\pi}{64}\left(D^4 - d^4\right) = 1.16 \times 10^{-3} \text{ in.}^4$$

D = 0.50 in. (fuel tube outside diameter)

d = 0.444 in. (fuel tube inside diameter)

$$A = \frac{\pi}{4}\left(D^2 - d^2\right) = 0.04 \text{ in.}^2$$

P = (fuel + fuel tube + end cap weight) × end impact acceleration

The margin of safety for Level B Service is:

$$M.S. = \frac{F_a}{f_a} - 1 = \frac{4.70 \text{ ksi}}{2.70 \text{ ksi}} - 1 = +0.74$$

For Service Level D, the fuel tubes are evaluated for axial compression in accordance with NUREG/CR-6322 and ASME Section III, Appendix F-1334.3.

Because Subparagraph F-1334.3 specifies no criteria for austenitic stainless steel, the following method from NUREG/CR-6322 is used to determine the criteria for the hypothetical accident condition (Service Level D).

The maximum allowable axial load, P_{allow}, is determined using the relation:

$$\frac{P_{allow}}{P_y} = SS_{Level\,D} = \left(\frac{SS}{CS}\right)_{Level\,A} \times CS_{Level\,D} = 0.45 \quad \text{NUREG/CR-6322 Equation 39}$$

where "SS" and "CS" stand for stainless steel and carbon steel, respectively.

$P_{allow} = P_y \times 0.45 = 0.75 \text{ ksi} \times 0.45 = 0.34 \text{ ksi}$

$$SS_{Level\,A} = \left(0.47 - \frac{\frac{KL\lambda}{r}}{444\sqrt{2}}\right) = 0.36 \qquad \text{NUREG/CR-6322 Equation 45}$$

$$CS_{Level\,A} = \frac{1 - \frac{\lambda^2}{4}}{\frac{5}{3} + \frac{3}{8}\left(\frac{\lambda}{\sqrt{2}}\right) - \frac{1}{8}\left(\frac{\lambda}{\sqrt{2}}\right)^3} = 0.46 \qquad \text{NUREG/CR-6322 Equation 43}$$

$$CS_{Level\,D} = \frac{1 - \frac{\lambda^2}{4}}{1.11 + 0.5\lambda + 0.17\lambda^2 - 0.28\lambda^3} = 0.58 \qquad \text{NUREG/CR-6322 Equation 33}$$

$$\lambda = \frac{1}{\pi}\left(\frac{KL}{r}\right)\sqrt{\left(\frac{S_y}{E}\right)} = 0.77$$

$P_y = S_y \times A = 18.8 \text{ ksi} \times 0.04 \text{ in.}^2 = 0.75 \text{ kips}$

The axial load, P, on the fuel tube is (fuel + fuel tube + end cap weight) × end impact acceleration:

$P = 5.14(57+1) = 0.30 \text{ kips}$

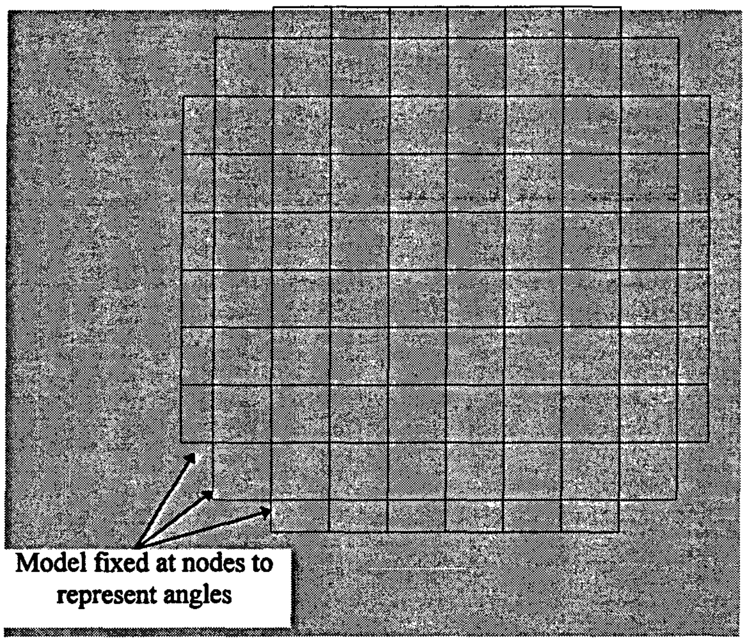
The margin of safety for the Service Level D condition is:

$$M.S. = \frac{P_{allow}}{P} - 1 = \frac{0.34 \text{kips}}{0.30 \text{kips}} - 1 = +0.13$$

11.5.2.5 Tie Plate End Impact

Analysis of the reconfigured fuel assembly tie plate uses a Stardyne finite element model to represent the tie plate during an end impact. The model consists of a square grid of identical

stainless steel beams spaced at 0.75 in. The beams are 0.375 in. deep and 0.23 inches wide (clear space between 0.50 in. dia. holes). The tie plate is welded to four corner angles where the plate is assumed fixed. The tie plate is made of 304 stainless steel. Loads are applied to the nodes to represent the (weight × g loading) of the plate.



Analysis is done for Service Level B and Service Level D conditions.

Shear and Bending

Stresses from Stardyne output:

	Service Level B: (20g loading)	Service Level D: (57g loading)
Maximum Shear Stress:	97 psi	276 psi
Maximum Bending Stress:	726 psi	2070 psi

Service Level B allowable stress at 750°F:

Primary Bending: $1.5 \times S_m = 1.5 \times 15.6$ ksi $= 23.4$ ksi

Shear: greater of: $0.6 \times S_m = 0.6 \times 15.6 = 9.36$ ksi or

$0.6 \times S_y = 0.6 \times 17.3 = 10.4$ ksi

For Service Level D, at the same temperature, the allowable stresses are:

Primary Bending: $1.0 \times S_u = 63.1$ ksi

Shear: $0.42 \times S_u = 0.42 \times 63.1 = 26.5$ ksi

The margins of safety at Service Level B, are:

$$\text{Primary Bending:} \quad MS = \frac{23.4}{0.726} - 1 = +\text{Large}$$

$$\text{Shear:} \quad MS = \frac{10.4}{0.97} - 1 = +\text{Large}$$

At Service Level D, the margins of safety are:

$$\text{Primary Bending:} \quad MS = \frac{63.1}{2.07} - 1 = +\text{Large}$$

$$\text{Shear:} \quad MS = \frac{26.5}{0.276} - 1 = +\text{Large}$$

Welds at Tie Plates to Corner Angles

Each tie plate is welded to four corner angles with top and bottom 0.25-in. fillet welds. From the Stardyne output, the critical shear, torsion, and bending loads are:

Service Level B:	Service Level D:
Shear = 9.03 lbs.	Shear = 25.72 lbs
Torsion = 1.68 in-lbs	Torsion = 13.28 in-lbs
Bending = 5.91 in-lbs	Bending = 8.36 in-lbs

The stresses for Service Level D are calculated using the beam cross section (0.23 in. wide × 0.375 in. deep) and the weld effective throat.

The weld effective throat is: $0.707 \times 0.25 = 0.177$ in.

Therefore:

$$\text{Shear Stress is: } F_s = \frac{25.72}{.23 \times 177} + \frac{13.28}{.0182 \times 177} = 4445 \text{ psi}$$

and,

$$\text{Bending Stress is: } F_b = \frac{8.36}{.086 \times 177} = 548 \text{ psi}$$

Allowables for the weld are:

ASTM A240 Type 304 Stainless Steel (Section II-D ASME) at 750°F

$S_u = 63.1$ ksi $S_y = 17.3$ ksi $S_m = 15.6$ ksi

Per ASME Section III-NG the minimum quality factor for a Category E Type V weld is n = 0.4.

At Service Level B:

Membrane + Bending:	$F = 1.5 \times S_m \times n = 1.5 \times 15.6 \times 0.4 = 9.36$ ksi
Shear:(greater of)	$F = 0.6 \times S_m \times n = 0.6 \times 15.6 \times 0.4 = 3.74$ ksi
	$F = 0.6 \times S_y \times n = 0.6 \times 17.3 \times 0.4 = 4.15$ ksi

At Service Level D:

Membrane + Bending:	$F = 1.0 \times S_u \times n = 1.0 \times 63.1 \times 0.4 = 25.24$ ksi
Shear:	$F = 0.42 \times S_u \times n = 0.42 \times 63.1 \times 0.4 = 10.60$ ksi

Since the actual weld stress during Service Level D is equal to or less than the allowables during Service Level B, ¼-in. double fillet weld is satisfactory.

A conservative analysis of the RFA Tie Plate shows the plate to be satisfactory for a Service Level B and D end impact.

11.5.2.6 Tie Plate Side Impact

The fuel tubes are supported by tie plates at 15 inches on center spacing. During a side impact the weight of the fuel tube, amplified by the g loading, puts the bottom edge of the tie plate in compression. The tie plate is analyzed as compression beam model. The weight of each fuel tube is carried in compression only and does not have the ability to shear to the next row of beams.

For Service Level B:

The weight of each fuel tube at 15 inch spacing is:

$$W_{20g} = \frac{1.18 \text{ lbs / tube}}{97.70 \text{ inches}} \times 15.0 \text{ inch spacing } \times (20+1) = 3.80 \text{ lbs / tube}$$

For Service Level D:

The weight of each fuel tube at 15 inch spacing is:

$$W_{55g} = \frac{3.80 \times (55+1)}{(20+1)} = 10.14 \text{ lbs / tube}$$

The compression and shear load at the bottom of the tie plate during a side impact is:

For Service Level B:

$$P = 3.80 \times 8 = 30.4 \text{ lbs}$$

$$F = \frac{30.4}{.375 \times .23} = 352 \text{ psi for both shear and compression}$$

The critical margin of safety is for shear:

$$M.S. = \frac{10400}{352} - 1 = +\text{large}$$

For Service Level D:

$$P = 10.14 \times 8 = 81.1 \text{ lbs}$$

$$F = \frac{81.1}{.375 \times .23} = 941 \text{ psi for both shear and compression}$$

The critical margin of safety for shear is:

$$M.S. = \frac{26500}{941} - 1 = +\text{large}$$

Because the tie plate and corner angles are of the same material 304 SS, and because the fuel tubes are not connected to the tie plates, thermal stresses can be ignored.

11.5.2.7 Tie Plate Thermal Stress Analysis

From Table 4.4.3-4 in Section 4.4.3, the maximum ΔT between the shell casing and the Reconfigured Fuel Assembly tube is 20°F. A ΔT of 25°F is conservatively used for the tie plate analysis.

The thermal stress is calculated using the formula (Roark):

$$S = K_t \, x \, \frac{\Delta T \alpha E}{1-\nu} = 3x \frac{25(9.76x10^{-6})(24.4x10^{6})}{1-0.275} = 24{,}636 \text{ psi (compression)}$$

where,

Material properties are taken at 750°F.
K_t is the stress concentration for a hole in an infinite plate.

For Service Level B:

$S = 352$ psi $+ 24{,}636$ psi $= 24{,}988$ psi (compression)

The margin of safety is:

$$M.S. = \frac{3.0x15{,}600}{24{,}988} = +0.87$$

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12.0 OPERATING CONTROLS AND LIMITS

This chapter identifies operating controls and limits, technical parameters and surveillance requirements imposed to ensure the safe operation of the NAC-MPC system.

12.1 Proposed Operating Controls and Limits

The NAC-MPC system is designed to provide passive dry storage of containerized Yankee Class spent fuel [redacted]. The principal controls and limits are satisfied by the selection of fuel for storage that meet the technical specifications presented in Section 2.1. The system has few operating controls. The general areas where controls and limits are necessary for safe operation of the system are shown in Table 12.1-1. The conditions and parameters noted in the table are based on the specifications and functionality of the system, and the safety assessments for normal and accident conditions. They are conditions of use of the NAC-MPC system.

The content of the identified individual operating controls and limits and the bases for them are presented in Section 12.2.

Table 12.1-1 NAC-MPC Controls and Limits

Control or Limit	Condition or Item Controlled
1. Fuel Characteristics	Type and Condition Dimensions and Weight Burnup and Initial Enrichment Cool Time
2. Canister Fuel Loading Draining Drying Backfilling Sealing External Surface	 Weight and Number of Assemblies Time to Drain Vacuum Pressure[1], Time at Vacuum Condition[1] Helium Pressure[1] Weld Condition[1], Helium Leak Rate[1], Time in Transfer Cask Level of Contamination
3. Storage Cask	Surface Dose Rates Cask Spacing
4. Surveillance	Air Inlets and Outlets Air Outlet Temperature Annual VCC Concrete Inspection
5. ISFSI Concrete Pad	Pad Concrete Thickness Pad Subsoil Thickness Pad Concrete Compressive Strength

1 Also Applies to Canister Overpack

12.2 Development of Operating Controls and Limits

The implementation of the operating controls and limits described in this section ensures that the NAC-MPC system is used in accordance with the conditions evaluated in this Safety Analysis Report.

12.2.1 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings

The controls and limits that apply to the NAC-MPC system that can be observed and measured are discussed in this section. Selection of these variables is based on the performance and integrity requirements of the equipment and confinement barriers.

The specifications contained in this section are:

- Maximum Permissible Canister Leak Rate
- Maximum Permissible Air Outlet Temperature
- Maximum External Surface Dose Rate
- Maximum Canister Surface Contamination

12.2.1.1 Maximum Permissible Canister Leak Rate

Limit: 1 x 10^{-7} ref cm^3/sec (air at standard conditions), based on the definition of "leaktight" in accordance with ANSI N14.5-1997. The calculated test leak rate is 8 x 10^{-8} cm^3/sec (helium) (Section 7.4.2.1). The leak test sensitivity is 4.0 x 10^{-8} cm^3/sec (helium). Any indication of a leak is cause for rejection of the canister weld.

Applicability: Canister Confinement Boundary.

Objective: 1. To limit the radioactive gases released by each canister to negligible levels. The canister confinement boundary will confine any fission gases that escape from the fuel cladding.

2. To retain backfilled helium cover gas in the canister and, thereby, prevent oxygen from entering the canister. The helium improves the heat dissipation from the canister assembly and minimizes any oxidation of the fuel cladding.

Action: The leak rate shall be checked using calibrated instruments and written procedures. The required leak test sensitivity is at least 4.0×10^{-8} cm^3/sec (helium). No evidence of leakage is permitted.

Surveillance: The canister shall be tested after the shield lid weld has been completed. The canister will be pressurized with helium to 1.5 atm absolute. No indications of a leak are permitted. If no indications of a leak are detected, additional testing and surveillance is not required, since there are no evaluated normal or accident conditions that will breach the structural integrity and leak tightness of the canister.

Bases: If the canister leaks at the largest undetectable leak rate, then only approximately 1 percent of the helium would escape over the 50-year service life. This amount is negligible.

12.2.1.2 <u>Maximum Permissible Air Outlet Temperature</u>

Limit: The equilibrium air temperature at the outlet of a fully loaded NAC-MPC (12.5 kW) shall not exceed the ambient temperature by more than 92°F. This temperature difference is applicable to both the normal conditions (75°F ambient) and the extreme high ambient temperature accident condition (125°F).

Applicability: This temperature limit applies to all NAC-MPC casks stored in the ISFSI. If a cask is placed in service with a heat load less than 12.5 kW, the limiting temperature difference between outlet and ambient shall be determined by a calculation performed by the user using the same methodology and inputs as were used for the 12.5 kW case.

Objective: The objective of this limit is to ensure that the temperatures of the fuel cladding and the concrete do not exceed the temperature limits determined in Section 4.0 of this SAR for the normal and accident conditions. That section shows that if the air temperature increase (for a 12.5 kW heat load) is below 92°F, the fuel cladding and concrete temperatures will be below their limits for normal operation and for the extreme heat load transient (125°F ambient, full solar and a full thermal load). The extreme heat load transient is considered an accident condition. An additional objective of the temperature measurements is to confirm the thermal performance of the cask and provide baseline data.

Action: If an air temperature rise of greater than 92°F is observed for any NAC-MPC placed in service, the first action will be to check all inlets and outlets for air flow blockage. If environmental factors are ruled out as the cause of the elevated cask temperatures, the decay heat of the contents will be reviewed for compliance with the upper limit specified in Chapter 2.0. If fuel assemblies meeting the specifications have been loaded into the cask and the temperature difference is greater than 92°F, this condition is not addressed in the SAR. Additional measurements and analyses to determine that the actual performance of the cask is within the limits analyzed in the SAR will be performed. If the elevated temperatures result in unacceptable cask performance, appropriate recovery actions shall be undertaken.

Surveillance: The ambient temperature and cask outlet air temperatures for the first cask shall be measured and recorded daily after the cask has been placed in service. The ambient temperature and cask outlet air temperatures for each cask placed in service shall also be verified on a daily basis in accordance with Section 12.2.3.1.2.

Bases: If the air temperature differential is 92°F, or less, the maximum concrete and fuel cladding temperatures are less than the limits that are applicable to the normal or accident conditions as appropriate.

12.2.1.3 <u>Maximum External Surface Dose Rate</u>

Limit: The average external surface dose rate for the concrete cask from all types of radiation will be less than 40 mrem per hour on the sides and top. The peak dose rate will be 50 mrem per hour. Dose rates at the air inlets or outlets will be below 100 mrem per hour.

Applicability: This dose limit shall apply to the entire external surface of the concrete cask, except the bottom surface, which is inaccessible.

Objective: The external dose rate is limited to this value to provide assurance that controlled area boundary doses are in compliance with 10CFR72.104 (a). Dose rates above these values may indicate that the cask has been loaded with spent fuel not meeting the specifications in Chapter 2.0.

Action: If the measured dose rates exceed the limit values, proper fuel loading shall be verified. If proper fuel is loaded, specific analyses must demonstrate compliance with 10CFR20 and 10CFR72 radiation protection requirements, or appropriate action must be taken to ensure compliance with the limits. A letter report, summarizing the action(s) taken and the results of the investigation conducted to determine the cause of the high dose rates, shall be submitted to the NRC within 30 days in accordance with 10CFR72.4.

Surveillance: The external surface dose rate of the concrete cask shall be measured immediately following loading of the canister into the concrete cask. The side dose rate shall be measured at a location approximately five feet above the bottom of the cask, at four equally spaced radial locations. The top dose rate shall be measured at the cask lid center and at the outer edge of the lid. The dose rate measurement will be corrected for background readings.

Basis: The basis for this limit is the shielding analysis presented in Chapter 5.0.

12.2.1.4 Maximum Canister Surface Contamination

Limit: A site-specific contamination limit shall be determined for β-γ and α activity before beginning fuel loading operations. The limits shall be based on Figures 12.2-1 and 12.2-2, and the following equation:

$$C = \frac{Q \times 2.22x10^{12}}{A \times N}$$

$$= 617 \times 10^5 Q$$

where,

C = the contamination limit in dpm/cm^2
Q = the number of curies interpolated from Figure 12.2-1 or 12.2-2 as applicable
A = the surface area of one canister = 2.25 x 10^5 cm^2
N = the number of canisters to be placed in service = 16

Based on an assumed limit of 1 mrem per year at 100 meters, the surface contamination limit is 190 dpm per 100 square centimeters of surface for alpha, and 22,900 dpm per 100 square centimeters of surface for beta/ gamma. Based on the procedure for minimizing the canister surface contact with contaminated water, the measured removable surface contamination is expected to be far less than the limiting values.

Applicability: Canister external surface.

Objective: To maintain surface contamination below a level that if the contamination became loose and behaved as a particulate release, the resulting contribution to the annual off-site dose would be less than 1 mrem.

Action: If the limit is exceeded, the canister exterior shall be washed by flushing the canister-transfer cask annulus with water, soapy water, or other suitable decontamination solution, and additional contamination surveys taken until the limit is satisfied.

Surveillance: Contamination surveys shall be performed on the canister exterior within six inches of the top. The contamination surveys for removable surface contamination shall be conducted after final closure of the loaded canister and before the concrete cask is moved to the storage pad.

Bases: Applying the methodologies set forth in Reg. Guides 1.109 and 1.145 for dose calculations and plume dispersion, an acceptable total activity release was calculated. If that acceptable total activity release occurred in a year of operation, it would contribute less than 1 mrem toward the 10CFR72.104(a) exposure limit. ^{60}Co and ^{241}Pu were selected as representative nuclides for this analysis. The acceptable total activity release that represents the dose contribution at the boundary is a fixed value that remains the same regardless of the number of casks, but increases with the distance to the controlled area boundary. Therefore, the activity determined for a distance must be divided by the number of casks placed in service. The purpose of imposing a variable limit is founded in the balance between maintaining occupational exposure and dose to the general public ALARA. The selection of a contamination limit intended to minimize the dose at 100 meters could result in a requirement for substantial decontamination effort.

12.2.2 Limiting Conditions For Operation

The following specifications are contained in this section:

- Fuel Specification
- Canister and Canister Overpack Vacuum Pressure and Helium Backfill Pressure
- Examination of Canister and Canister Overpack Closure Welds
- Time Limits for Canister and Canister Overpack Loading Operations
- Placement on Storage Pad
- Minimum Temperature for Moving the Canister
- Minimum Temperature for Lifting the Transfer Cask
- Handling Height

12.2.2.1 Fuel Specification

Specification: The spent fuel to be stored in the NAC-MPC storage system must satisfy limits defined in Table 2.1-1. The principal fuel characteristics of reconfigured fuel are described in Section 2.1.1 and in Table 6.2-2.

Applicability: This specification is applicable to all fuel to be stored in the NAC-MPC system.

Objective: This specification defines limiting fuel characteristics to ensure that the peak fuel rod temperatures, maximum surface doses, and nuclear criticality effective multiplication factor are below the design values. In addition, the use of a bounding fuel weight and type ensures that structural evaluations in this SAR bound those of the actual fuel being stored.

Action: The characteristics of each fuel assembly to be loaded into a canister must be independently verified and documented to meet the specification above. Fuel not meeting this specification shall not be stored in the NAC-MPC system.

Surveillance: The identity of each fuel assembly shall be independently verified and documented immediately before insertion into the canister.

Bases: The specification is based on consideration of the design basis fuel characteristics included in this SAR and limitations imposed by the NRC. Such characteristics are a function of the type of fuel analyzed, physical and structural limitations, criteria for criticality safety, criteria for heat removal, and criteria for radiological protection. The principal design characteristics of the fuel to be stored are found in Section 2.1. The NAC-MPC system can accommodate Yankee Class PWR fuel assemblies of the designs manufactured by Combustion Engineering (CE), Exxon, Westinghouse, and fuel assemblies bounded by these fuel designs. The analyses presented in this SAR are based on intact, zircaloy or stainless steel clad fuel with no known or suspected gross cladding failures.

The physical parameters that define the mechanical and structural design of the concrete cask and the canister are the fuel assembly dimensions and weights provided in Table 2.1-1.

The criticality design criteria ensure that the spent fuel remains subcritical under normal, off-normal, and accident conditions. Misloading of fresh fuel and optimum moderation are considered in the criticality analyses.

The design basis for nuclear criticality safety is the most reactive fuel assemblies, of the types listed, with initial enrichments up to 4.0 wt % ^{235}U for zircaloy clad fuel and 4.94 wt % ^{235}U for stainless steel clad fuel.

Fuel cladding temperature criteria were established based on methodology in PNL-6189 and PNL-6364. Based on this methodology, a maximum heat generation rate of .347 kW per assembly is a bounding value for the Yankee Class fuel to be stored. This limit ensures that the maximum heat generation rate per assembly is such that the fuel cladding temperature is maintained within established criteria during normal and off-normal conditions.

The radiological design basis for determining minimum cool time is the surface dose rate of the vertical concrete cask. To meet the design basis surface dose rate, the Combustion Engineering Type A assembly with an enrichment of 3.9 wt % ^{235}U irradiated to an average burnup of 36,000 MWD/MTU, must have a minimum cool time of 8 years. Minimum cool times are calculated for the alternate loading (32,000 MWD/MTU) based on the maximum allowable surface dose rate of the concrete cask and the source magnitude and source spectrum at the specific combination of burnup and cool time for the alternate fuel.

12.2.2.2 <u>Canister and Canister Overpack Vacuum Pressure During Drying</u>

Specification: Vacuum Pressure: 5 mm Hg (maximum vacuum pressure)
Time at Pressure: 20 min.
Number of Pump-Downs: 2

Applicability: This specification is applicable to all canisters and to the canister overpack.

Objective: To ensure removal of the free water from the canister and removal of air from the canister overpack.

Action: If the required vacuum pressure cannot be obtained:

1. Continue to operate the vacuum drying system;
2. Check and repair or replace the vacuum system connections and plumbing;
3. Check operation of gauge(s) indicating vacuum pressure;
4. Check and, if necessary, repair the weld between the shield lid and the canister shell and/or the weld between the vent port cover and the shield lid.

Surveillance: Surveillance of the vacuum gauge shall be maintained during the vacuum drying operation.

Bases: The value of 5 mm Hg for a vacuum pressure was selected to allow the use of standard vacuum pumps. If the only gas contained within the canister cavity is considered to be super-heated steam at a pressure of 5 mm Hg and 450°F, the moisture content of the canister cavity is approximately 0.729 moles (assuming a perfect gas) and, hence, only 0.364 moles of O_2 are available (if 100% radiolysis is assumed). This O_2 could react with 1.09 moles of UO_2 (295 grams). However, the reaction of 295 grams of UO_2 would be negligible compared to the 2225 grams of UO_2 in a single rod. Since the multiple pump-down is performed, the O_2 partial pressure after backfilling will not exceed $(5/760)^2 \times 760 = 0.03$ mm Hg.

12.2.2.3 Canister and Canister Overpack Helium Backfill Pressure

Specification: Helium backfill pressure of 0.0 psig (nominal) (one atmosphere (absolute)).

Applicability: This specification is applicable to all canisters and to the canister overpack.

Objective: To ensure that (1) there is a nonoxidizing gas atmosphere surrounding the irradiated fuel; (2) the atmosphere enhances the transfer of decay heat (over that of air); and (3) over pressure of the canister or canister overpack does not occur.

Action: If the required pressure cannot be obtained, check/repair/replace in order the following components: pressure gauge, pressure tubes/connections/valves, helium source, and weld at the canister shell to shield lid juncture.

If the pressure exceeds 0 psig, perform a controlled release of a sufficient quantity of helium to lower the cavity pressure.

Surveillance: No maintenance or tests are required during the normal storage operations. Surveillance of the pressure gauge is required during the helium backfilling operation.

Bases: The value of 0 psig (one atmosphere [absolute]) was selected to assure that the pressure within the canister or canister overpack is within the design limits of 50 psig during any expected off-normal operating condition.

12.2.2.4 Examination of Canister and Canister Overpack Closure Welds

Specification: Examination of Canister Closure Welds

The root and final surfaces of the shield lid/canister shell weld are liquid penetrant (PT) examined per ASME Code Section V, Article 6, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5350. Following completion and examination of the shield lid/canister shell weld, the canister is pressure tested to 22 psia with no loss of pressure permitted in 10 minutes. After the loaded canister is drained, dried, and backfilled with helium, the shield lid/canister shell weld is leak tested with an internal pressure of 22 psia and a leak test sensitivity of 4×10^{-8} std cm^3/sec (helium). The vent port cover/shield lid and drain port cover/shield lid welds are progressively liquid penetrant examined - i.e. root, each 1/4-inch layer, and final surfaces - in accordance with the ASME Code Section V, Article 6, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5350. The structural lid/canister shell weld is either: (1) ultrasonic examined in accordance with ASME Code Section V, Article 5, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5330, followed by final weld surface liquid penetrant examination and acceptance per the previously defined Code sections; or (2) progressively liquid penetrant

examined - i.e. root, each 1/4-inch layer, and final surfaces - and accepted in accordance with the previously described Code sections.

Examination of Canister Overpack Closure Welds

The canister overpack is closed at its upper end by two lids: an inner lid which includes a vent port with cover; and an outer lid. Partial-penetration groove welds attach the inner lid to the canister overpack shell and the vent port cover to the inner lid. The outer lid is attached to the canister overpack shell by an effectively full penetration groove weld. The root and final surfaces of the inner lid/canister overpack shell weld are liquid penetrant examined in accordance with ASME Code Section V, Article 6, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5350. Following completion and examination of the inner lid/canister overpack shell weld, the loaded canister overpack is backfilled with helium and the weld is leak tested with an internal pressure of 22 psia and a leak test sensitivity of 4×10^{-8} std cm^3/sec (helium). The vent port cover/inner lid weld is progressively liquid penetrant examined - i.e. root, each 1/4-inch layer, and final surfaces - per ASME Code Section V, Article 6, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5350. The outer lid/canister overpack shell weld is either: (1) ultrasonic examined in accordance with ASME Code Section V, Article 5, with acceptance criteria as specified in ASME Code Section III, Subsection NB, NB-5330, followed by final weld surface liquid penetrant examination and acceptance per the previously defined Code sections; or (2) progressively liquid penetrant examined - i.e. root, each 1/4-inch layer, and final surfaces - and accepted in accordance with the previously described Code sections.

Applicability: This is applicable to the closure welds of the canister and canister overpack.

Objective: To ensure that the canister or canister overpack is welded closed and leak tight.

Action: If the liquid penetrant or ultrasonic examination indicates that the weld is unacceptable:

1. The weld shall be ground down and rewelded; and
2. The new weld shall be re-examined in accordance with this specification.

Surveillance: The liquid penetrant or ultrasonic examination shall be done during canister or canister overpack closure operations.

Bases: ASME Code, Section III, NB-5330 or NB 5350.

12.2.2.5 Time Limits for Canister Loading Operations

Specification: Time limits for canister loading operations are established for the following activities:

- Draining of water from the canister — 20 hours
- Vacuum drying of the canister — 10 hours
- Transfer to concrete cask after helium backfill — 36 hours

Applicability: This specification is applicable to all loaded canisters. Based on the actual (lower) heat load and the spent fuel pool water temperature, a longer time limit for the canister loading operations can be determined.

Objective: To preclude significant boiling of the water within the canister and to ensure that component normal operating condition temperature limits are not exceeded.

Action: If the canister loading operations can not be completed within the specified time, it must be placed back into the spent fuel pool for a minimum of 4 hours and allowed to cool.

Surveillance: Canister handling times are monitored to ensure that the time limits associated with the indicated operations are not exceeded. Handling time limits applied are: (1) The time elapsed between removal of the canister from the spent fuel pool and completion of draining of water from the canister (20 hours); (2) time that the canister cavity contains either air or a vacuum (10 hours); and, (3) time that the canister cavity contains helium but the canister is in the transfer cask (36 hours). The 36 hour limit also applies to transfer of a canister using the transfer cask to a canister overpack.

Basis: The 20-hour limit is determined from a conservative thermal transient analysis based on the 12.5 kW heat load and an initial spent fuel pool water temperature of 100°F. The 10-hour limit for the vacuum condition and the 36-hour limit with a helium atmosphere in the transfer cask are based on the component and material temperature limits for normal conditions at the same heat load.

12.2.2.6 Placement on Storage Pad

Specification: Each concrete cask shall be placed in the storage array with a center-to-center spacing of not less than 15 feet (+1, -0 ft.)

Applicability: This specification applies to all concrete casks.

Objective: To satisfy the thermal analysis assumptions and to provide easy access to each of the casks.

Action: The center-to center spacing shall be measured during placement.

Basis: The access requirements reflect engineering judgment on handling needs. The 15-foot center-to-center spacing was used to determine thermal radiation view factors in the thermal analysis

12.2.2.7 Minimum Temperature for Moving the Canister

Specification: This specification is not directly applicable to the canister because the canister and basket are fabricated entirely of stainless steel and aluminum, which are not subject to a ductile-to-brittle transition in the temperature range of interest. However, low temperature handling limits do apply to the transfer cask. The canister cannot be moved without using the transfer cask.

12.2.2.8 Minimum Temperature for Lifting the Transfer Cask

Specification: The transfer cask shall not be used to move the loaded canister if the transfer cask temperature is below 0°F. Material tests shall be conducted during

fabrication of the transfer cask to show that the material's NDT is less than or equal to -40°F.

Objective: To preclude potential brittle fracture of the transfer cask material.

Action: Confirm that the transfer cask temperature is equal to, or greater than, 0°F before using the transfer cask.

Surveillance: The minimum temperature of the transfer cask shall be determined prior to its use.

Basis: Appropriate ASTM material ductility tests performed at -40°F will demonstrate that the transfer cask material NDT is below -40°F, so that at NDT 0°F, the potential for brittle failure is precluded. The transfer cask shell temperature will be higher than ambient due to the decay heat of the irradiated fuel in the canister. The minimum temperature of the shell, trunnions, rails, and doors must be determined prior to use and must be at or above 0°F. The temperatures of these components must remain at or above 0°F during the period of use.

12.2.2.9 Concrete Cask Handling Height

Specification: The loaded concrete cask shall not be handled at a height greater than 6.0 inches above a supporting surface.

Applicability: The specification applies to handling all concrete casks, containing a loaded canister or canister overpack, on route to and at the storage pad.

Objectives:

1. To preclude a loaded concrete cask drop from a height greater than 6.0 inches.

2. To maintain spent fuel integrity, confinement integrity of the canister, and concrete cask functional capability.

Surveillance: The lifting height of the concrete cask will be administratively controlled to preclude raising the cask higher than 6.0 inches during jacking to permit insertion or removal of the air pads.

Basis: This specification ensures that handling height limit of 6.0 inches will not be exceeded in transit to, from, or at the storage pad. Structural evaluation(s) ensure that the spent fuel will continue to meet the requirements for storage, the canister or canister overpack will continue to provide confinement, and the concrete cask will continue to provide its design functions of protection, cooling, and shielding.

12.2.2.10 ISFSI Concrete Pad Specifications

Specification: The concrete pad shall have the following requirements:

• Concrete Pad	3 feet maximum thickness (excluding pad footer)
• Pad Subsoil (Back Fill)	3 feet minimum thickness
• Pad Concrete	<3,000 psi compressive strength (design strength) at 28 days
• Pad Concrete Density	125 to 140 lbs/ft^3

Applicability: The specification applies to all concrete pads where the NAC-MPC storage cask is used.

Objectives: To satisfy the concrete cask tip over analysis bounding assumptions for pad stiffness.

Action: ISFSI pad Design Specifications shall specify the pad requirements to be verified during construction of the pad.

Basis: These specifications ensure that a concrete cask tip over accident does not result in exceeding the design limits of the canister or canister overpack.

12.2.2.11 Canister Re-Flood

Specification: The minimum temperature of the water used for re-flooding the canister is 70°F. The maximum re-flood flow rate while filling the canister is 8 gallons per minute (gpm).

Applicability: The specification applies to all loaded transportable storage canisters.

Objectives:

1. To reduce thermal stress on canister and basket components and to limit internal pressure, during re-flooding of the canister cavity.

2. To reduce thermal stress on the spent fuel to preserve spent fuel integrity.

Action: Confirm that the temperature of the water is above 70°F. Maintain the re-flood water flow rate no greater than 8 gpm during canister re-flooding. Normal operating re-flood water flow rate should be maintained at 5 (+3, -0) gpm.

Surveillance: Initially measure the water temperature then monitor the water temperature every 1/2 hour during re-flood operations. Monitor the re-flooding water flow rate every 1/2 hour to maintain a water flow rate no greater than 8 gpm.

Basis: This specification is based on consideration of thermal stresses imposed on the canister and basket components and to reduce the potential for damage to spent fuel cladding. Restricting the re-flood water flow rate assists in maintaining the pressure within the canister within acceptable design limits.

12.2.3 Surveillance Requirements

12.2.3.1 Normal Operation Surveillance

The surveillance requirements for normal operations presented in this section are applicable to all loaded NAC-MPC storage systems:

- Visual Inspection of Air Inlets and Outlets
- Cask Thermal Performance
- Concrete Cask Exterior Surface Inspection

12.2.3.1.1 Visual Inspection of Air Inlets and Outlets

Surveillance: A visual surveillance of the screens covering the air inlets and outlets shall be conducted daily for concrete casks containing canisters and twice daily (every 12 hours) for concrete casks containing loaded canister overpacks.

Action: If the screens show signs of degradation, breach, or other sources of blockage, such as an insect infestation, a close-up inspection of the air inlets and outlets shall be conducted to determine whether any blockage exists. If blockage exists, the obstruction(s) shall be removed promptly.

Basis: The concrete temperature could exceed 350°F in the accident condition of complete blockage of all inlets and outlets assuming the design basis heat load. Concrete temperatures exceeding 350°F are undesirable as they have uncertain impact on strength and durability. Conservative analysis (adiabatic heat case) of complete blockage of all air inlets and outlets of the concrete cask indicates that the event must continue for more than 40 hours before the concrete temperature would rise to 350°F. For concrete casks containing loaded canister overpacks, increased surveillance is necessary to ensure that fuel cladding temperatures are maintained below the allowable temperature limits for normal conditions.

12.2.3.1.2 Cask Thermal Performance

Surveillance: Verify the thermal performance for each loaded concrete cask on a daily basis by measuring the ambient temperature and the outlet air temperature. The difference between ambient temperature and outlet air temperature should not exceed 92°F.

Action: If the temperature measurements show a difference between ambient temperature and outlet air temperature that exceeds 92°F, take appropriate action to determine the cause and return the cask to normal operation. If the measurement, or other evidence, suggests that the concrete accident (short-term) temperature criteria (350°F) has been exceeded for more than 24 hours, provision must be made for removing the storage cask from service. The cask shall be removed from service unless the licensee can provide test results in accordance with ACI-349, Appendix

A.4.3, demonstrating that the structural strength of the concrete cask has an adequate margin of safety. Surveillance of the compromised storage cask should be increased until remedial action is taken.

Basis: The temperature measurements are sufficient for the licensee to identify conditions that may approach the temperature limits for normal cask operation. If used, air and ambient temperatures must be measured in such a manner as to obtain representative values.

12.2.3.1.3 Concrete Cask Exterior Surface Inspection

Surveillance: The concrete cask exterior surface shall be visually inspected annually for any damage (chipping, spalling, etc.).

Action: Any defects larger than one inch in diameter (or width) and deeper than one inch shall be regrouted, according to the grout manufacturer's recommendations.

Basis: Maintenance of the exterior surface of the concrete cask prevents degradation of the concrete interior and avoids adverse impacts on shielding performance.

12.2.3.2 Surveillance After an Accident

The NAC-MPC storage cask shall be inspected within 24 hours after the occurrence of a tornado, earthquake (larger than 5.0 on the Richter scale), or other natural disaster in the area of the ISFSI. This inspection must specifically verify that the storage cask inlets and outlets are not blocked. At least one-half of the inlets and outlets must be cleared to restore air circulation within 24 hours. Provision must be made for removing the storage cask from service if the inlets and outlets have been fully blocked for more than 24 hours. An extended period of extreme heat can reduce the strength of the concrete below the design basis evaluated in Chapters 3 and 11.

The concrete cask and the contained canister shall be inspected if they experience a drop from a height of more than 6.0 inches or a tipover.

12.2.4 Design Features

The operating controls and limits described in this section cover the features of the NAC-MPC storage system that are important to maintenance of safety margins in the cask design. The objective of these limits is to control design changes in the equipment that are important to safety.

The essential design features of the cask are as follows:

- Concrete density
- Concrete compressive strength
- Canister shield lid and structural lid material densities and thicknesses
- Reinforcing steel quantities and placement
- Canister confinement boundary
- Canister basket and shell material thicknesses and strengths

Each of these design features is important to the ability of the NAC-MPC storage system to meet the requirements of 10CFR72 for at least 50 years. Each parameter is closely controlled by the fabrication specifications for the canister and the concrete cask. The design of these features may not be altered without affecting the safety and durability of the cask. Verification inspections must be performed during NAC-MPC component fabrication and construction.

12.2.5 Administrative Controls

Controls used by NAC International as part of the NAC-MPC design and fabrication are provided in the NAC Quality Assurance Manual and Quality Procedures. Quality assurance is discussed in Chapter 13.0. Site-specific controls for the organization, administrative system, procedures, record keeping, review, audit and reporting necessary to ensure that the NAC-MPC storage system installation is operated in a safe manner are the responsibility of the user of the system.

Figure 12.2-1 Determination of Activity Limit (Alpha)

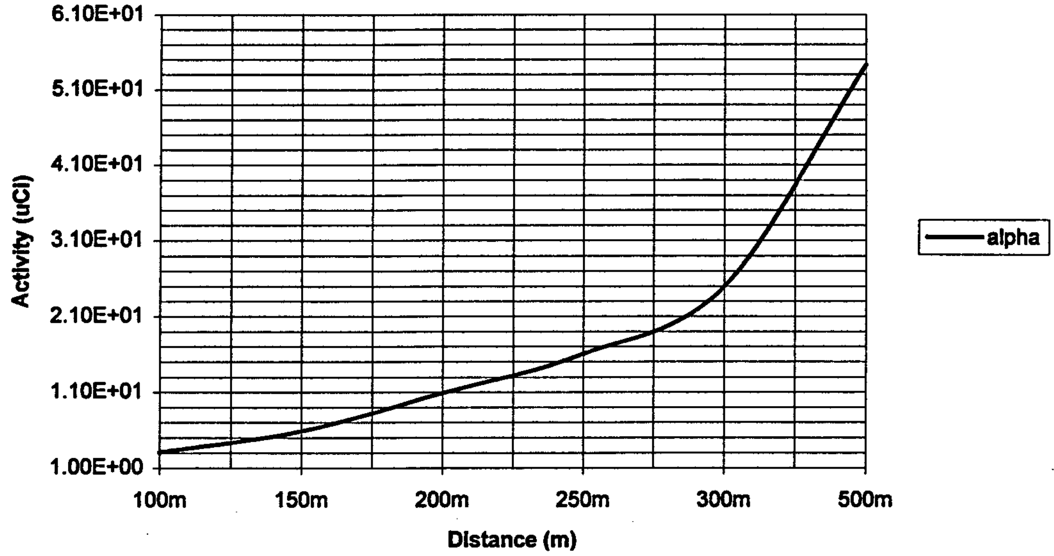
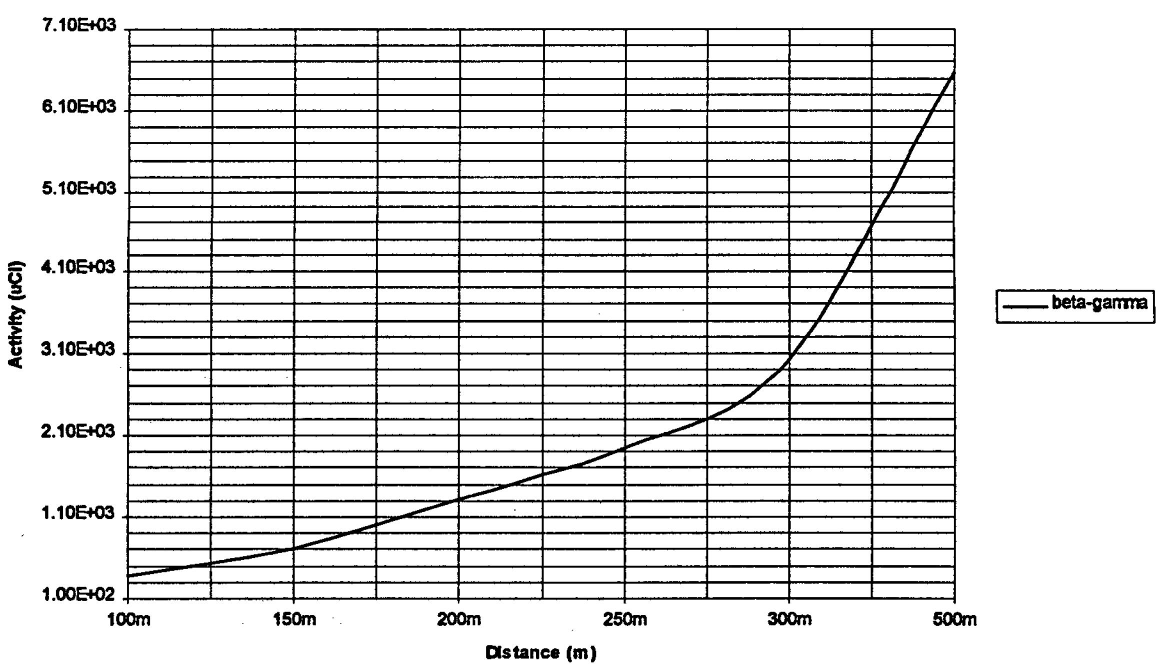


Figure 12.2-2 Determination of Activity Limit (Beta-Gamma)



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13.0 QUALITY ASSURANCE

13.1 Introduction

The NAC International Quality Assurance Program is designed and administered to meet all Quality Assurance criteria of 10 CFR 72, Subpart G, 10 CFR 50, Appendix B, 10 CFR 71, Subpart H, and NQA-1 (Basic and Supplemental Requirements). The program is defined in a QA Program description document that has been reviewed and approved by the Nuclear Regulatory Commission (Approval No. 0018).

The NAC International Quality Assurance Program is described in a Quality Assurance Manual. This Quality Assurance Manual, as approved by the President & Chief Executive, contains policy as to how NAC International intends to comply with the applicable regulatory QA criteria. Detailed implementing quality procedures are used to provide the procedural direction to comply with the policy of the QA Manual.

Employing a graded methodology, as described in USNRC Regulatory Guide 7.10, NAC International applies quality controls to items and activities consistent with their safety significance. Table 13.1-1 identifies the relationships among the applicable quality criteria and the NAC Quality Assurance Manual.

A synopsis of the NAC Quality Assurance Program has been developed and is presented in Section 13.2 of this Safety Analysis Report.

Table 13.1-1 Relationship of the 18 Criteria to the NAC Quality Assurance Program

Criteria of: 10 CFR 50 Appendix B 10 CFR 71 Subpart H 10 CFR 72 Subpart G	Corresponding NAC International QA Manual Section
I. Organization	Quality Assurance Manual Section 1
II. Quality Assurance Program	Quality Assurance Manual Section 2
III. Design Control	Quality Assurance Manual Section 3
IV. Procurement Document Control	Quality Assurance Manual Section 4
V. Procedures, Instructions, and Drawings	Quality Assurance Manual Section 5
VI. Document Control	Quality Assurance Manual Section 6
VII. Control of Purchased Items and Services	Quality Assurance Manual Section 7
VIII. Identification and Control of Material, Parts and Components	Quality Assurance Manual Section 8
IX. Control of Special Processes	Quality Assurance Manual Section 9
X. Inspection	Quality Assurance Manual Section 10
XI. Test Control	Quality Assurance Manual Section 11
XII. Control of Measuring and Test Equipment	Quality Assurance Manual Section 12
XIII. Handling, Storage and Shipping	Quality Assurance Manual Section 13
XIV. Inspection, Test and Operating Status	Quality Assurance Manual Section 14
XV. Control of Nonconforming Items	Quality Assurance Manual Section 15
XVI. Corrective Action	Quality Assurance Manual Section 16
XVII. Records	Quality Assurance Manual Section 17
XVIII. Audits	Quality Assurance Manual Section 18

13.2 NAC Quality Assurance Program Synopsis

13.2.1 Organization

The President & Chief Executive of NAC International has the ultimate authority and responsibility over all organizations and their functions within the corporation. However, the President delegates and empowers qualified personnel with the authority and responsibility over selected key areas, as identified in the NAC Organization Chart, Figure 13.2-1.

The Vice President, Quality is responsible for definition, development, implementation and administration of the NAC Quality Assurance Program. The Quality Assurance organization is independent from other organizations within NAC and has complete authority to assure adequate and effective program execution, including problem identification, satisfactory corrective action implementation and the authority to stop work, if necessary. The Vice President, Quality reports directly to the President & Chief Executive of NAC International. The Vice President, Quality has sufficient expertise in the field of quality to direct the quality function and will be capable of qualifying as a lead auditor.

Strategic Business Unit (SBU) Vice Presidents direct operations under NAC International operations, utilizing project teams as appropriate for a particular work scope. SBU Vice Presidents are responsible to the President & Chief Executive for the proper implementation of the NAC International Quality Assurance Program.

13.2.2 Quality Assurance Program

NAC International has established a Quality Assurance Program that meets the requirements of 10 CFR 72, Subpart G, 10 CFR 50 Appendix B, 10 CFR 71, Subpart H, and NQA-1. Employing a grading methodology consistent with U.S. NRC Regulatory Guide 7.10, the Quality Assurance program provides control over activities affecting quality from the design to fabrication, operation, and maintenance of nuclear products and services for nuclear applications. The Quality Assurance Program is documented in the Quality Assurance Manual and implemented via Quality Procedures. These documents are approved by the Vice President, Quality, and the President & Chief Executive, as well as the Vice President from each SBU performing activities within the scope of the NAC International Quality Assurance plan.

Personnel assigned responsibilities by the Quality Assurance Program may delegate performance of activities associated with that responsibility to other personnel in their group when those individuals are qualified to perform those activities by virtue of their education, experience and training. Such delegations need not be in writing. The person assigned responsibility by the Quality Assurance Program retains full accountability for the activities.

13.2.3 Design Control

The established Quality Procedures covering design control assure that the design activity is planned, controlled, verified and documented so that applicable regulatory and design basis requirements are correctly translated into specifications, drawings, and procedures with appropriate acceptance criteria for inspection and test delineated.

When computer software is utilized to perform engineering calculations, verifications of the computational accuracy are performed, and error tracking of the software is controlled in accordance with approved Quality Procedures.

Design interface control is established and adequate to assure that the review, approval, release, distribution and revision of design documents involving interfaces are performed by appropriately trained, cognizant design personnel using approved procedures.

Design verification is performed by individuals other than those who performed the original design. These verifications may include design reviews, alternate calculations or qualification tests. Selection of the design verification method is based on regulatory, contractual or design complexity requirements. When qualification testing is selected, the "worst case" scenario will be utilized. The verification may be performed by the originator's supervisor, provided the supervisor did not specify a singular design approach or rule out certain design considerations and did not establish the design inputs used in the design, or provided the supervisor is the only individual in the organization competent to perform the verification. When verification is provided by the supervisor, the need shall be so documented in advance and evaluated after performance by internal audit.

Design changes are controlled and require the same review and approvals as the original design.

13.2.4 Procurement Document Control

Procurement documents and their authorized changes are generated, reviewed and approved in accordance with the Quality Procedures. These procedures assure that all purchased material, components, equipment and services adhere to design specification, regulatory and contractual requirements including Quality Assurance Program and documentation requirements.

NAC Quality Assurance personnel review and approve all purchase orders invoking compliance with the Quality Assurance Program for inclusion of quality related requirements in the procurement documents.

13.2.5 Procedures, Instructions, and Drawings

All activities affecting quality are delineated in the Quality Procedures, Specifications, Inspection/Verification Plans or on appropriate drawings. These documents are developed via approved Quality Procedures and include appropriate quantitative and qualitative acceptance criteria. These documents are reviewed and approved by Quality Assurance personnel prior to use.

13.2.6 Document Control

All documents affecting quality, including revisions thereto, are reviewed and approved by authorized personnel, and are issued and controlled in accordance with Quality Procedures by those persons or groups assigned responsibility for the document to be controlled. Transmittal forms, with provisions for receipt acknowledgment, are utilized and controlled document distribution logs are maintained.

All required support documentation for prescribed activities is available at the work location prior to initiation of the work effort.

13.2.7 Control of Purchased Items and Services

Items and services affecting quality are procured from qualified and approved suppliers. These suppliers have been evaluated and selected in accordance with the Quality Procedures based upon their capability to comply with applicable regulatory and contractual requirements.

Objective evidence attesting to the quality of items and services furnished by NAC suppliers is provided with the delivered item or service, and is based on contract requirements and item or service complexity. This vendor documentation requirement is delineated in the procurement documents.

Source inspection, receipt inspection, vendor audits and vendor surveillance are performed as required to assure product quality, documentation integrity, and supplier compliance to the procurement, regulatory and contractual requirements.

13.2.8 Identification and Control of Material, Parts, and Components

Identification is maintained either on the item or in quality records traceable to the item throughout fabrication and construction to prevent the use of incorrect or defective items.

Identification, in accordance with drawings and inspection plans, is verified by Quality Assurance personnel prior to releasing the item for further processing or delivery.

13.2.9 Control of Special Processes

Special processes, such as welding, heat treating and nondestructive testing, are performed in accordance with applicable codes, standards, specifications and contract requirements by qualified personnel. NAC and NAC suppliers' special process procedures and personnel certifications are reviewed and approved by NAC Quality Assurance prior to their use.

13.2.10 Inspection

NAC has an established and documented inspection program that identifies activities affecting quality and verifies their conformance with documented instructions, plans, procedures and drawings.

Inspections are performed by individuals other than those who performed the activity being inspected. Inspection personnel report directly to the Vice President, Quality.

Process monitoring may also be used in conjunction with identified inspections, if beneficial to achieve required quality.

Mandatory inspection hold points are used to assure verification of critical characteristics. Such hold points are delineated in appropriate process control documents.

13.2.11 Test Control

NAC testing requirements are developed and applied in order to demonstrate satisfactory performance of the tested items to design/contract requirements.

The NAC test program is established to assure that preoperational or operational tests are performed in accordance with written test procedures. Test procedures developed in accordance with approved Quality Procedures identify test prerequisites, test equipment and instrumentation and suitable environmental test conditions. Test procedures are reviewed and approved by NAC Quality Assurance personnel.

Test results are documented, evaluated and accepted by qualified personnel as required by the Quality Assurance inspection instructions prepared for the test, as approved by cognizant quality personnel.

13.2.12 Control of Measuring and Testing Equipment

Control of measuring and testing equipment/instrumentation is established to assure that devices used in activities affecting quality are calibrated and properly adjusted at specified time intervals to maintain their accuracy.

Calibrated equipment is identified and traceable to calibration records, which are maintained. Calibration accuracy is traceable to national standards when such standards exist. The basis of calibration shall always be documented.

Whenever measuring and testing equipment is found to be out of calibration, an evaluation shall be made and documented of the validity of inspection or test results performed and of the acceptability of items inspected or tested since the previous calibration.

13.2.13 Handling, Storage and Shipping

Requirements for handling, storage and shipping are documented in specifications and applicable procedures or instructions. These requirements are designed to prevent damage or deterioration to items and materials.

Information pertaining to shelf life, environment, packaging, temperature, cleaning and preservation are also delineated as required.

Quality Assurance Surveillance/Inspection personnel are responsible for verifying that approved handling, storage, and shipping requirements are met.

13.2.14 Inspection, Test and Operating Status

Procedures are established to indicate the means of identifying inspection and test status on the item and/or on records traceable to the item. These procedures assure identification of items that have satisfactorily passed required inspections and/or tests, to preclude inadvertent bypassing of inspection/test.

Inspection, test, and operating status indicators may only be applied or modified by Quality Assurance personnel or with formal Quality Assurance concurrence.

13.2.15 Control of Nonconforming Items

NAC has established and implemented procedures that assure appropriate identification, segregation, documentation, notification and disposition of items that do not conform to specified requirements. These measures prevent inadvertent usage of the item and assure appropriate authorization or approval of the item's disposition.

All nonconformances are reviewed and accepted, rejected, repaired or reworked in accordance with documented approved procedures. If necessary, a Review Board is convened, consisting of members of engineering, licensing, quality, operations and testing to provide disposition of nonconforming conditions.

NAC procurement documents provide for control, review and approval of nonconformances noted on NAC items, including associated dispositions.

13.2.16 Corrective Action

Conditions adverse to quality, such as failures, malfunction, deficiencies, defective material/ equipment, and nonconformances are promptly identified, documented and corrected.

Significant conditions adverse to quality will have their cause determined and sufficient corrective action taken to preclude recurrence. These conditions are documented and reported to the Vice President, Quality who assures awareness by the President & Chief Executive on an annual basis.

13.2.17 Records

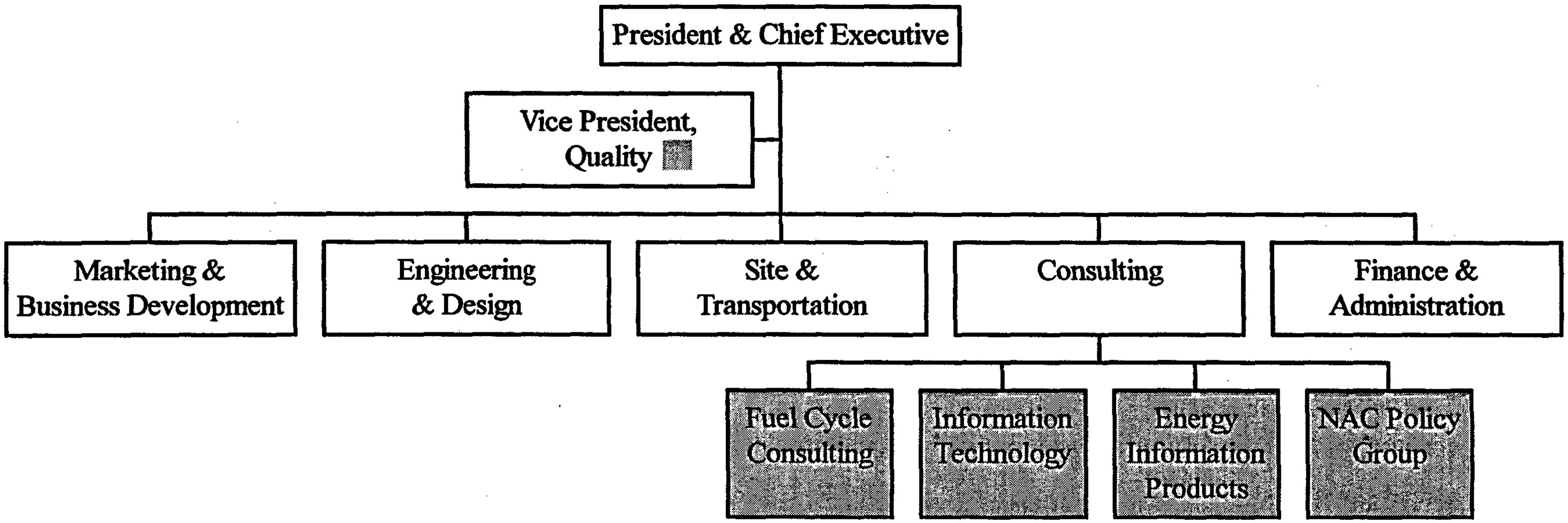
NAC maintains a records system in accordance with approved procedures to assure that documented objective evidence pertaining to quality related activities is identifiable, retrievable and retained to meet regulatory and contract requirements, including retention duration, location and responsibility.

Quality records include, but are not limited to, inspection and test reports, audit reports, quality personnel qualifications, design documents, purchase orders, supplier evaluations, fabrication documents, nonconformance reports, drawings, specifications, etc. Quality Assurance maintains a complete list of records and provides for record storage and disposition to meet regulatory and contractual requirements.

13.2.18 Audits

Approved Quality Procedures provide for a comprehensive system of planned and periodic audits performed by qualified personnel, independent of activities being audited. These audits are performed in accordance with written procedures and are intended to verify program adequacy and its effective implementation and compliance, both internally and at approved-supplier locations. Internal audits are conducted annually and approved suppliers are audited on a triennial basis, as a minimum.

Figure 13.2-1 NAC International Organization Chart



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