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NAC-MPC

SAFETY ANALYSIS REPORT

for the

NAC Multi-Purpose Canister System

Docket No. 72-1025

NAC INTERNATIONAL

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1.0 GENERAL DESCRIPTION

NAC International Inc. (NAC) has designed a Multi-Purpose Canister system (NAC-MPC) for the long term storage of spent nuclear fuel. The NAC-MPC system consists of a transportable storage canister, vertical concrete cask, and a transfer cask. The system also includes a canister overpack for the transportable storage canister to allow continued dry storage of the fuel in the unlikely event a canister did not continue to maintain double confinement of the stored spent fuel after it is placed in service.

The transportable storage canister is designed and fabricated to meet the requirements for transport in the NAC Storable Transport Cask (NAC-STC) and to be compatible with the U. S. Department of Energy (DOE) MPC Design Procurement Specification so as not to preclude the possibility of permanent disposal in a deep Mined Geological Disposal System.

In long-term storage, the transportable storage canister is installed in a vertical concrete cask, which provides passive radiation shielding and natural convection cooling. The vertical concrete storage cask also provides protection during storage for the transportable storage canister under adverse environmental conditions. The NAC-MPC employs a double-welded closure design to preclude loss of contents and to preserve the general health and safety of the public during long term storage of spent fuel.

The transfer cask is used to move the transportable storage canister from the work stations where the canister is loaded and closed to the vertical concrete cask. It is also used to transfer the canister from the vertical concrete cask to the NAC-STC for transport.

This Safety Analysis Report demonstrates the ability of the NAC-MPC System to satisfy the Nuclear Regulatory Commission (NRC) requirements for the storage of spent fuel, as prescribed by 10 CFR 72.

This chapter provides a general description of the major components of the system, and a description of the system operation. The terminology used throughout this report is summarized in Table 1-1.

Table 1-1 Terminology

NAC-STC Cask	The licensed spent-fuel transport cask consisting of a spent fuel storable transport cask body with dual closure lids and energy-absorbing impact limiters (Certificate of Compliance No. 71-9235).
Confinement System	The components of the transportable storage canister intended to retain the radioactive material during storage.
Transportable Storage Canister (Canister)	The stainless steel cylindrical shell, bottom end plate, shield lid, and structural lid that holds the spent fuel in the canister basket.
Contents	Up to 36 pressurized water reactor (PWR) fuel assemblies in the transportable storage canister.
Canister Basket	The structure placed in the transportable storage canister to support the fuel assemblies (fuel basket).
- Support Disk	A circular stainless steel plate with square holes machined in a symmetrical pattern that provides the primary lateral load-bearing component of the canister basket.
- Heat Transfer Disk	A circular aluminum plate with square holes machined in a symmetrical pattern. The heat transfer disk enhances heat transfer in the fuel basket.
- Fuel Tube	A stainless steel tube having a square cross-section and BORAL neutron poison material on its exterior surfaces.

Table 1-1 Terminology (continued)

- Tie Rod	A stainless steel rod used to align the supports disks and heat transfer disks in the fuel basket structure.
- Split Spacer	Spacers installed on the tie rod between the support disks to properly position, and provide axial support for, the support disks and the heat transfer disks.
Shield Lid	The primary confinement boundary for the canister. It is located directly above the canister basket.
- Drain Port	A penetration located in the shield lid to permit draining of the canister cavity.
- Vent Port	A penetration located in the shield lid to aid in draining and backfilling the canister cavity.
- Port Cover	The stainless steel covers that close the vent and drain ports, which are welded in place following draining, drying, and backfilling operations.
Structural Lid	The secondary confinement boundary for the canister. The structural lid provides the lifting point for the loaded canister.
Quick Disconnect	The quick-disconnect valved nipple used in the vent and drain ports to facilitate operations.

Table 1-1 Terminology (continued)

Yankee Class Spent Fuel	Fuel that includes United Nuclear Type A and Type B, Combustion Engineering Type A and Type B, Exxon-ANF Type A and Type B, and Westinghouse Type A and Type B spent fuel assemblies.
Reconfigured Fuel Assembly	A component having the same external dimension as a standard fuel assembly that ensures geometry control and confinement of Yankee Class spent fuel having cladding defects. The Reconfigured Fuel Assembly can contain a maximum of 64 full length fuel rods.
Failed Fuel	Individual Yankee Class spent fuel rods having cladding defects identified by inspection or testing; or rod sections having gross cladding defects.
Vertical Concrete Cask (Concrete Cask) (Storage Cask)	A reinforced concrete cylinder closed at the top end by a shield plug and lid that holds the transportable storage canister or canister overpack during storage. The vertical concrete cask is formed around a steel inner liner and base.
- Shield Plug	A thick carbon steel plug installed in the top end of the storage cask to reduce skyshine radiation. The shield plug contains a one-inch thick neutron shield.
- Lid	A thick carbon steel bolted closure for the storage cask. The lid precludes access to the canister and provides additional radiation shielding.

- Liner — A thick carbon steel shell that forms the annulus of the concrete storage cask. The liner serves as the inner form during concrete pouring and provides radiation shielding of the canister contents.

- Base — A carbon steel weldment that contains the inlet air vents, the storage cask jacking points, and the pedestal that supports the canister inside the storage cask.

Transfer Cask — A shielded lifting device for the empty and loaded canister. It is used for the vertical transfer of the canister between work stations and the storage cask or the transport cask. The transfer cask incorporates bottom doors that permit the vertical loading of the storage and transport casks.

- Transfer Cask Lifting Trunnions — Two carbon steel trunnions used to lift and move the transfer cask.

Adapter Plate — A carbon steel plate that attaches to the top of the transport or storage cask to facilitate the installation and alignment of the transfer cask. It also provides the operating mechanism for the transfer cask bottom doors.

Margin of Safety — An analytically determined value defined as the "factor of safety" minus 1. Factor of safety is also analytically determined, and is defined as the allowable stress of a material divided by its actual (calculated) stress.

Canister Overpack — A stainless steel cylindrical shell that holds a transportable storage canister. The cylindrical shell, a bottom end plate and an inner and outer lid provide redundant confinement of the stored canister.

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1.1 Introduction

The NAC-MPC system is a transport compatible dry storage system that uses a vertical concrete storage cask and a stainless steel transportable storage canister (canister) with a welded closure to safely store irradiated nuclear fuel (spent fuel). The canister is stored in the central cavity of the concrete cask and is compatible with the NAC-STC transport cask for future off-site shipment. The concrete storage cask provides radiation shielding and contains internal air flow paths that allow the decay heat from the canister contents to be removed by natural air circulation around the canister wall. The system is designed to meet the requirements for storage of Yankee Class spent fuel. The NAC-MPC has been designed and analyzed for a 50-year life.

The principal components of the NAC-MPC system are the canister, the vertical concrete cask, and the transfer cask. The loaded canister is moved to and from the concrete cask with the transfer cask. The transfer cask provides radiation shielding while the canister is being closed and sealed and while the canister is being transferred. The canister is placed in the concrete cask by positioning the transfer cask with the loaded canister on top of the concrete cask and lowering the canister into the concrete cask. Figure 1.1-1 depicts the major components of the NAC-MPC system and shows the transfer cask positioned on the top of the concrete cask.

The NAC-MPC is designed to safely store up to 36 Yankee Class spent fuel assemblies. The fuel is initially loaded into a canister containing a fuel basket. Figure 1.1-2 depicts the canister and the spent fuel basket. The design characteristics of the NAC-MPC are shown in Table 1.1-1.

Yankee Class fuel includes United Nuclear, Combustion Engineering, Exxon-ANF, and Westinghouse Type A and Type B fuel designs. The Type A and Type B fuel designs are complementary configurations that accommodate the use of a cruciform control blade in reactor operations. The fuel specifications that serve as the design basis for the NAC-MPC are presented in Section 2.1.

The system design and analyses were performed in accordance with Title 10, Code of Federal Regulations, Part 72 (10 CFR 72), ANSI/ANS 57.9-1984 and the applicable sections of the ASME Boiler and Pressure Vessel Code and the American Concrete Institute Code.

Figure 1.1-1 Major Components of the NAC-MPC System

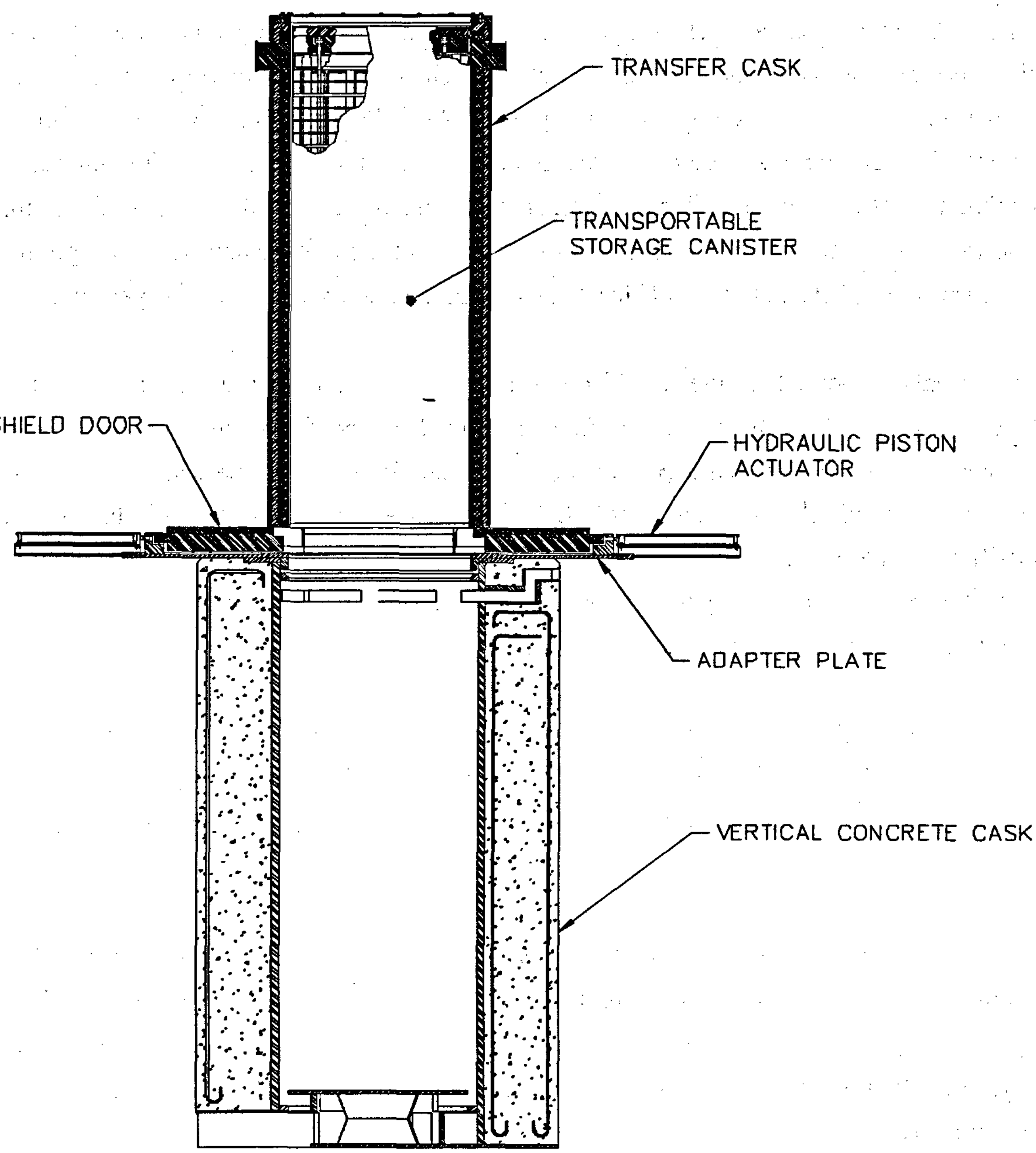

Figure 1.1-2 Transportable Storage Canister Showing the Spent Fuel Basket

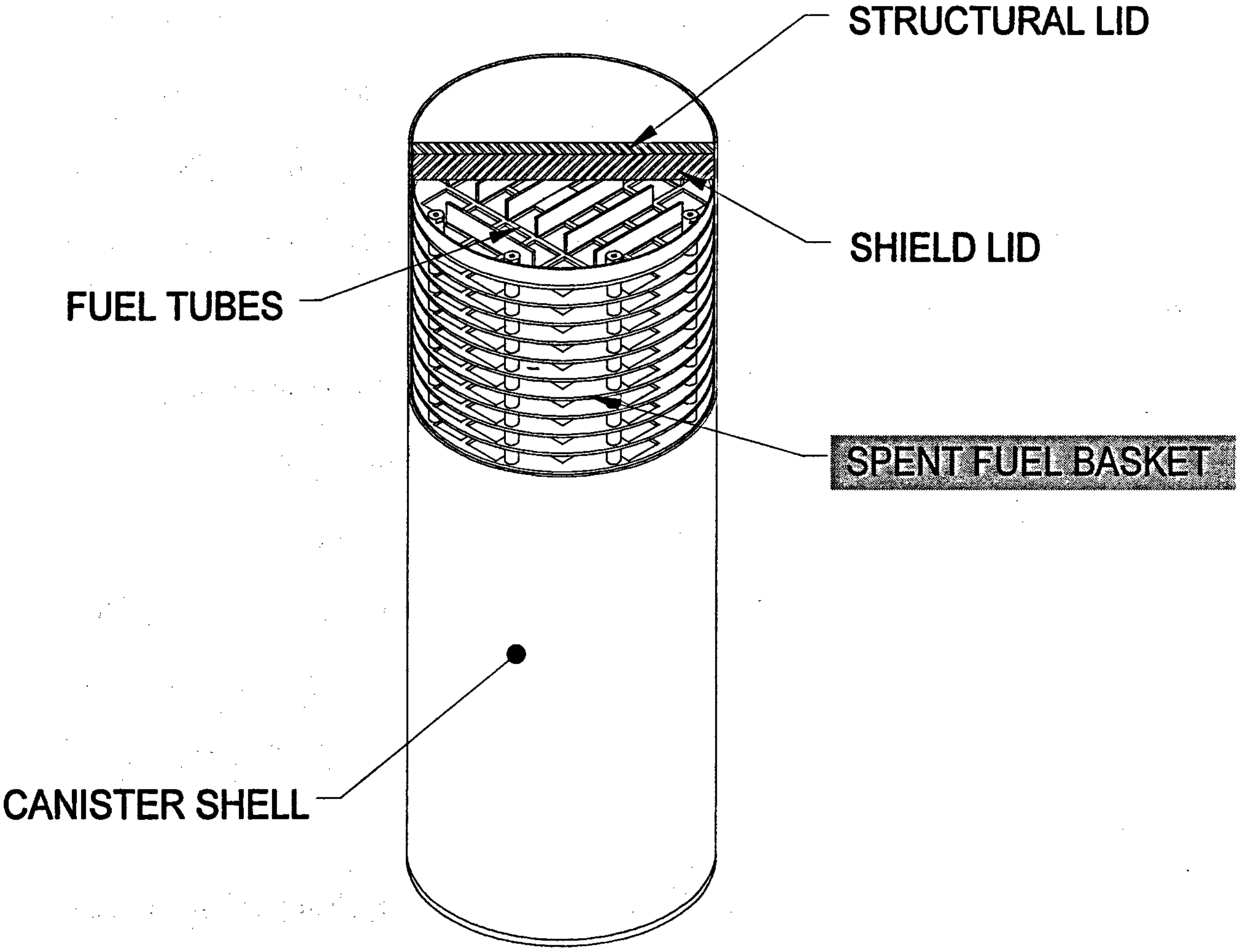

Table 1.1-1 Design Characteristics of the NAC-MPC

Design Characteristic	Dimension[1]	Material
Canister		
Shell	5/8 thick Plate	Type 304L Stainless Steel
Bottom	1.0 thick Plate	Type 304L Stainless Steel
Shield Lid	5.0 thick Plate	Type 304 Stainless Steel
Structural Lid	3.0 thick Plate	Type 304L Stainless Steel
Canister Fuel Basket		
End Weldments	0.5 x 68.98 dia	Type 304 Stainless Steel
Support Disks	0.5 x 69.15 dia	Type 17-4 PH Stainless Steel
Heat Transfer Disks	0.5 x 68.70 dia	Type 6061-T6 Aluminum Alloy
Tube	7.80 x 7.80 x 0.048	Type 304 Stainless Steel encasing BORAL
Spacers	2.5 diameter	Type 304 Stainless Steel
Tie Rods (8)	1-1/8 diameter	Type 304 Stainless Steel
Canister Overpack		
Shell	1/2 thick Plate	Type 304L Stainless Steel
Bottom	1.38 thick Plate	Type 304L Stainless Steel
Inner Lid	5.0 thick Plate	Type 304 Stainless Steel
Outer Lid	2.0 thick Plate	Type 304L Stainless Steel

Table 1.1-1 Design Characteristics of the NAC-MPC (continued)

Design Characteristic	Dimension[1]	Material
Transfer Cask		
- Outer Shell	1.5 x 86.5 dia.	ASTM A588 Low Alloy Steel
- Inner Shell	0.75 x 73.0 dia.	ASTM A588 Low Alloy Steel
- Retaining Ring	0.75 x 80.8 dia.	A350 LF2 Carbon Steel
- Trunnions	10.0 dia.	Type 304L Stainless Steel
- Bottom Plate	1.0 thick Plate	ASTM A588 Low Alloy Steel
- Top Plate	2.0 thick Plate	ASTM A588 Low Alloy Steel
-Shield Doors	9 1/2 thick Plate	A350 LF2 Carbon Steel
- Door Rails	9.88 x 6.5	A350 LF2 Carbon Steel
- Gamma Shield	3.5 thick	ASTM B29, Chem. Grade Lead
- Neutron Shield	2.0 thick	NS-4-FR, Solid Synthetic Polymer
Transfer Adapter		
- Base Plate	2 thick Plate	ASTM A36 Carbon Steel
- Locating Ring	2.0 wide x 78.25 dia.	ASTM A36 Carbon Steel

1. Dimensions in inches unless noted.

Table 1.1-1 Design Characteristics of the NAC-MPC (continued)

Design Characteristic	Dimension[1]	Material
Vertical Concrete Cask		
Weldment Structure		
- Shell	3.5 thick x 86.0 dia.	ASTM A36 Carbon Steel
- Top Flange	2.0 thick x 97.9 dia.	ASTM A36 Carbon Steel
- Support Ring	2.5 thick x 79.0 dia.	ASTM A36 Carbon Steel
- Base Plate	2.0 thick x 72.0 dia.	ASTM A36 Carbon Steel
Concrete Cask		
- Concrete Shell	21.0 thick x 128 dia.	Type II Portland Cement
- Top Plate	1.5 thick x 92.1 dia.	ASTM A36 Carbon Steel
- Shield Plug[2]	5.13 x 78.5 dia. 1.0 x 68.0 dia	ASTM A36, Carbon Steel NS-4-FR
- Top Plate[3]	1.5 x 92.1 dia. 1.0 x 78.0 dia	ASTM A36, Carbon Steel NS-4-FR
- Rebar	Various	ASTM A613, GR 60, Carbon Steel

1. Dimensions in inches unless otherwise noted.
2. Without Canister Overpack
3. With Canister Overpack

1.2 The NAC-MPC System

The NAC-MPC system provides long term storage and subsequent transport of Yankee Class spent fuel using the certified NAC-STC. During long term storage, the system provides an inert environment; passive shielding, cooling, and criticality control; and, a confinement boundary closed by welding. The structural integrity of the system precludes the release of contents in any of the design basis normal conditions and off-normal or accident events, thereby assuring public health and safety during use of the system.

1.2.1 NAC-MPC System Components

The NAC-MPC system consists of three principal components:

- Transportable storage canister (canister),
- Vertical concrete cask, and
- Transfer cask.

Ancillary equipment needed to use the NAC-MPC System are:

- Automated or manual welding equipment;
- An air pallet or hydraulic roller skid (used to move the storage cask on and off the heavy haul transfer trailer and to position the storage cask on the storage pad);
- Suction pump, vacuum drying, helium backfill and leak detection equipment;
- A heavy haul trailer or cask transporter (for storage cask transport to the storage pad);
- Alignment plates and hardware to position the transfer cask with respect to the storage or transport cask; and,
- A lifting yoke for the transfer cask and lifting slings for the canister and canister lids.

In addition to these items, the system requires utility services (electric, air and water), common tools and fittings, and miscellaneous hardware.

The transportable storage canister is designed to be transported in the NAC-STC Storable Transport Cask (Certificate of Compliance No. 71-9235). Transport conditions established the design basis load conditions for the canister, except for canister lifting. The transport load

conditions produce higher stresses in the canister than would be produced by the storage load conditions alone. Consequently, the canister design is conservative with respect to storage conditions. The evaluation of the canister for transport conditions is found in the Safety Analysis Report for the NAC-STC Storable Transport Cask, Docket No. 71-9235.

1.2.1.1 Transportable Storage Canister and Baskets

The transportable storage canister contains a basket that accommodates up to 36 Yankee Class spent fuel assemblies.

The canister assembly consists of a right circular cylindrical shell with a welded bottom plate, a fuel basket, a shield lid, two penetration port covers, and a structural lid. The cylindrical shell, plus the bottom plate and lids, constitutes the confinement boundaries. The fuel basket is based on the directly loaded fuel basket design used in the certified NAC-STC. This basket features the NAC-patented poison tubes and stacked disk design with heat transfer disks. The basket was analyzed using the ANSYS computer code to demonstrate that it can withstand the horizontal drop loads without deforming in a way that damages or constrains a fuel assembly. This tube and disk design has been accepted and approved by the NRC, pursuant to 10 CFR 71 and 10 CFR 72. Table 1.2-1 summarizes the major physical design parameters of the canister.

The fuel basket design is a right-circular cylinder configuration with 36 fuel tubes laterally supported by a series of support disks, which are retained by spacers on eight radially located tie rods. The support disks are stainless steel (17-4 PH) with holes for the poison fuel tubes. The basket top and bottom weldments are fabricated from Type 304 stainless steel. The tie rods and spacer sleeves are also fabricated from Type 304 stainless steel. The fuel assemblies are contained in fuel tubes. The fuel tubes are fabricated from Type 304 stainless steel with encased BORAL sheets on all four outside surfaces of the fuel tube. The BORAL provides criticality control in the basket.

The heat transfer disks are aluminum with holes for the fuel tubes. The heat transfer disks are spaced midway between the support disks and are the primary path for conducting the heat from the fuel assemblies to the canister wall. Holes in the heat transfer disks for the tubes and tie rods are sized to accommodate thermal expansion occurring after the fuel is placed into the basket.

The fuel basket tube and disk design provides the structural integrity to maintain the spent fuel in a subcritical configuration during normal operations and the hypothetical accident events, even if optimum moderator condition and fresh fuel are assumed. With the most reactive fuel, the fuel basket maintains $K_{eff} \leq 0.95$. Subcriticality is assured assuming fresh fuel loading and no soluble boron in the spent fuel pool water during fuel loading operations.

The transportable storage canister assembly is designed to facilitate filling with water and subsequent draining and drying. A rounded notch is located at the bottom of each fuel tube, ensuring free flow of water between the inner tube regions and the disk regions. Each of the disks also has three holes to supplement the flow of water between disks. In addition, the bottom plate is positioned by supports above the bottom of the canister to facilitate water flow to the drain line.

The canister is fabricated from 5/8-inch thick Type 304L stainless steel rolled plate, joined at its edges by a full penetration weld, which is radiographed. The bottom closure is a 1-inch thick Type 304L stainless steel plate joined to the canister shell by a full penetration weld, which is ultrasonically examined. The stainless steel material was selected to be compatible with the DOE MPC program guidelines for future disposal and to minimize the potential for any adverse chemical reactions in the spent fuel pool. The design of the shield lid and structural lid allows a redundant confinement seal at the top of the canister. Each lid weld is liquid penetrant examined.

The vent and drain ports through the shield lid allow the inner cavity to be drained, evacuated, and backfilled with helium to provide an inert atmosphere for long-term dry storage. The drain port is equipped with a quick disconnect fitting and a drain tube that extends nearly to the bottom of the canister. The vent port extends to the underside of the shield lid and is equipped with a quick disconnect fitting used for vacuum drying and helium backfilling. After draining, drying, backfilling, and testing operations are complete, port covers are installed and welded to the shield lid to seal the penetration.

A summary of the canister fabrication specifications is presented in Table 1.2-2.

1.2.1.2 Vertical Concrete Cask

The vertical concrete cask (storage cask) is the storage overpack for the transportable storage canister. It provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the canister during long term storage. Table 1.2-3 lists the principal physical design parameters of the storage cask. The storage cask is a reinforced concrete (Type II Portland cement) structure with a structural steel inner liner. The concrete wall and steel liner provide the neutron and gamma radiation shielding to reduce the average contact dose rate to less than 50 millirem per hour for design basis fuel. Inner and outer reinforcing steel (rebar) assemblies are contained within the concrete. The reinforced concrete wall provides the structural strength to protect the canister and its contents in natural phenomena events such as tornado wind loading and wind driven missiles. The storage cask incorporates reinforced chamfered corners at the edges to facilitate construction. "Fire block," an insulating material provided by BISCO, is placed on the base of the cavity to prevent contact between the stainless steel canister and the carbon steel pedestal. The storage cask is shown in Figure 1.2-1.

The storage cask has an annular air passage to allow the natural circulation of air around the canister to remove the decay heat from the spent fuel [redacted]. The air inlet and outlet vents are steel-lined penetrations that take nonplanar paths to the concrete cask cavity to minimize radiation streaming. The decay heat is transferred from the fuel assemblies to the tubes in the fuel basket and through the heat transfer disks to the canister wall. Heat flows by radiation and conduction from the canister wall to the air circulating through the concrete cask annular air passage and is exhausted through the air outlet vents. This passive cooling system is designed to maintain the peak cladding temperature of both stainless steel and zircaloy clad fuel well below acceptable limits during long-term storage. This design also maintains the bulk concrete temperature below 150°F and localized concrete temperatures below 200°F in normal operating conditions.

The top of the storage cask is closed by a shield plug and lid. The shield plug is approximately 5 inches thick and incorporates carbon steel plate as gamma radiation shielding, and NS-4-FR as neutron radiation shielding. A carbon steel lid that provides additional gamma radiation shielding is installed above the shield plug. The shield plug and lid reduce skyshine radiation and provide a cover and seal to protect the canister from the environment and postulated tornado

missiles. The lid is bolted in place and has tamper indicating seals on two of the installation bolts.

Fabrication of the storage cask involves no unique or unusual forming, concrete placement, or reinforcement requirements. The concrete portion of the storage cask is constructed by placing concrete between a reusable, exterior form and the inner metal liner. Reinforcing bars are used at the inner and outer concrete surfaces, to provide structural integrity. The inner liner and base of the storage cask are shop fabricated.

The principal fabrication specifications for the storage cask are shown in Table 1.2-4.

1.2.1.3 Transfer Cask

The transfer cask, with its lifting yoke, is primarily a lifting device used to move the canister assembly. It provides biological shielding when it contains a loaded canister. The transfer cask is used for the vertical transfer of the canister between work stations and the storage cask, or transport cask.

Table 1.2-5 shows the principal design parameters of the transfer cask.

The transfer cask is a multiwall (steel/lead/NS-4-FR neutron shield/steel) design, which limits the average contact radiation dose rate to less than 200 mrem/hr. The transfer cask design incorporates a top retaining ring, which is bolted in place, that prevents a loaded canister from being inadvertently removed through the top of the transfer cask. The transfer cask has retractable bottom shield doors. During loading operations, the doors are closed and secured by pins so they cannot inadvertently open. During unloading, the doors are retracted using hydraulic cylinders to allow the canister to be lowered into the storage or transport casks. The transfer cask is shown in Figure 1.2-2.

To qualify the transfer cask as a heavy lifting device, it is designed, fabricated, and load tested to the requirements of NUREG-0612 and ANSI N14.6.

To minimize potential contamination during loading operations in the spent fuel pool, clean water is circulated in the gap between the transfer cask interior surface and the canister exterior surface. The transfer cask has two supply and two discharge lines passing through its wall.

These lines allow hoses to be connected and clean water to be pumped into and through the annular gap to preclude the intrusion of pool water when the canister is being loaded.

1.2.1.4 Auxiliary Equipment

This section presents a brief description of the principal auxiliary equipment needed to operate the NAC-MPC in accordance with its design.

1.2.1.4.1 Adapter Plate

The adapter plate is a carbon steel table that bolts to the top of the vertical concrete (storage) cask or the NAC-STC and mates the transfer cask to either of those casks. It has a large center hole that allows the transportable storage canister to be raised or lowered through the plate into or out of the transfer cask. Rails are incorporated in the adapter plate to guide and support the bottom shield doors of the transfer cask when they are in the open position. The adapter plate also supports the hydraulic system and the actuators that open and close the transfer cask bottom doors.

1.2.1.4.2 Air Pad Rig Set

The air pad rig set (air pad set) is a commercially available device, sometimes referred to as an air pallet. When inflated, the air pad set lifts the concrete cask by using high volume air. The air pads employ a continuous, regulated air flow and a control system that equalizes lifting heights of the four air pads by regulating compressed air flow to each of the air pads. The compressed air supply creates an air filler between the inflated air cushion and the supporting surface. The thin film of air allows the concrete cask to be lifted and moved. Once lifted, the storage cask can be moved by a suitable towing vehicle, such as a commercial tug or forklift.

1.2.1.4.3 Automatic Welding System

The automatic welding system consists of commercially available components with a customized weld head. The components include a welding machine, a remote pendant, a carriage, a drive motor and welding wire motor, and the weld head. The system is designed to make at least one weld pass automatically around the canister after its weld tip is manually positioned at the proper location. As a result, radiation exposure during canister closure is much less than would be incurred from manual welding.

1.2.1.4.4 Draining and Drying System

The draining and drying system consists of a suction pump and a vacuum pump. The suction pump is used to remove free water from the canister cavity. The vacuum pump is a two-stage unit for drying the interior of the canister. The first stage is a large capacity or "roughing" pump intended to remove free water not removed by the suction pump. The second stage is a vacuum pump used to evacuate the canister interior of the small amounts of remaining moisture and establish the vacuum condition.

1.2.1.4.5 Helium Leak Test Equipment

A helium leak detector is required to verify the integrity of the welds of the canister shield lid. The helium leak detector is the mass spectrometer type.

1.2.1.4.6 Heavy-Haul Trailer

The heavy haul trailer is used to move the vertical concrete storage cask. A special trailer has been designed for transport of the empty or loaded storage cask. The design incorporates a built-in jacking system that facilitates raising the storage cask to allow installation of the air pad set used to move the cask onto the storage pad. The trailer incorporates both reinforcing to increase the trailer load-bearing area and design features that reduce its turning radius. However, any commercial double-drop-frame trailer having a deck height approximately matching that of the storage pad could be used.

1.2.1.4.7 Lifting Jacks

Hydraulic jacks are installed at jacking pads in the bottom air ducts to lift the storage cask so that the air pad set can be installed or removed. Four hydraulic pad jacks are provided, along with a control panel, an electric hydraulic oil pump, an oil reservoir tank and all hydraulic lines and fittings. The jacks are used to lift the cask approximately three inches. This permits installation of four air pads under the concrete cask.

1.2.1.4.8 Rigging and Slings

Load rated rigging attachments and slings are provided for major components. The rigging attachments are swivel hoist rings that allow attachment of the slings to the hook. All slings are commercially purchased to have adequate safety margin to meet the requirements of ANSI N14.6 and NUREG 0612. The slings include a concrete cask lid sling, concrete cask shield plug sling, and canister shield lid sling, loaded canister transfer sling (also used to handle the structural lid), canister retaining ring sling. The appropriate rings or eye bolts are provided to accommodate each sling and component.

The transfer cask lifting yoke is specially designed and fabricated for lifting the transfer cask. It is designed to meet the requirements of ANSI N14.6 and NUREG 0612. It is single-failure-proof by design. The transfer cask lifting yoke is initially load tested to 300 percent of the design load.

1.2.1.4.9 Temperature Instrumentation

The vertical concrete cask has four outlet vents near the top of the cask and four inlet vents at the bottom. Each outlet is equipped with a permanent remote temperature detector mounted in the outlet air plenum. The detector is used to measure the outlet air temperature, which can be read at a display device located on the outside surface of the concrete cask or at a remote location. The detectors are installed on all of the storage casks at the ISFSI. One inlet of one concrete cask, or the ambient temperature of the ISFSI site, is also monitored.

1.2.1.5 Transport Cask

The transportable storage canister is designed to be transported in the NAC-STC. The canister is positioned in the NAC-STC cavity with two axial spacers. The spacers are required because the transport cask cavity length is 165 inches while the length of the canister is 122.5 inches.

The NAC-STC is licensed by the NRC pursuant to 10 CFR 71 (Certificate of Compliance No. 71-9235). A request for an amendment to the NAC-STC Certificate of Compliance to incorporate transport of the canister was submitted to the NRC on December 30, 1996. The NAC-STC is designed for free interchange/rail shipment.

The transport configuration of the NAC-STC is shown in Figure 1.2-3.

1.2.2 Operational Features

This section outlines the principal handling activities of the NAC-MPC storage system. The system provides passive long term storage of spent fuel [redacted] in an inert environment. In storage, the only active system is for temperature monitoring of the outlet air. This temperature is recorded daily as a check of the thermal performance of the storage system design. This system does not penetrate the confinement boundary and is not essential to the safe operation of the NAC-MPC.

The principal activities associated with the use of the system are closing the canister and loading the canister in the storage cask. The transfer cask is designed to meet the requirements of these operations. The transfer cask holds the canister during loading with fuel [redacted]; provides biological shielding during closing of the canister; and provides the means by which the loaded canister is moved to, and installed in, the storage cask. The canister assembly consists of five principal components: the canister shell (side wall and bottom); the shield lid; the vent port; the drain port (together with the vent and drain port covers); and, the structural lid. A drain tube extends from the shield lid drain port to the bottom of the canister. The location of the drain and vent ports is shown in Figure 8.1-1.

The vent and drain ports allow the draining, vacuum drying, and backfilling with helium necessary to provide a dry, inert atmosphere for the contents. The vent and drain port covers, the shield lid, the canister shell, and the joining welds form the primary confinement boundary. This boundary is shown in Figure 7.1-1. A secondary confinement boundary is formed over the shield lid by the structural lid and the weld that joins it to the canister shell. This boundary is shown in Figure 7.1-2.

The structural lid contains the drilled and tapped holes for attachment of the swivel hoist rings used to lift the loaded canister. The drilled and tapped holes are filled with bolts or plugs to avoid collecting debris, and to preclude the possibility of radiation streaming from the holes, when the hoist rings are not installed.

The step-by-step procedures for use of the NAC-MPC system are presented in Chapter 8. The following list presents a brief description of the principal activities. This list assumes that the empty canister is installed in the transfer cask for spent fuel pool loading.

- Lift the transfer cask over the pool and start the flow of water to the transfer cask annulus and canister. After the annulus and canister are filled, lower the cask to the bottom of the pool.
- Load the selected spent fuel assemblies into the canister and set the shield lid.
- Raise the transfer cask from the pool. Decontaminate the transfer cask exterior as it clears the pool surface. Drain the annulus. Place the transfer cask in the decontamination area.
- Weld the shield lid to the canister shell. Pressure test the weld. Drain the pool water from the canister. Attach the vacuum system to the drain line, and operate the system to achieve a vacuum.
- Hold the vacuum and backfill with helium to 1 atmosphere. Restart the vacuum system and remove the helium. After achieving vacuum, backfill and pressurize the canister with helium.
- Helium leak check the shield lid welds. Vent the helium pressure to 1 atmosphere (absolute). Install the vent and drain port covers and weld them to the shield lid.
- Install the structural lid and weld it to the canister shell. Install the hoist rings, and attach the canister lifting sling. Install the adapter plate on the storage cask
- Lift the transfer cask to the top of the storage cask and set it on the adapter plate, ensuring that the bottom door hydraulic actuators are engaged.
- Attach the canister lifting slings to the crane hook and lift the canister.
- Open the bottom doors of the transfer cask.
- Lower the canister into the storage cask. Detach the canister slings from the hook.
- Remove the transfer cask and adapter plate. Remove the canister lifting slings.
- Install the shield plug and lid on the concrete cask.
- Move the loaded storage cask to the storage pad.
- Using the air pad rig set and a towing vehicle, move the storage cask to its designated location on the storage pad.

The removal operations are essentially the reverse of these steps, except that weld removal and cool down of the contents is required.

The special equipment needed to operate the NAC-MPC system has been described in Section 1.2.1.4. Other items required are miscellaneous hardware, connection hose and fittings, and hand tools typically found at a reactor site.

1.2.3 Cask Contents

The NAC-MPC is designed to store up to 36 Yankee Class spent fuel assemblies. The Yankee Class fuel consists of fuel assemblies manufactured by Westinghouse, United Nuclear, Exxon, and Combustion Engineering. The assemblies vary in initial enrichment from 3.7 to 4.94 w/o U^{235}. Each manufacturer's types of assemblies include two configurations identified as Type A and Type B. The arrangement of fuel rods differ in each types to allow the fuel assembly to accept a segment of a control blade, used for criticality control. The characteristics of the Yankee Class spent fuels are presented in Table 1.2-6.

A canister may contain one or more Reconfigured Fuel Assemblies designed to confine Yankee Class spent fuel rods, or portions thereof, which are classified as failed, and to maintain the geometric configuration of the rods. It is designed to confine failed fuel during all storage and transport conditions. Since there is no significant remaining "gap activity" in the failed rods, pressure retention is not a concern. The assembly can accept up to 64 full length spent fuel rods in an eight by eight array of tubes. A sketch of the assembly is provided in Figure 1.2-5.

The Reconfigured Fuel Assembly consists of a shell (square tube with end fittings), a basket assembly and 64 fuel tubes. The external dimensions of the shell are the same as those of a standard Yankee Class spent fuel assembly and all materials are stainless steel. It is designed such that it can be handled in the same manner as a standard Yankee Class spent fuel assembly. The spent fuel is confined in the fuel tubes. The tubes are supported by a basket assembly within the shell and have end plugs with drilled holes to permit draining drying and inerting with helium. The shell has holes in the top and bottom fittings to permit draining, drying and inerting of the assembly.

The total number of full length rods that can be placed in the Reconfigured Fuel Assembly is less than the number that are in the Yankee Class fuel assemblies (maximum of 64 versus 231 rods of the most reactive fuel). Consequently, the effects of a Reconfigured Fuel Assembly placed in a canister (e.g., criticality, thermal output, source term) are significantly less than the effects of a design basis Yankee Class spent fuel assembly. These effects are evaluated in the appropriate chapters that follow.

1.2.4 Canister Overpack

A canister overpack (overpack) has been designed and evaluated which is sized to accommodate a transportable storage canister. The overpack is a right circular cylinder similar in design to the canister described in Section 1.2.1.1. A sketch of the overpack is provided in Figure 1.2-4. The major physical design parameters for the canister overpack are provided in Table 1.2-1.

The overpack is designed to the same criteria as the transportable storage canister, and provides a confinement boundary in continuing long-term storage. The stainless steel components of the overpack provide incidental additional shielding. A penetration in the inner lid allows the overpack to be filled with helium to provide an inert atmosphere for the installed canister.

The overpack is not required for the satisfactory operation of the NAC-MPC system. As shown in the following sections, there are no design basis normal, off-normal, or accident conditions which can result in the failure of a canister. The overpack is designed to provide a confinement boundary and structural integrity to allow continued dry storage of canistered fuel in the absence of physical facilities, such as a spent fuel pool, where the contents of a canister could be transferred to a new canister. Alternately, the NAC-STC cask could provide a confinement boundary for the transportable storage canister during transport to a facility where the canister contents could be placed into a new canister. The evaluation of the overpack is presented in Section 11.4.

Figure 1.2-1 Vertical Concrete Storage Cask

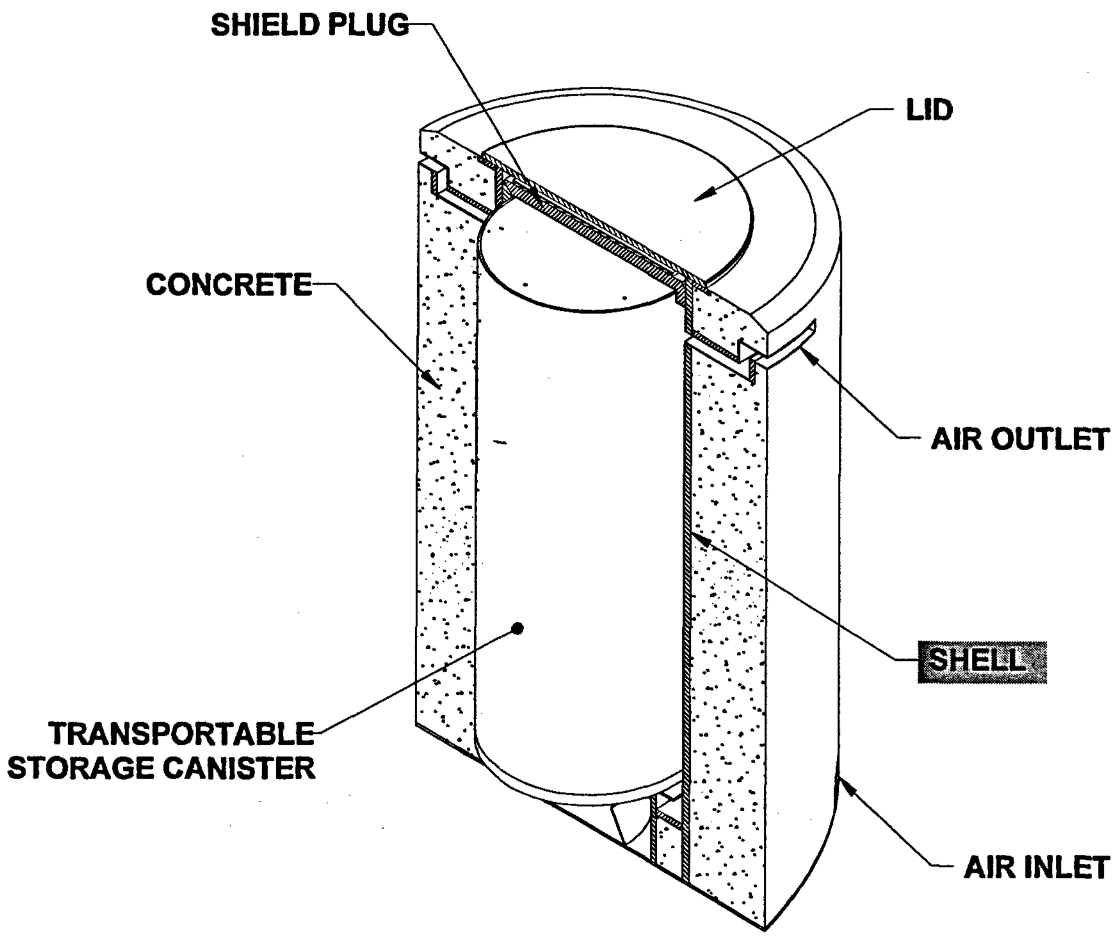

Figure 1.2-2 Transfer Cask

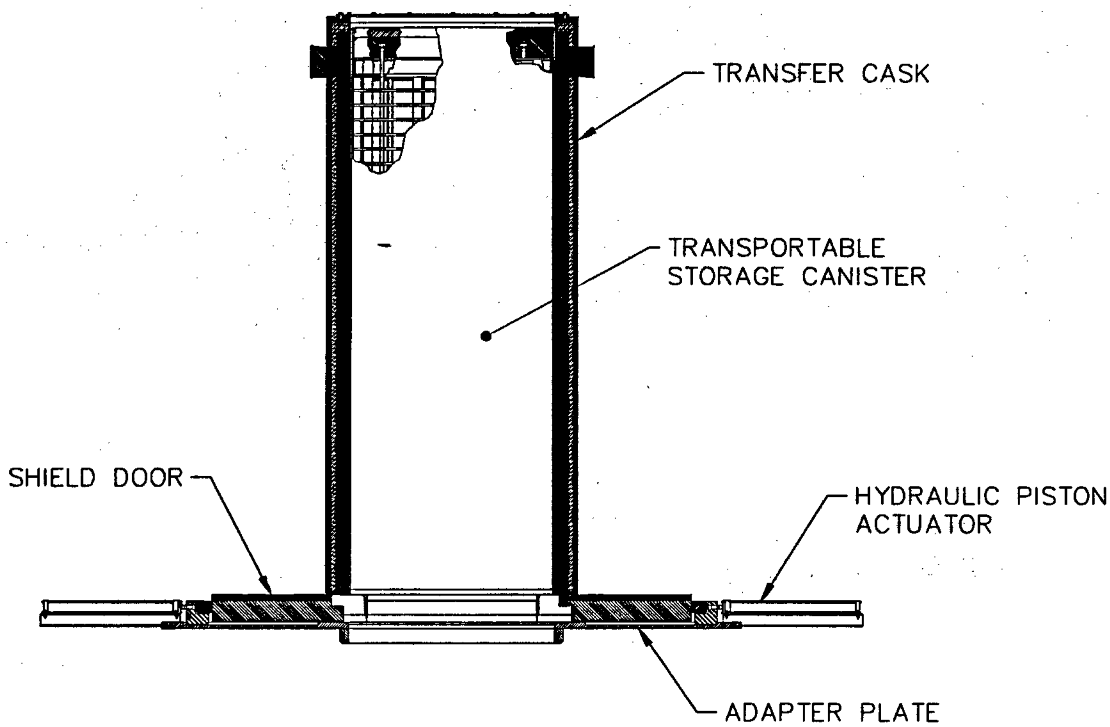

Figure 1.2-3 NAC-STC Transport Configuration

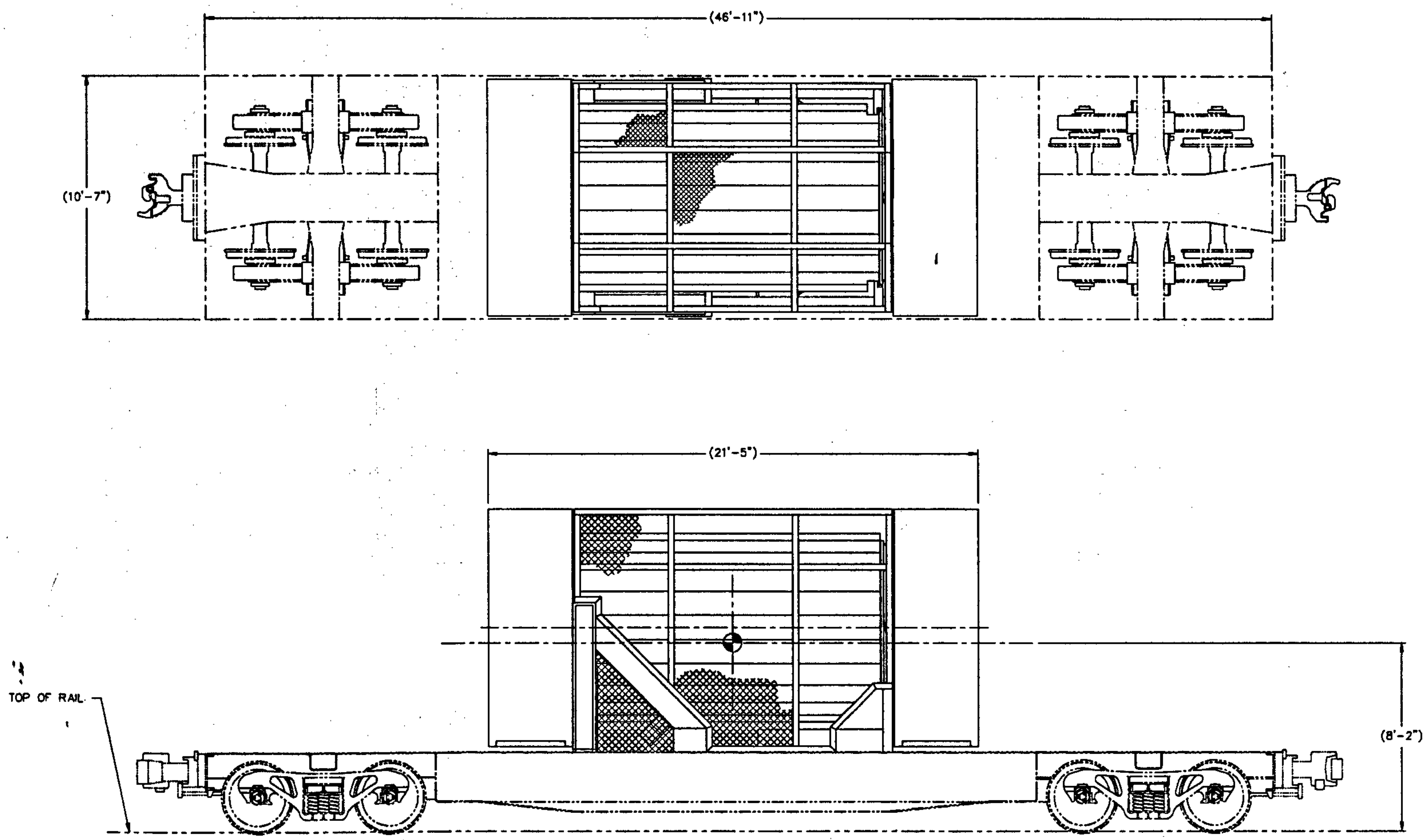

Figure 1.2-4 Canister Overpack Configuration

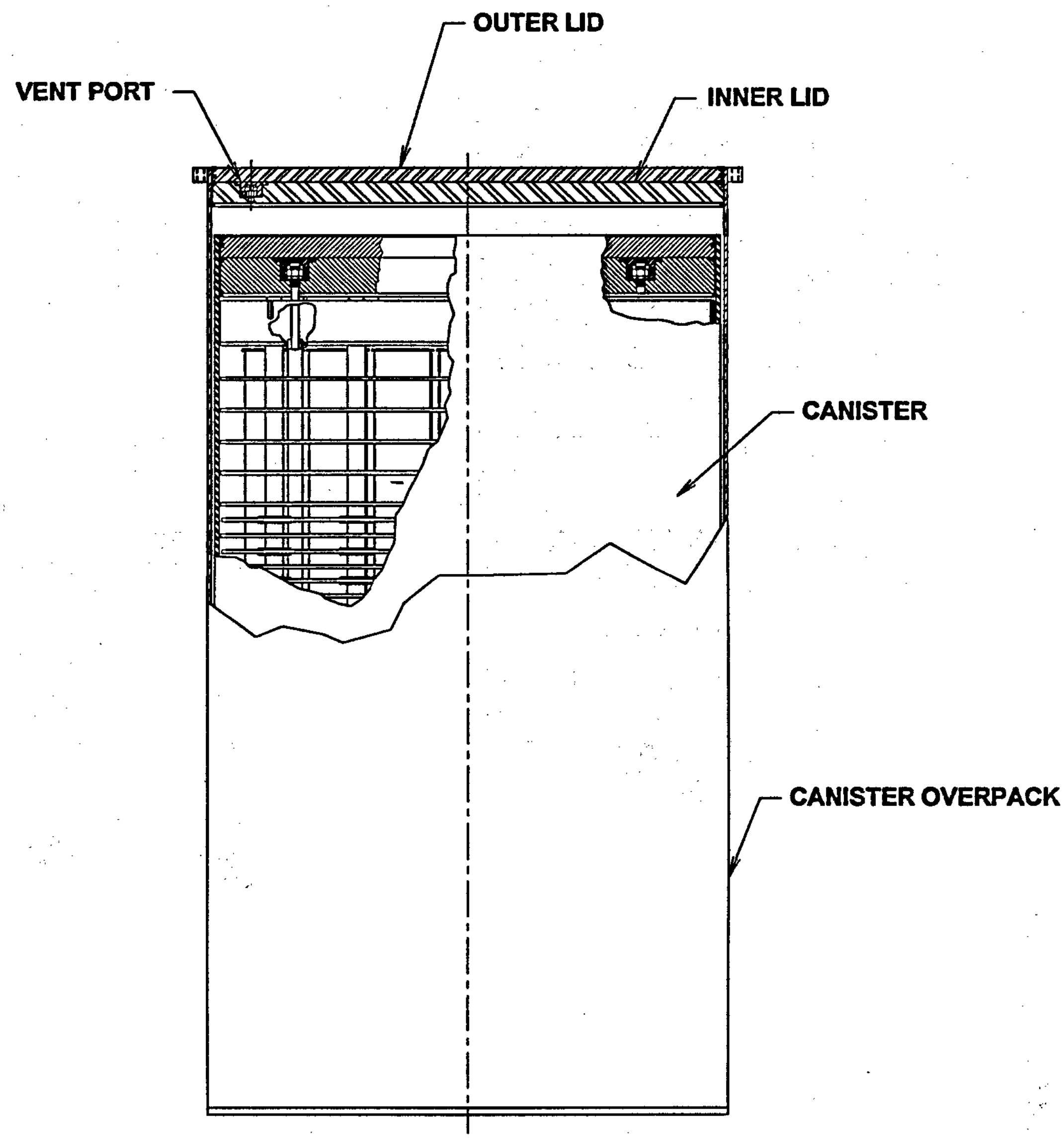

Figure 1.2-5 Reconfigured Fuel Assembly

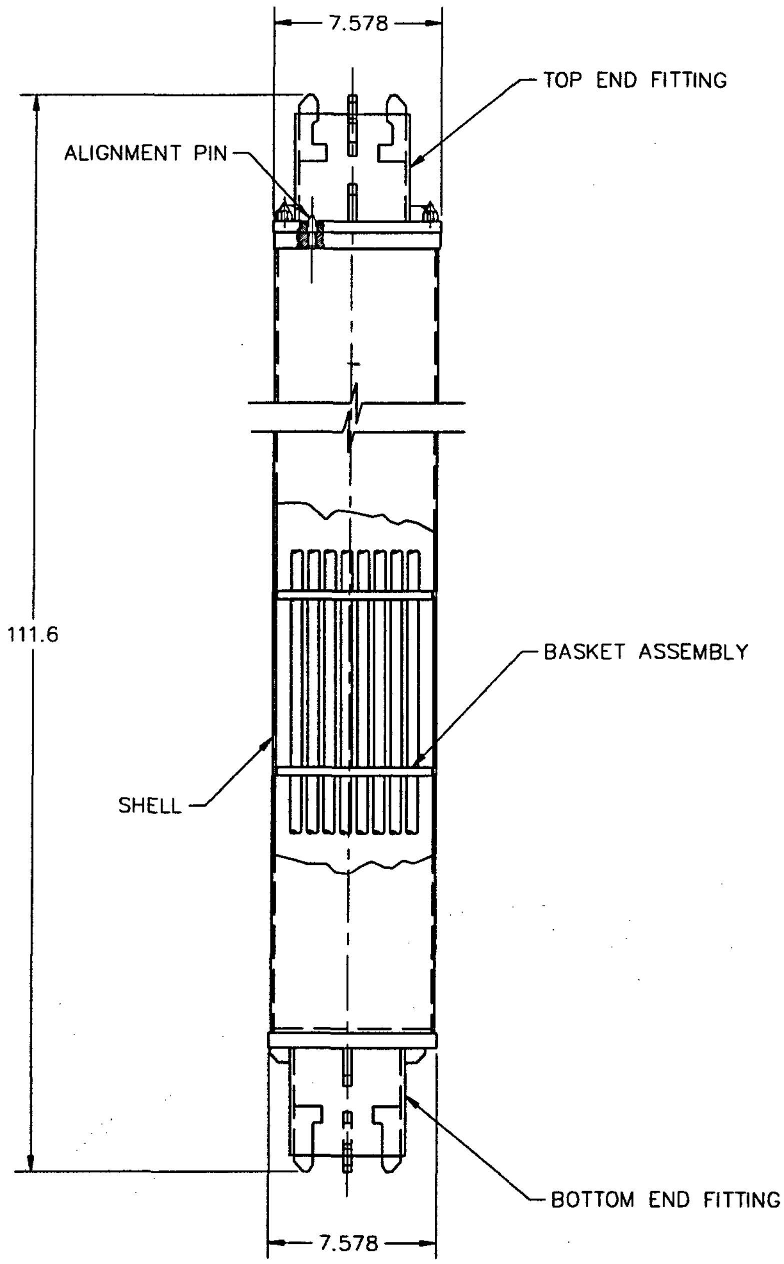

Figure 1.2-6 Transfer Cask and Canister Arrangement

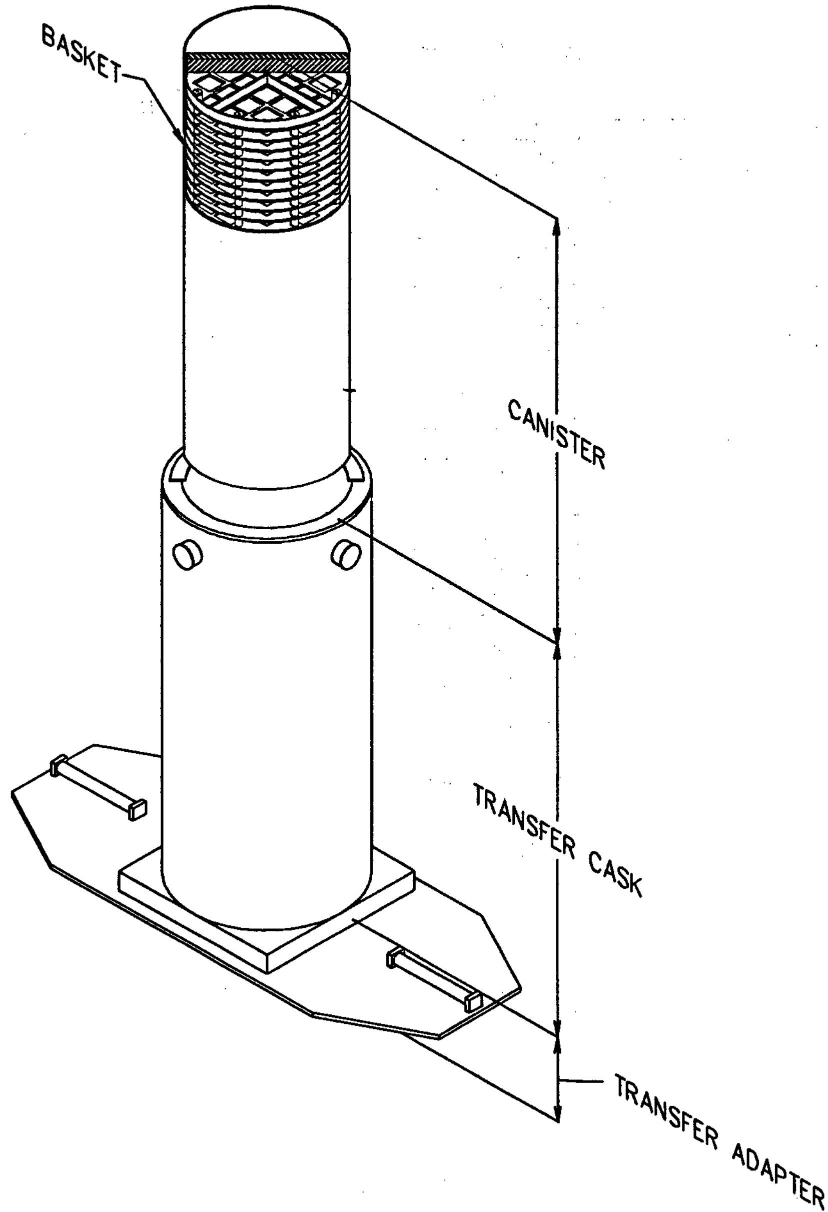

Figure 1.2-7 Vertical Concrete Cask and Transfer Cask Arrangement

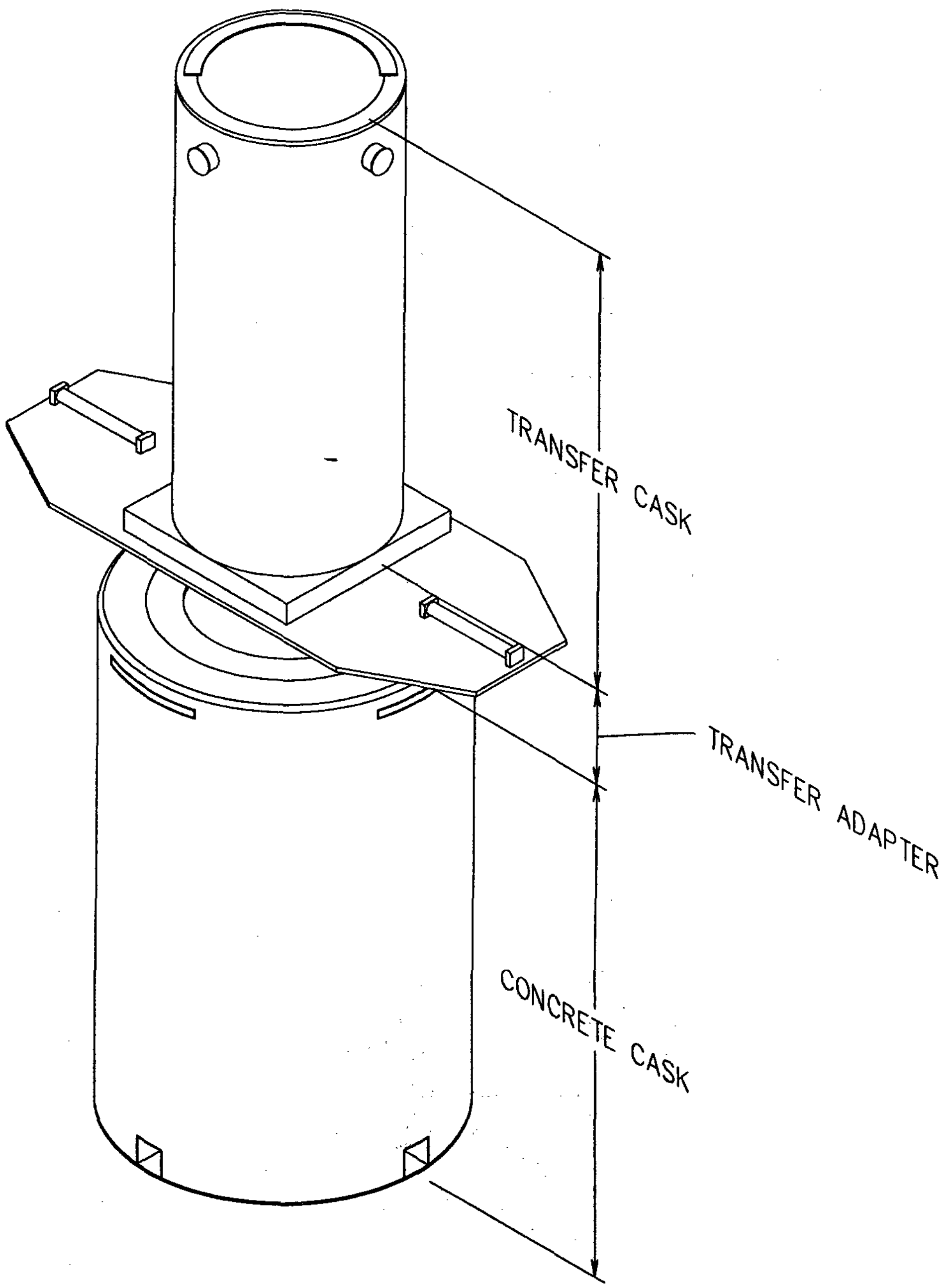

Figure 1.2-8 Major Component Configuration for Loading the Canister Overpack

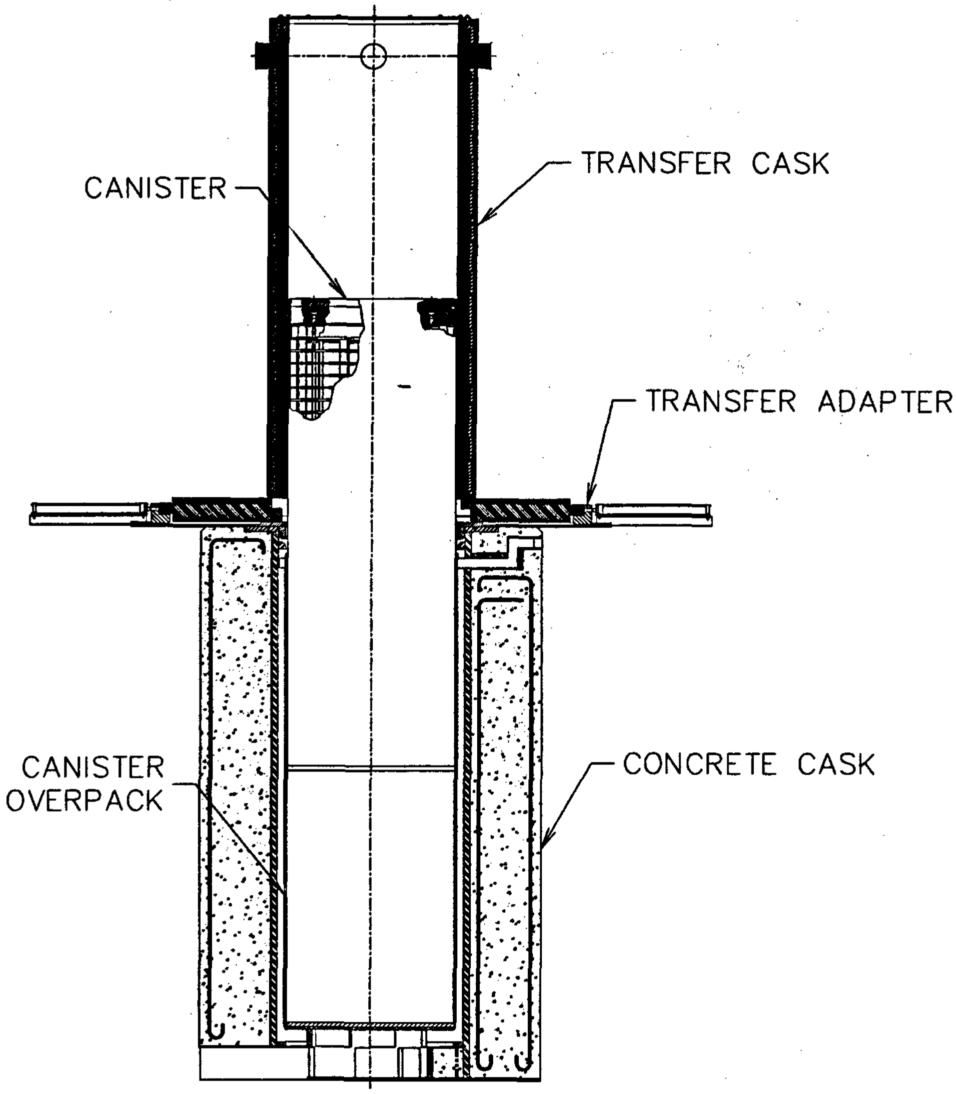

Table 1.2-1 Major Physical Design Parameters for the Transportable Storage Canister and the Canister Overpack

Parameter	Value	
	Transportable Storage Canister	Canister Overpack
Outside Diameter	70.64 in.	72.64 in.
Length	122.5 in.	133.0 in.
Capacity	36 Yankee Class spent fuel assemblies	1 Transportable Storage Canister
Weight	54,730 lb. (nominal) w/ fuel	11,800 lb (nominal)
Maximum heat load	12.5 kW (fuel)	12.5 kW (fuel)
Maximum fuel cladding temperature	380°C for 5-year cooled fuel 340°C for 10-year cooled fuel	380°C for 5-year cooled fuel 340°C for 10-year cooled fuel
Internal atmosphere	Helium	Helium

Table 1.2-2 Transportable Storage Canister and Canister Overpack Fabrication Specification Summary

Materials

- All material shall be in accordance with the referenced drawings and meet the applicable ASME standard.

Welding

- All welds shall be in accordance with the referenced drawings.
- All filler metals shall be appropriate ASME material.
- All welders and welding operators shall be qualified in accordance with ASME Section IX.
- All welding procedures shall be written and qualified in accordance with ASME Section IX.
- All welds specified to be visually examined shall be examined as specified in ASME Section V, Article 9 with acceptance per ASME Section VIII, UW-35 and UW-36.
- All welds specified to be dye penetrant examined shall be examined in accordance with the requirements of ASME Section V, Article 6, with acceptance in accordance with ASME Section III, NB-5350.
- All personnel performing examinations shall be qualified in accordance with the NAC International quality assurance program and SNT-TC-1A.
- All welds specified to be radiographed shall be examined in accordance with the requirements of ASME Section V, Article 2, with acceptance per ASME Section III, NB 5320.
- All welds specified to be ultrasonically examined shall be examined in accordance with ASME Section V, Article 5, with acceptance in accordance with ASME Section III, NB-5330.

Fabrication

- All cutting, welding, and forming shall be in accordance with ASME, Section III, NB-4000 unless otherwise specified. Code stamping is not required.
- All surfaces shall be cleaned to a surface cleanness classification C or better as defined in ANSI N45.2.1, Section 2.
- All fabrication tolerances shall meet the requirements of the referenced drawings after fabrication.

Packaging

- Packaging and shipping shall be in accordance with ANSI N45.2.2.

Quality Assurance

- The canister and canister overpack assemblies shall be fabricated under a quality assurance program that meets 10 CFR 72 Subpart G and 10 CFR 71 Subpart H.
- The supplier's quality assurance program must be accepted by the licensee prior to initiation of work.
- Hold points for inspection of a completed basket assembly are verification of the basket assembly diameter and length, insertion of a "dummy" fuel assembly into each fuel tube, and insertion of the basket into the canister shell.
- A Certificate of Compliance shall be issued by the fabricator stating that the canister and canister overpack meet the specifications and drawings.

Table 1.2-3 Major Physical Design Parameters for the Vertical Concrete Cask

Parameter	**Value**
Height	160 in.
Outside diameter	128 in.
Shielding (side wall) Concrete thickness Steel thickness	 21 in. 3.50 in.
Radiation dose rate (average): Side surface Top surface Air inlet/ outlet vents	 ≤ 50 mrem/hr ≤ 55 mrem/hr ≤ 100 mrem/hr
Weight	155,000 lbs. (nominal)
Air flow at design heat load	1 (lb-m)/sec
Material of construction Concrete Reinforcing steel Steel liner	 Type II Portland Cement A615 Grade 60 A36 Carbon Steel
Service life	50 years
Maximum concrete temperatures for normal operation	150°F bulk 200°F local

Table 1.2-4 Concrete Cask Fabrication Specification Summary

Materials

- Concrete mix shall be in accordance with the requirements of ACI 318 and ASTM C94.
- Type II Portland Cement, ASTM C150.
- Fine aggregate ASTM C33 and C637.
- Coarse aggregate ASTM C33 and C637.
- Admixtures
  Water Reducing ASTM C494.
  Pozzolanic Admixture ASTM C618.
- Minimum Compressive Strength 4000 psi at 28 days.
- Specified Air Entrainment 3% - 6%.
- All steel components shall be of material as specified in the referenced drawings.

Welding

- Visual inspection of all welds shall be performed to the requirements of AWS D1.1, Section 8.15.

Construction

- Specimens shall be obtained or prepared for each batch or truck load of concrete per ASTM C172 and ASTM C192.
- Test specimens shall be tested in accordance with ASTM C39.
- Formwork shall be in accordance with ACI 318.
- All sidewall formwork and shoring shall remain in place for at least 24 hours.
- All bottom formwork and shoring shall remain in place for 14 days.
- Grade, type, and details of all reinforcing steel shall be in accordance with the referenced drawings.
- Embedded items shall conform to ACI 318 and the referenced drawings.
- The placement of concrete shall be in accordance with ACI 318.
- Surface finish shall be in accordance with ACI 318.

Quality Assurance

- The concrete cask shall be constructed under a quality assurance program that meets 10 CFR 72 Subpart G. The quality assurance program must be accepted by NAC International and the licensee prior to initiation of the work.

Table 1.2-5 Major Physical Design Parameters for the Transfer Cask

Parameter	Value
Inside Diameter	71.5 in.
Outside Diameter	86.5 in.
Height	133.38 in.
Empty Weight (nominal)	80,800 lbs.
Side Wall Dose Rate (average)	≤ 200 mrem/hr

Table 1.2-6 NAC-MPC Design Basis Fuel Characteristics

Parameter	Yankee Class Spent Fuel[1, 2,]		
	United Nuclear Type A	Combustion Type A	Westinghouse Type B
Number of Assemblies per Canister	36	36	34
Assembly Weight, lb	850	850	900
Assembly Length, in	111.25	111.79	111.25
Active Fuel Length, in	91	91	92
Fuel Rod Cladding	Zircaloy	Zircaloy	Stainless Steel
Maximum Uranium, kgU	245.6	239.4	286.9
Maximum Initial ^{235}U, wt %	4.0	3.9	4.94
Maximum Burnup, MWD/MTU	32,000	36,000	32,000
Maximum Assembly Decay Heat, kW	0.347	0.347	0.368
Maximum Decay Heat, kW	12.5	12.5	12.5
Minimum Cool Time, yr	7.1	8	21

1. The Yankee Class spent fuel includes United Nuclear Type A and Type B, Combustion Engineering Type A and Type B, Exxon-ANF Type A and Type B, Westinghouse Type A and Type B. The United Nuclear Type A is the most reactive assembly and is used as the design basis fuel for criticality analyses. The Combustion Type A is the design basis fuel for shielding and thermal evaluations. The Westinghouse Type B fuel is the heaviest assembly and is the design basis fuel for structural considerations.

2. The Exxon-ANF fuel was provided by Exxon after Exxon was acquired by Advanced Nuclear Fuel (ANF). Fuel provided by ANF was designated Exxon-ANF. This fuel is considered to be Exxon fuel throughout this report. Exxon fuel (and therefore, Exxon-ANF fuel) has the same characteristics as Combustion Engineering fuel.

3. The NAC-MPC can accommodate one or more Reconfigured Fuel Assemblies containing up to 64 fuel rods or rod segments classified as failed.

4. Combustion Engineering fuel assemblies with burnups up to 32,000 MWD/MTU require minimum cooling times of 7.0 years. Exxon fuel has the same minimum cool time as Combustion Engineering fuel.

1.3 Agents and Contractors

The prime contractor for the NAC-MPC design is NAC International Inc. (NAC). All design and specification activities are performed by NAC. Fabrication of the steel components will be by qualified vendors. Assembly of the vertical concrete storage cask will be performed by a qualified concrete contractor. All fabrication activities will be performed in accordance with quality assurance programs meeting the requirements of 10 CFR 71 and 10 CFR 72.

NAC is a private corporation founded in 1968, whose primary focus is the tracking, inspection, handling, storage, and transportation of spent nuclear fuel. NAC is recognized in the industry as expert in all aspects of the design, licensing, and operation of spent fuel handling, inspection, storage, and transport equipment, as well as in the management of spent fuel inventories.

NAC is the leading United States company in the transport and storage of spent nuclear fuel, owning and operating the largest fleet of commercial spent fuel transport casks in the United States. This fleet includes the following casks:

- 5 NLI-1/2 (LWT) - 1 PWR/2 BWR - Licensed for LWR and metallic fuel and High Level Waste (HLW)
- 5 NAC LWT - 1 PWR/2 BWR - Licensed for LWR fuel, metallic fuel and HLW
- 2 NLI-10/24 (Rail) - 10 PWR/24 BWR - Licensed for LWR fuel

These casks are licensed by the U.S. NRC under 10 CFR 71 and have successfully and safely completed more than 1,000 shipments of spent fuel and high level waste for more than 40 nuclear facilities in the last 15 years. NAC has also designed and licensed the NAC-STC rail cask for the storage and transport of spent fuel. The NAC-MPC canister is designed to be transported in the NAC-STC.

NAC also has designed, analyzed, and licensed the following storage casks:

- NAC-I26 S/T - General license for storage of 26 PWR fuel assemblies
- NAC-I28 S/T - Approved for the storage of 28 PWR fuel assemblies
- NAC-C28 S/T - General license for the storage of 28 consolidated PWR fuel canisters (56 assemblies)

Within the last 10 years, NAC contractors have completed the fabrication of two NAC-I28 S/T storage casks, five NAC LWT transport casks, and one NAC-I26 S/T storage cask.

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1.4 Generic Storage Cask Arrays

A typical ISFSI storage pad layout for 16 storage casks is provided in Figure 1.4-1. As shown in this figure, roads parallel the sides of the pad to facilitate transfer of the storage cask from the transporter to the designated storage position on the pad. Loaded storage casks are placed in the vertical position on the pad in a linear array. Array sizes could accommodate from 1 to more than 200 casks. Figure 1.4-1 shows typical spacing and representative site dimensions. However, these are dependent on the general site layout, access roads, site boundaries, and transfer equipment selection.

The reinforced concrete foundation is capable of sustaining the transient loads from the air pad and the general loads of the stored casks. If necessary, the pad can be constructed in phases to specifically meet utility-required expansions.

Figure 1.4-1 Typical ISFSI Storage Pad Layout

FIGURE WITHHELD UNDER 10 CFR 2.390

1.5 License Drawings

This section presents the License Drawings for the NAC-MPC System.

1.5.1 NAC-MPC License Drawings

Drawing Number	Title	Revision No.	No. of Sheets
455-821	Adapter Ring, Transfer Adapter to NAC-STC MPC-Yankee	0	1
455-856	Name Plate - NAC-VCC Cask	0	1
455-857	Assembly, Canister Overpack, MPC-Yankee	1	1
455-858	Canister Overpack Shell, MPC-Yankee	2	3
455-859	Assembly, Transfer Adapter, NAC-MPC	0	3
455-860	Assembly, Transfer Cask (TFR), MPC-Yankee	2	4
455-861	Weldment, Structure, Vertical Concrete Cask (VCC), MPC-Yankee	2	2
455-862	Loaded Vertical Concrete Cask (VCC), MPC-Yankee	1	2
455-863	Lid, Vertical Concrete Cask (VCC), MPC-Yankee	1	2
455-864	Shield Plug, Vertical Concrete Cask (VCC), MPC-Yankee	0	1
455-866	Reinforcing Bar and Concrete Placement, Vertical Concrete Cask (VCC), MPC-Yankee	0	3
455-870	Canister Shell, MPC-Yankee	3	1
455-871	Details, Canister, MPC-Yankee	2	2
455-872	Assembly, Transport Storage Canister (TSC), MPC-Yankee	4	1
455-873	Assembly, Drain Tube, Canister, MPC-Yankee	2	1
455-881	PWR Fuel Tube, Captivated BORAL, MPC-Yankee	1	1
455-887	Drawing Deleted		
455-888	Drawing Deleted		
455-891	Bottom Weldment, Fuel Basket, MPC-Yankee	0	1
455-892	Top Weldment, Fuel Basket, MPC-Yankee	1	1
455-893	Support Disk and Misc. Basket Details, MPC-Yankee	3	1
455-894	Heat Transfer Disk, Fuel Basket, MPC-Yankee	1	1
455-895	Fuel Basket Assembly, MPC-Yankee	2	1

1.5.2 Yankee Class Reconfigured Fuel Assembly License Drawings

Drawing Number	Title	Revision No.	No. of Sheets
YR-00-060	Yankee-Class Reconfigured Fuel Assembly	1	1
YR-00-061	Yankee-Class Reconfigured Fuel Assembly, Shell Weldment	1	1
YR-00-062	Yankee-Class Reconfigured Fuel Assembly, Top End Fitting Assembly	1	1
YR-00-063	Yankee-Class Reconfigured Fuel Assembly, Bottom End Fitting Assembly	1	1
YR-00-064	Yankee-Class Reconfigured Fuel Assembly, Nozzle Bolt and Alignment Pin	1	1
YR-00-065	Yankee-Class Reconfigured Fuel Assembly, Fuel Basket Assembly	1	1
YR-00-066	Yankee-Class Reconfigured Fuel Assembly, Fuel Tube Assembly	1	1

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.06
	ANGULARITY	OVER 12		OVER 18	±.09
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	
		FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°	
	PARALLELISM	THREADS-UNIFIED CL2A-2B		CORNERS R.03	
	CONCENTRICITY	NEXT ASSEMBLY:			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER		
CHECKER		
PROJECT MANAGER		
VP/CHIEF ENGINEER		
DIRECTOR of PROJECTS		
LICENSING MANAGER		
QUALITY		
SBU VP		

NAC INTERNATIONAL

ADAPTER RING,
TRANSFER ADAPTER
TO NAC-STC
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 821	REV 0
SCALE 1/6	EST.WT. 1725#	SH 1 OF 1	10:49AM 4-23-97

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY							
QUANTITY									
SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP	NAME	DATE	NAC INTERNATIONAL
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.	PREPARER	[illegible]	4/24/97	NAMEPLATE– NAC–VCC CASK
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER	[illegible]	4/24/97	
		3–12		6–18	±.06	PROJECT MANAGER	[illegible]	4/24/97	
	ANGULARITY	OVER 12		OVER 18	±.09	VP/CHIEF ENGINEER	[illegible]	4/24/97	
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR of PROJECTS	[illegible]	4/24/97	
		FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER	[illegible]	4/24/97	
	PARALLELISM	THREADS–UNIFIED CL2A–2B		CORNERS R.03					PROJECT 455 / DESIGN PACKAGE / DRAWING 856 / REV 0
	CONCENTRICITY	NEXT ASSEMBLY: 455–866				QUALITY	[illegible]	4/24/97	
	TRUE POSITION	DRAWING TYPE: LICENSE				SBU VP	[illegible]	4/24/97	SCALE FULL / EST.WT. / SH 1 OF 1 / 11:39AM 4-24-97

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY
⏥	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⊕	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3		UNDER 6	±.04
3–12		6–1[illegible]	±.06
OVER 12		OVER [illegible]8	±.08
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
THREADS–UNIFIED CL2A–2B		CORNERS R.03	
NEXT ASSEMBLY:			
DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	8-26-96
CHECKER	[illegible]	8-26-96
PROJECT MANAGER	[illegible]	8-26-96
VP/CHIEF ENGINEER	N/A	
DIRECTOR of PROJECTS	[illegible]	8-27-96
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	8/28/96
SBU VP	N/A	

NAC INTERNATIONAL

ASSEMBLY,
CANISTER OVERPACK,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 857	REV 1
SCALE 1/6	EST. WT.	SH 1 OF 1	10:33AM 8-26-96

3 2 1

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CANISTER OVERPACK SHELL, MPC–YANKEE

NEXT ASSEMBLY:	455–057
DRAWING TYPE:	LICENSE
PROJECT	455
DESIGN PACKAGE	
DRAWING	858
REV	2
SCALE	1/8
EST.WT.	
SH	1 OF 3
	1:53PM 9-4-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CANISTER OVERPACK SHELL,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 858	REV 2
SCALE 1/8	EST.WT.	SH 2 OF 3	1:54PM 9-4-98

A

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CANISTER OVERPACK SHELL,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 858	REV 2
SCALE 1/8	EST.WT.	SH 3 OF 3	

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY							NAC INTERNATIONAL
QUANTITY									
SYM	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP	NAME	DATE	ASSEMBLY, TRANSFER ADAPTER, MPC-YANKEE
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.	PREPARER	[illegible]	4/24/97	
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER	[illegible]	4/24/97	
		3-12		6-18	±.06	PROJECT MANAGER	[illegible]	4/24/97	
	ANGULARITY	OVER 12		OVER 18	±.09	VP/CHIEF ENGINEER	[illegible]	4/24/97	
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR of PROJECTS	[illegible]	4/25/97	
		FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER	[illegible]	4/25/97	PROJECT 455 / DESIGN PACKAGE / DRAWING 859 / REV 0
	PARALLELISM	THREADS-UNIFIED CL2A-2B		CORNERS R.03					
	CONCENTRICITY	NEXT ASSEMBLY:				QUALITY	[illegible]	4/25/97	
	TRUE POSITION	DRAWING TYPE: LICENSE				S&U VP	[illegible]	4/25/97	SCALE 1/10 / EST.WT. NOTED / SH 1 OF 3 / 5:25PM 4-23-97

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER ADAPTER,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 859	REV 0
SCALE 1/10	EST.WT. NOTED	SH 2 OF 3	5:26PM 6-23-97

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER ADAPTER,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 859	REV 0
SCALE 1/5	EST.WT. NOTED	SH 3 OF 3	3:25PM 4-23-97

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER CASK (TFR)
MPC–YANKEE

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.	PREPARER
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER
	ANGULARITY	3–12		6–18	±.06	PROJECT MANAGER
		OVER 12		OVER 18	±.09	VP/CHIEF ENGINEER
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR of PROJECTS
	PARALLELISM	FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER
		THREADS–UNIFIED CL2A–2B		CORNERS R.03		
	CONCENTRICITY	NEXT ASSEMBLY:				QUALITY
	TRUE POSITION	DRAWING TYPE: LICENSE				SBU VP

PROJECT 455 | DESIGN PACKAGE | DRAWING 860 | REV 2

SCALE 1/10 | EST.WT. | SH 1 OF 4 | 9:17AM 7-22-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER CASK (TFR)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 860	REV 2
SCALE 1/10	EST.WT.	SH 2 OF 4	9:18AM 7-22-96

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER CASK (TFR)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 860	REV 2
SCALE 1/10	EST.WT.	SH 3 OF 4	7-22-96

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
TRANSFER CASK (TFR)
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 860	REV 2
SCALE 1/8	EST.WT.	SH 4 OF 4	9:19AM 7-22-98

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP	NAME	DATE
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.	PREPARER	R. [illegible]	9-28-[illegible]
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER	[illegible]	9-28-[illegible]
		3–12		6–18	±.06	PROJECT MANAGER	[illegible]	[illegible]
	ANGULARITY	OVER 12		OVER 18	±.09	VP/CHIEF ENGINEER	NA	
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR OF PROJECTS	[illegible]	[illegible]
	PARALLELISM	FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER	[illegible]	[illegible]
	CONCENTRICITY	NEXT ASSEMBLY: 855-866				QUALITY	[illegible]	[illegible]
	TRUE POSITION	DRAWING TYPE: LICENSE				SBU VP	NA	

NAC INTERNATIONAL

WELDMENT, STRUCTURE,
VERTICAL CONCRETE CASK (VCC)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 861	REV 2
SCALE 1/16	EST.WT.	SH 1 OF 2	2:33PM 8-28-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT, STRUCTURE,
VERTICAL CONCRETE CASK (VCC)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 861	REV 2
SCALE 1/16	EST.WT.	SH 2 OF 2	2:34PM 6-28-96

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04
		3–12		6–18	±.06
	ANGULARITY	OVER 12		OVER 18	±.09
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	
	PARALLELISM	FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
		THREADS–UNIFIED 0.2A–2B		CORNERS R.03	
	CONCENTRICITY	NEXT ASSEMBLY:			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	9-2-98
CHECKER	[illegible]	9-2-98
PROJECT MANAGER	[illegible]	9-2-98
VP/CHIEF ENGINEER	NA	
DIRECTOR of PROJECTS	[illegible]	9-2-98
LICENSING MANAGER	[illegible]	9/2/98
QUALITY	[illegible]	9-4-98
SBU VP	NA	

NAC INTERNATIONAL

LOADED VERTICAL CONCRETE CASK (VCC) MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 862	REV 1
SCALE 1/8	EST.WT.	SH 1 OF 2	9:24AM 9-2-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

LOADED VERTICAL
CONCRETE CASK (VCC)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 862	REV 1
SCALE 1/8	EST.WT.	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY
⏥	FLATNESS
⏤	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⌖	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.
UNDER 3		UNDER 6	±.04
3-12		6-18	±.06
OVER 12		OVER 18	±.09
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B		CORNERS R.03	
NEXT ASSEMBLY: 455-862			
DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	8-28-98
CHECKER	[illegible]	8-28-98
PROJECT MANAGER	[illegible]	8-31-98
VP/CHIEF ENGINEER	NA	
DIRECTOR OF PROJECTS	[illegible]	8-31-98
LICENSING MANAGER	[illegible]	9/2/98
QUALITY	[illegible]	9-2-98
SBU VP	NA	

NAC INTERNATIONAL

LID,
VERTICAL CONCRETE CASK (VCC)
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 863	REV 1
SCALE 1/5	EST.WT.	SH 1 OF 2	2:14PM 8-28-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL					
LID, VERTICAL CONCRETE CASK (VCC) MPC-YANKEE					
PROJECT 455	DESIGN PACKAGE	DRAWING 863		REV 1	
SCALE 1/5	EST. WT.	SH 2 OF 2		8:04AM 8-2-98	

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY	3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.
	FLATNESS	TOLERANCES UNLESS OTHERWISE SPECIFIED			
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.06
	ANGULARITY	OVER 12		OVER 18	±.09
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	
		FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°	
	PARALLELISM	THREADS-UNIFIED 0.2A-2B		CORNERS R.03	
	CONCENTRICITY	NEXT ASSEMBLY: 455-862			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER		
CHECKER		
PROJECT MANAGER		
VP/CHIEF ENGINEER		
DIRECTOR of PROJECTS		
LICENSING MANAGER		
QUALITY		
SBU VP		

NAC INTERNATIONAL

SHIELD PLUG,
VERTICAL CONCRETE CASK (VCC)
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 864	REV 0
SCALE 1/5	EST. WT.	SH 1 OF 1	3:12PM 4-22-97

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			
		3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.
▱	FLATNESS	UNDER 3		UNDER 6	±.04
—	STRAIGHTNESS	3–12		6–18	±.06
∠	ANGULARITY	OVER 12		OVER 18	±.09
⊥	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	
//	PARALLELISM	FINISH (√)-AA-125 MICRO IN		ANGLES ± 5°	
◎	CONCENTRICITY	THREADS-UNIFIED CL2A-2B		CORNERS R.03	
⊕	TRUE POSITION	NEXT ASSEMBLY: 455-862			
		DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	[illegible]
CHECKER	[illegible]	4/15/97
PROJECT MANAGER	[illegible]	[illegible]
VP/CHIEF ENGINEER	[illegible]	[illegible]
DIRECTOR of PROJECTS	[illegible]	[illegible]
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
SBU VP	[illegible]	[illegible]

NAC INTERNATIONAL

REINFORCING BAR AND CONCRETE PLACEMENT, VERTICAL CONCRETE CASK (VCC) MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 866	REV 0
SCALE 1/16	EST.WT.	SH 1 OF 3	9:13AM 4-25-97

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

REINFORCING BAR AND
CONCRETE PLACEMENT,
VERTICAL CONCRETE CASK (VCC)
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 866	REV 0
SCALE 1/16	EST.WT.	SH 2 OF 3	9:14AM 2-11-97

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

REINFORCING BAR AND
CONCRETE PLACEMENT,
VERTICAL CONCRETE CASK (VCC)
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 866	REV 0
SCALE 1/12	EST. WT.	SH 3 OF 3	9:34AM 2-11-97

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP	NAME	DATE
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.	PREPARER	[illegible]	8-7-98
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER	M. Liu	8-7-98
	ANGULARITY	3–12		6–18	±.06	PROJECT MANAGER	[illegible]	8-7-98
		OVER 12		OVER 18	±.08	VP/CHIEF ENGINEER	N/A	
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR PROJECTS	[illegible]	8-7-98
	PARALLELISM	FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER	[illegible]	8/7/98
	CONCENTRICITY	THREADS–UNIFIED CL2A–2B		CORNERS R.03		QUALITY	[illegible]	8/7/98
		NEXT ASSEMBLY: 455–872						
	TRUE POSITION	DRAWING TYPE: LICENSE				SBU VP	N/A	

NAC INTERNATIONAL

CANISTER SHELL,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 870	REV 3
SCALE 1/8	EST. WT.	SH 1 OF 1	10:28AM 8-6-98

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY
▱	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⊕	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3		UNDER 6	±.04
3–12		6–18	±.06
OVER 12		OVER 18	±.09
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B		CORNERS R.03	
NEXT ASSEMBLY: 455–872			
DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	[illegible]
CHECKER	[illegible]	5-13-98
PROJECT MANAGER	[illegible]	[illegible]
VP/CHIEF ENGINEER	NA	
DIRECTOR of PROJECTS	[illegible]	5-14-98
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
SBU VP	NA	

NAC INTERNATIONAL

DETAILS,
CANISTER,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 871	REV 2
SCALE 1/8	EST.WT.	SH 1 OF 2	1:46PM 5-13-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

DETAILS,
CANISTER,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 871	REV 2
SCALE 1/8	EST. WT.	SH 2 OF 2	1:46PM 5-13-96

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04
		3–12		6–18	±.06
	ANGULARITY	OVER 12		OVER 18	±.09
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	
	PARALLELISM	FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
		THREADS–UNIFIED CL2A–2B		CORNERS R.03	
	CONCENTRICITY	NEXT ASSEMBLY: 455–800/862			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	[illegible]
CHECKER	MAR	9/29/98
PROJECT MANAGER	[illegible]	9/28/98
VP/CHIEF ENGINEER	[illegible]	[illegible]
DIRECTOR OF PROJECTS	[illegible]	[illegible]
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
SNU VP	NA	

NAC INTERNATIONAL

ASSEMBLY, TRANSPORTABLE STORAGE CANISTER (TSC), MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 872	REV 4
SCALE 1/8	EST.WT.	SH 1 OF 1	2:52PM 9-28-98

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY					NAC INTERNATIONAL	
QUANTITY								
SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			GROUP	NAME	DATE	ASSEMBLY, DRAIN TUBE, CANISTER MPC-YANKEE
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC / TOL.	PREPARER	[illegible]	[illegible]	
	STRAIGHTNESS	UNDER 3		UNDER 6 ±.04	CHECKER	R. [illegible]	[illegible]	
		3-12		6-18 ±.06	PROJECT MANAGER	[illegible]	5-13-98	
	ANGULARITY	OVER 12		OVER 18 ±.09	VP/CHIEF ENGINEER	NA		
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03	DIRECTOR of PROJECTS	[illegible]	5-14-98	
	PARALLELISM	FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°	LICENSING MANAGER	[illegible]	[illegible]	PROJECT 455 / DESIGN PACKAGE / DRAWING 873 / REV 2
	CONCENTRICITY	NEXT ASSEMBLY: 455-872			QUALITY	[illegible]	[illegible]	
	TRUE POSITION	DRAWING TYPE: LICENSE			SBU VP	NA		SCALE FULL / EST.WT. / SH 1 OF 1 / 1:45PM 5-13-98

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

PWR FUEL TUBE,
CAPTIVATED BORAL,
MPC–YANKEE

ASSY	ASSY	ASSY
QUANTITY		

SYM	GEOMETRY
	FLATNESS
	STRAIGHTNESS
	ANGULARITY
	PERPENDICULARITY
	PARALLELISM
	CONCENTRICITY
	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3		UNDER 6	±.04
3–12		6–18	±.06
OVER 12		OVER 18	±.09
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
THREADS–UNIFIED CL2A–2B			
RADIUS CORNERS .03			
TYPE OF DRAWING: LICENSE			

GROUP	NAME	DATE
DRAWN	[illegible]	[illegible]
CHECK	[illegible]	[illegible]
DESIGN AND ANALYSIS	[illegible]	[illegible]
LICENSING	[illegible]	[illegible]
PROJECTS	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
V.P. ENGINEERING	NA	
NEXT ASSEMBLY	455–895	

PROJECT 455	DESIGN PACKAGE	DRAWING 881	REV 1
SCALE 1/1	EST. WT.	SH 1 OF 1	12:46PM 6-22-98

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY
	FLATNESS
	STRAIGHTNESS
	ANGULARITY
	PERPENDICULARITY
//	PARALLELISM
	CONCENTRICITY
	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3		UNDER 6	±.04
3-12		6-18	±.06
OVER 12		OVER 18	±.09
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)-AA-125 MICRO IN		ANGLES ±.5'	
THREADS-UNIFIED CL2A-2B			
RADIUS CORNERS .03			
TYPE OF DRAWING:	LICENSE		

GROUP	NAME	DATE
DRAWN	[illegible]	12/6/96
CHECK	[illegible]	12/6/96
DESIGN AND ANALYSIS	[illegible]	12/6/96
LICENSING	[illegible]	12/6/96
PROJECTS	[illegible]	12/6/96
QUALITY	[illegible]	12/6/96
V.P. ENGINEERING	[illegible]	12/6/96
NEXT ASSEMBLY	455-895	

NAC INTERNATIONAL

BOTTOM WELDMENT,
FUEL BASKET,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 891	REV 0
SCALE 1/5	EST. WT.	SH 1 OF 1	1:23PM 12-6-96

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY		
QUANTITY				

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED				GROUP	NAME	DATE
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.	PREPARER	[illegible]	[illegible]
	STRAIGHTNESS	UNDER 3		UNDER 6	±.04	CHECKER	[illegible]	[illegible]
		3-12		6-10	±.06	PROJECT MANAGER	[illegible]	[illegible]
	ANGULARITY	OVER 12		OVER 18	±.09	VP/CHIEF ENGINEER	[illegible]	[illegible]
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .03		DIRECTOR of PROJECTS	[illegible]	[illegible]
	PARALLELISM	FINISH (√)-AA-125 MICRO IN		ANGLES ±.5°		LICENSING MANAGER	[illegible]	[illegible]
		THREADS-UNIFIED CL2A-2B		CORNERS R.03				
	CONCENTRICITY	NEXT ASSEMBLY: 455-895				QUALITY	[illegible]	[illegible]
	TRUE POSITION	DRAWING TYPE: LICENSE				SBU VP	[illegible]	[illegible]

NAC INTERNATIONAL

TOP WELDMENT,
FUEL BASKET,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 892	REV 1
SCALE 1/5	EST.WT.	SH 1 OF 1	5:12PM 4-15-97

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM	GEOMETRY
⏥	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⌖	TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED			
3 PLACE DEC.	TOL.	2 PLACE DEC	TOL.
UNDER 3		UNDER 6	±.04
3–12		6–18	±.06
OVER 12		OVER 18	±.08
1 PLACE DEC.	±.1	FILLETS .03	
FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
THREADS–UNIFIED CL2A–2B		CORNERS R.03	
NEXT ASSEMBLY: 455–895			
DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	[illegible]
CHECKER	[illegible]	[illegible]
PROJECT MANAGER	[illegible]	[illegible]
VP/CHIEF ENGINEER	[illegible]	[illegible]
DIRECTOR of PROJECTS	NA	
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
SBU VP	NA	

NAC INTERNATIONAL

SUPPORT DISK AND
MISC. BASKET DETAILS,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 893	REV 3
SCALE 1/5	EST.WT. NOTED	SH 1 OF 1	8:36AM 6–25–98

FIGURE WITHHELD UNDER 10 CFR 2.390

97 | 98 | 99 | ITEM | NAME | MATERIAL | SPEC | DRAWING No. | DESCRIPTION

ASSY | ASSY | ASSY

QUANTITY

NAC INTERNATIONAL

SYM. GEOMETRY: FLATNESS; STRAIGHTNESS; ANGULARITY; PERPENDICULARITY; PARALLELISM; CONCENTRICITY; TRUE POSITION

TOLERANCES UNLESS OTHERWISE SPECIFIED

3 PLACE DEC. | TOL. | 2 PLACE DEC. | TOL.
UNDER 3 | | UNDER 6 | ±.04
3–12 | | 6–18 | ±.06
OVER 12 | | OVER 18 | ±.08
1 PLACE DEC. ±.1 | FILLETS .03
FINISH (√)-AA-125 MICRO IN | ANGLES ±.5°
THREADS-UNIFIED CL.2A-2B
RADIUS CORNERS .03

TYPE OF DRAWING: LICENSE

GROUP | NAME | DATE: DRAWN; CHECK; DESIGN AND ANALYSIS; LICENSING; PROJECTS; QUALITY; V.P. ENGINEERING N/A

NEXT ASSEMBLY 455–895

HEAT TRANSFER DISK,
FUEL BASKET,
MPC–YANKEE

PROJECT 455 | DESIGN PACKAGE | DRAWING 894 | REV 1

SCALE 1/5 | EST.WT. 57 LBS | SH 1 OF 1 | 2:39PM 7-30-98

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE SPECIFIED			
▱	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
—	STRAIGHTNESS	UNDER 3		UNDER 6	±.04
∠	ANGULARITY	3–12		6–18	±.06
⊥	PERPENDICULARITY	OVER 12		OVER 18	±.09
//	PARALLELISM	1 PLACE DEC.	±.1	FILLETS .03	
◎	CONCENTRICITY	FINISH (√)–AA–125 MICRO IN		ANGLES ±.5°	
⊕	TRUE POSITION	THREADS–UNIFIED CL2A–2B		CORNERS R.03	
		NEXT ASSEMBLY: 455–872			
		DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	[illegible]
CHECKER	[illegible]	[illegible]
PROJECT MANAGER	[illegible]	[illegible]
VP/CHIEF ENGINEER	NA	
DIRECTOR of PROJECTS	[illegible]	[illegible]
LICENSING MANAGER	[illegible]	[illegible]
QUALITY	[illegible]	[illegible]
SBU VP	NA	

NAC INTERNATIONAL

FUEL BASKET ASSEMBLY,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 895	REV 2
SCALE 1/6	EST.WT.	SH 1 OF 1	1:42PM 5-13-98

FIGURE WITHHELD UNDER 10 CFR 2.390

102	101	100	ITEM	NAME	MATERIAL	SPEC	DRAWING NO.	DESCRIPTION
ASSY	ASSY	ASSY						
QUANTITY								

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.
NUCLEAR SERVICES DIVISION

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE NOTED			
⏥	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
—	STRAIGHTNESS	UNDER 3	±.003	UNDER 6	±.02
∠	ANGULARITY	3-12	±.005	6-18	±.03
⊥	PERPENDICULARITY	OVER 12	±.010	OVER 18	±.06
//	PARALLELISM	1 PLACE DEC.	±.1	FILLETS .015-.030	
◎	CONCENTRICITY	FINISH √-AA-125 MICRO IN		ANGLES ±.5°	
⌖	TRUE POSITION	THREADS-UNIFIED CL2A-2B			
		RADIUS CORNERS .015-.030			
		SCALE: AS NOTED			

TITLE: YANKEE-CLASS RECONFIGURED FUEL ASSEMBLY

DWG. NO. YR-00-060

JOB NO. W.O. F500

FIGURE WITHHELD UNDER 10 CFR 2.390

102	101	100	ITEM	NAME	MATERIAL	SPEC	DRAWING NO.	DESCRIPTION
ASSY	ASSY	ASSY						
QUANTITY								

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE NOTED			
	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
	STRAIGHTNESS	UNDER 3	±.003	UNDER 6	±.02
		3-12	±.006	6-18	±.03
	ANGULARITY	OVER 12	±.010	OVER 18	±.06
	PERPENDICULARITY	1 PLACE DEC.	±.1	FILLETS .015-.030	
	PARALLELISM	FINISH-√-AA-125 MICRO IN		ANGLES ±.5°	
		THREADS-UNIFIED CL2A-2B			
	CONCENTRICITY	RADIUS CORNERS .015-.030			
	TRUE POSITION	SCALE: AS NOTED			

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.

NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS RECONFIGURED FUEL ASSEMBLY SHELL WELDMENT

DWG. NO. YR-00-061

JOB NO. W.O. F500

A

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY			
QUANTITY					

SYM.	GEOMETRY	TOLERANCES UNLESS OTHERWISE NOTED			
▱	FLATNESS	3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
—	STRAIGHTNESS	UNDER 3	±.003	UNDER 6	±.02
∠	ANGULARITY	3-12	±.005	6-18	±.03
⊥	PERPENDICULARITY	OVER 12	±.010	OVER 18	±.06
//	PARALLELISM	1 PLACE DEC.	±.1	FILLETS .015-.030	
◎	CONCENTRICITY	FINISH√-AA-125 MICRO IN		ANGLES ±.5°	
⌖	TRUE POSITION	THREADS-UNIFIED CL2A-2B			
		RADIUS CORNERS .015-.030			
		SCALE:			

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.

NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS
RECONFIGURED
FUEL ASSEMBLY
TOP END FITTING ASSEMBLY

DWG. NO. YR-00-062

JOB NO. W.O. F500

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY
QUANTITY		

SYM.	GEOMETRY
▱	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⌖	TRUE POSITION

TOLERANCES UNLESS OTHERWISE NOTED

3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3	±.003	UNDER 6	±.02
3-12	±.005	6-18	±.03
OVER 12	±.010	OVER 18	±.06
1 PLACE DEC.	±.1	FILLETS .015-.030	
FINISH-√-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B			
RADIUS CORNERS .015-.030			

SCALE:

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.
NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS RECONFIGURED FUEL ASSEMBLY BOTTOM END FITTING ASSY.

DWG. NO. YR-00-063

JOB NO. W.O. F500

A

FIGURE WITHHELD UNDER 10 CFR 2.390

ASSY	ASSY	ASSY	
QUANTITY			

SYM.	GEOMETRY
▱	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⌖	TRUE POSITION

TOLERANCES UNLESS OTHERWISE NOTED			
3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3	±.003	UNDER 6	±.02
3-12	±.006	6-18	±.03
OVER 12	±.010	OVER 18	±.06
1 PLACE DEC.	±.1	FILLETS .015-.030	
FINISH-√-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B			
RADIUS CORNERS .015-.030			
SCALE:			

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.

NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS
RECONFIGURED
FUEL ASSEMBLY NOZZLE
BOLT AND ALIGNMENT PIN

DWG. NO. YR-00-064

JOB NO. W.O. F500

FIGURE WITHHELD UNDER 10 CFR 2.390

102 ASSY	101 ASSY	100 ASSY	ITEM	NAME	MATERIAL	SPEC	DRAWING NO.	DESCRIPTION
QUANTITY								

SYM.	GEOMETRY
⏥	FLATNESS
—	STRAIGHTNESS
∠	ANGULARITY
⊥	PERPENDICULARITY
//	PARALLELISM
◎	CONCENTRICITY
⌖	TRUE POSITION

TOLERANCES UNLESS OTHERWISE NOTED

3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3	±.003	UNDER 6	±.02
3-12	±.005	6-18	±.03
OVER 12	±.010	OVER 18	±.06
1 PLACE DEC.	±.1	FILLETS .015-.030	
FINISH-√-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B			
RADIUS CORNERS .015-.030			
SCALE:			

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.
NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS RECONFIGURED FUEL ASSEMBLY FUEL BASKET ASSEMBLY

DWG. NO. YR-00-065

JOB NO. W.O. FS00

FIGURE WITHHELD UNDER 10 CFR 2.390

102	101	100	ITEM	NAME	MATERIAL	SPEC	DRAWING NO.	DESCRIPTION
ASSY	ASSY	ASSY						
QUANTITY								

SYM.	GEOMETRY
	FLATNESS
	STRAIGHTNESS
	ANGULARITY
	PERPENDICULARITY
	PARALLELISM
	CONCENTRICITY
	TRUE POSITION

TOLERANCES UNLESS OTHERWISE NOTED

3 PLACE DEC.	TOL.	2 PLACE DEC.	TOL.
UNDER 3	±.003	UNDER 6	±.02
3-12	±.005	6-18	±.03
OVER 12	±.010	OVER 18	±.05
1 PLACE DEC.	±.1	FILLETS .015-.030	
F.MISH-7-AA-125 MICRO IN		ANGLES ±.5°	
THREADS-UNIFIED CL2A-2B			
RADIUS CORNERS .015-.030			
SCALE:			

YANKEE ATOMIC ELECTRIC COMPANY
580 MAIN STREET BOLTON, MA.

NUCLEAR SERVICES DIVISION

TITLE: YANKEE-CLASS RECONFIGURED FUEL ASSEMBLY FUEL TUBE ASSEMBLY

DWG. NO. YR-00-066

JOB NO. W.O. FS00

A

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2.0 PRINCIPAL DESIGN CRITERIA

The NAC-MPC is a canister-based dry storage cask system that is designed to be transported in the NAC-STC licensed transport cask. It is designed to store Yankee Class spent fuel.

This chapter presents the design basis, including the principal design criteria, limiting load conditions, and operational parameters of the NAC-MPC dry storage system. The principal design criteria are summarized in Table 2-1.

Table 2-1 Summary of the NAC-MPC Design Criteria

Design Criteria	
Design Life	50 years
Design Code - Confinement	ASME Code, Section III, Subsection NB for confinement boundary
Design Code - Nonconfinement	
Basket	ASME Code, Section III, Subsection NG and NUREG/CR-6322
Vertical Concrete Cask	ACI-349, ACI-318
Transfer Cask	ANSI N 14.6 and NUREG-0612
Design Weight:	
Canister Assembly w/fuel	54,730 lbs.
Canister Overpack	11,726 lbs
Transfer Cask	80,743 lbs.
Vertical Concrete Cask	151,364 lbs.
Thermal:	
Maximum Fuel Cladding Temperature	340°C for 10-yr. Cooled 380°C for 5-yr. Cooled 570°C Off-Normal/Accident/Transfer
Ambient Temperature Range	-40° to 125°F
Average Annual Ambient Temperature	75°F
Concrete Temperature:	
Normal Conditions	≤ 150°F; ≤ 200°F local
Off-Normal/Accident Conditions	≤ 350°F local/ surface
Canister Cavity Atmosphere	Helium
Canister Overpack Atmosphere	Helium

Table 2-1 Summary of the NAC-MPC Design Criteria (Continued)

Design Criteria	
Radiation Protection/Shielding	
Concrete Cask Side Wall Contact Dose Rate	< 50 mrem/hr. (max)
Concrete Cask Top Lid Contact Dose Rate	< 55 mrem/hr. (max)
Concrete Cask Air Inlet/Outlet	< 100 mrem/hr. (max)
Owner Controlled Area Boundary Normal/Off-Normal Annual Whole Body Dose Accident Whole Body Dose	 25 mrem/yr. 5 rem
Spent Fuel Specifications	
Spent Fuel Type	Yankee Class
Fuel Configuration/Vendor	Westinghouse 18 x 18, 4.94 wt. % ^{235}U United Nuclear 16 x 16, 4.0 wt. % ^{235}U Combustion Engineering 16 x 16, 3.9 wt. % ^{235}U Exxon/ANF 16 x 16, 4.0 wt. % ^{235}U
Fuel Cladding	Stainless Steel - Westinghouse Zircaloy - All others
Spent Fuel Capacity (May include one or more Reconfigured Fuel Assemblies)	36 United Nuclear Assemblies 36 Combustion Engineering Assemblies 36 Exxon/ANF Assemblies, or 34 Westinghouse Assemblies
Spent Fuel Assembly Burnup (max)	36,000 MWD/MTU[1]
Decay Heat/Fuel Assembly or Reconfigured Fuel Assembly Westinghouse All Others	 0.368 kW 0.347 kW

1. Based on the design basis Combustion Engineering fuel at 36,000 MWD/MTU, cooled 8 years. The maximum burnup of all other fuel types is 32,000 MWD/MTU.

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2.1 Spent Fuel To Be Stored

The NAC-MPC has been designed to safely store up to 36 Yankee Class spent fuel assemblies. The spent fuel designs are delineated by various factors including manufacturer, type, enrichment, burnup, cool time, and cladding material. The design basis consists of two types, designated A and B. The Type A assembly incorporates a protruding corner of fuel pins while the Type B assembly omits one corner of the fuel pins. These fuel types, as well as minor differences among manufacturers, are illustrated in Figures 6.2-1 through 6.2-3. During reactor operations, the symmetric stacking of the alternating assemblies permitted the insertion of cruciform control blades between the assemblies. Table 2.1-1 lists the parameters of each fuel design type.

2.1.1 Bounding Fuel Evaluation

The criticality evaluations show that the United Nuclear Type A 16 x 16 fuel assembly is the most reactive fuel type, even though the stainless steel clad Westinghouse fuel has a higher enrichment (4.94 wt % ^{235}U). The shielding evaluations show that the Combustion Engineering Type A has the largest source term. The United Nuclear assemblies are evaluated for a source term based on an initial enrichment of 4.0 weight percent ^{235}U, a maximum burnup of 32,000 megawatt days per metric ton of uranium, and a minimum cool time of 7.1 years after reactor discharge. The Combustion Engineering assemblies are evaluated for a source term based on an initial enrichment of 3.9 weight percent ^{235}U, a maximum burnup of 36,000 megawatt days per metric ton of uranium, and a minimum cool time of 8 years after reactor discharge. For Combustion Engineering assemblies at a maximum burnup of 32,000 MWD/MTU, a minimum cool time of 7.0 years is required.

The NAC-MPC maximum decay heat load is 12.5 kilowatts. This results in a maximum decay heat load for the design basis fuel assemblies of 0.347 kilowatt per assembly, based on 36 fuel assemblies per canister, except for Westinghouse stainless steel clad fuel. The Westinghouse fuel maximum decay heat load is 0.368 kilowatts per assembly for a canister containing 35 fuel assemblies.

The bounding neutron and gamma sources for the Combustion Engineering fuel assemblies in the NAC-MPC are shown in Table 2.1-2. The source terms are based on 36 fuel assemblies

cooled 8 years, having a burnup of 36,000 MWD/MTU per assembly. The maximum fuel assembly initial enrichment is 4.94 percent.

2.1.2 Reconfigured Fuel Assembly

One or more transportable storage canisters may hold Reconfigured Fuel Assemblies containing spent fuel rods classified as failed fuel. The Reconfigured Fuel Assembly may consist of up to 64 rod segments or whole rods having cladding defects. The rods, or rod segments, are held in individual tubes in an 8 by 8 array. The array of tubes is positioned in a stainless steel container having the same external dimensions as a standard fuel assembly. It has a top end fitting that has the same configuration as a standard fuel assembly. The container is closed on the top and bottom ends by perforated plates which act as a barrier to the release of gross particles to the canister, but allow the draining and drying of the container. The tubes are stainless steel and are closed on each end by a plug. Each plug has a small hole drilled through it, that is screened. The screened hole allows the draining and drying of the individual tubes during routine closing of the canister. The screen precludes the release of gross particles to the canister. The effects of the container of failed fuel are evaluated in the appropriate sections. The structural, thermal, shielding, confinement, and criticality effects of the Reconfigured Fuel Assembly are bounded by those of an intact fuel assembly.

The physical parameters of the Reconfigured Fuel Assembly are provided in Table 6.2-2.

Table 2.1-1 Yankee Class Fuel Parameters

	Combustion Engineering	Combustion Engineering	Exxon	Exxon	Exxon	Exxon	Westinghouse	Westinghouse	United Nuclear	United Nuclear
Assembly Configuration	Type A	Type B	Type A	Type B	Type A	Type B	Type A	Type B	Type A	Type B
Assembly Length (cm)	283.9	283.9	283.3	283.3	283.9	283.9	282.6	282.6	282.4	282.4
Assembly Width (cm)	19.2	19.2	19.3	19.3	19.3	19.3	19.3	19.3	19.4	19.4
Assembly Cross Section (cm)	18.1	18.1	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
Assembly Array	16x16	16x16	16x16	16x16	16x16	16x16	18x18	18x18	16x16	16x16
Assembly Weight (kg)	352	350.6	372	372	372	372	408.2	408.2	385.5	385.5
Enrichment (wt. % U^{253})	3.9	3.9	4.0	4.0	3.7	3.7	4.94	4.94	4.0	4.0
Initial Fuel Weight ($KgUO_2$/Assembly)	264.8	264.1	268.3	266.6	266.2	265.0	311	310	273.8	272.6
Initial Heavy Metal (KgU/Assembly)	233.4	232.8	236.5	235	234.5	233.6	274.1	273.2	241.3	240.3
Max. Burnup (MWD/MTU)	36,000	36,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Min. Cool Time (yr)	8.0	8.0	7.0	7.0	7.0	7.0	11.0	11.0	7.1	7.1
Fuel Rod Configuration										
Fuel Rod Pitch (cm)	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.2	1.2
Rod Length (cm)	242.3	242.3	242.2	242.2	242.2	242.2	237.7	237.7	242.1	242.1
Active Fuel Length (cm)	231.1	231.1	231.1	231.1	231.1	231.1	234.0	234.0	231.1	231.1
Rod OD (cm)	0.9	0.9	0.9	0.9	0.9	0.9	0.86	0.86	0.9	0.9
Clad ID (cm)	0.8	0.8	0.8	0.8	0.8	0.8	0.76	0.76	0.8	0.8
Pellet OD (cm)	0.79	0.79	0.79	0.79	0.79	0.79	0.75	0.75	0.79	0.79
Rods per Assembly	231	230	231	230	231	230	305	304	237	236
Fuel Material	UO2	UO2	UO2	UO2	UO2	UO2	UO2	UO2	UO2	UO2
Clad Material	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	SS 348	SS 348	Zircaloy	Zircaloy
Fill Gas	Helium	Helium	Helium	Helium	Helium	Helium	Air	Air	Helium	Helium
Fill Gas Pressure (psi)	315	315	125	125	125	125	0.0	0.0	140	140
Displacement Rod Configuration										
Displacement Rod Material	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Zircaloy - 4	Zircaloy - 4
Displacement Rod Diameter (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.9	0.9
Displacement Rod Length (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	242.1	242.1
Number Per Assembly	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	2

Table 2.1-1 Yankee Class Fuel Parameters (Continued)

	Combustion Engineering	Combustion Engineering	Exxon	Exxon	Exxon	Exxon	Westinghouse	Westinghouse	United Nuclear	United Nuclear
Guide Bar Configuration										
Guide Bar Material	Zircaloy - 4	Zircaloy - 4	SS 304L	SS 304L	Zircaloy	Zircaloy	N/A	N/A	N/A	N/A
Guide Bar Width (cm)	1.1	1.1	1.1	1.1	1.1	1.1	N/A	N/A	N/A	N/A
Guide Bar Length (cm)	245.2	245.2	244.6	244.6	244.6	244.6	N/A	N/A	N/A	N/A
Assembly Configuration	Type A	Type B	Type A	Type B	Type A	Type B	Type A	Type B	Type A	Type B
Top Nozzle Material	SS 304	SS 304	SS 304	SS 304	SS304	SS304	SS 304	SS 304	SS 304	SS 304
Bottom Nozzle Material	SS 304	SS 304	SS 304	SS 304	SS304	SS304	SS 304	SS 304	SS 304	SS 304
Upper Plenum Spring Material	SS 302	SS 302	Inconel X 750	Inconel X 750	Inconel X 750	Inconel X 750	N/A	N/A	Inconel X 750	Inconel X 750
Lower Plenum Spacer Material	N/A	N/A	SS 304	SS 304	SS 304	SS 304	N/A	N/A	SS 304	SS 304
Shroud Material	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	SS 304	SS 304
Top Nozzle Length (cm)	20.0	20.0	19.8	19.8	20.4	20.4	22.2	22.2	18.9	18.9
Bottom Nozzle Length (cm)	18.3	18.3	18.9	18.9	18.9	18.9	22.2	22.2	18.9	18.9
Upper Plenum Length (cm)	4.9	4.9	4.9	4.9	4.9	4.9	4.6	4.6	4.8	4.8
Lower Plenum Length (cm)	N/A	N/A	3.2	3.2	3.2	3.2	N/A	N/A	3.1	3.1
Shroud Length (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	246.9	246.9
Shroud Thickness (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.09	0.09
Top Nozzle Weight (kg)	5.50	5.50	6.70	6.70	6.70	6.70	6.70	6.70	17.02**	17.02**
Bottom Nozzle Weight (kg)	9.10	9.10	5.18	5.18	5.18	5.18	5.20	5.20	13.21**	13.21**
Upper Plenum Spring Weight (g)	3.3	3.3	3.3	3.3	3.3	3.3	N/A	N/A	3	3
Lower Plenum Spring Weight (g)	N/A	N/A	4.5	4.5	4.5	4.5	N/A	N/A	7.5	7.5
Grid Spacer Material	Zirc-4/Inconel 625*	Zirc-4/Inconel 625*	SS 304L	SS 304L	Zircaloy-4	Zircaloy-4	N/A	N/A	Inconel 718	Inconel 718
Grid Spacer Weight (g)	590/960	590/960	622.3	622.3	634.3	648.4	N/A	N/A	0	0
Number of Grid Spacers	6	6	6	6	6	6	N/A	N/A	6	6

* Five grid spacers are Zircaloy 4. The bottom spacer is Inconel 625.

** Estimated weight.

Table 2.1-2 Nuclear and Thermal Parameters for 36 Combustion Engineering Design Basis Fuel Assemblies

Parameter	Value
Decay Heat	12.5 kW
Gamma Source	6.423×10^{16} photons/sec
Neutron Source	2.415×10^{9} neutrons/sec
Upper End Fitting	8.33×10^{13} photons/sec
Lower End Fitting	7.876×10^{13} photons/sec
Upper Plenum	2.309×10^{13} photons/sec
Lower Plenum	5.242×10^{13} photons/sec

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2.2 Design Criteria for Environmental Conditions and Natural Phenomena

The design criteria defined in this section identify the site environmental conditions and natural phenomena to which the storage system could reasonably be exposed during the period of storage. Analyses to demonstrate that the NAC-MPC design meets the design criteria defined in this chapter are presented in later chapters of this report. The NAC-MPC system includes a canister overpack which is designed to the same criteria as the transportable storage canister.

2.2.1 Tornado and Wind Loadings

The NAC-MPC may be stored on an unsheltered reinforced concrete storage pad at an ISFSI site. This storage configuration exposes the NAC-MPC to tornado and wind loading.

2.2.1.1 Applicable Design Parameters

The design basis tornado and wind loading is defined based on Regulatory Guide 1.76 Region 1 and NUREG-0800. The tornado and wind loading criteria are presented in Table 2.2-1.

2.2.1.2 Determination of Forces on Structures

Tornado wind forces on the NAC-MPC are calculated by multiplying the dynamic wind pressure by the frontal area of the cask normal to the wind direction. Wind forces are applied to the cask in the wind direction. No streamlining is assumed. The evaluation of wind loading and tornado missile effects on the NAC-MPC is presented in Section 11.2.13

2.2.1.3 Tornado Missiles

The design basis tornado missile impacts are defined in Paragraph 4, Subsection III, Section 3.5.1.4 of NUREG-0800. The design basis tornado is considered to generate three types of missiles that impact the cask at normal incidence:

1. Massive Missile - (Deformable w/high kinetic energy)	Weight = 1800 kg (3960 pounds) Frontal Area = 20 sq.-ft
2. Penetration Missile - (Rigid hardened steel)	Weight = 125 kg (275 pounds) Diameter = 8.0 inches
3. Protective Barrier Missile - (Solid steel sphere)	Weight = 0.068 kg (0.15 pounds) Diameter = 1.0 inch

Each missile is assumed to impact the cask at a velocity of 126 miles per hour, horizontal to the ground, which is 35 percent of the maximum wind speed of 360 miles per hour. For missile impacts in the vertical direction, the assumed missile velocity is (0.7)(126) = 88.2 miles per hour.

The detailed analysis of the NAC-MPC for the missile impacts applies the laws of conservation of momentum and conservation of energy to estimate the impact force on the cask as a function of the time of impact and the amount of missile deformation. Each missile impact is evaluated, and all missiles are assumed to impact in a manner that produces the maximum damage to the NAC-MPC.

2.2.2 Water Level (Flood) Design

The NAC-MPC may be exposed to a flood during storage on an unsheltered concrete storage pad at an ISFSI site. The source and magnitude of the probable maximum flood depend on several variables.

2.2.2.1 Flood Elevations

The NAC-MPC is evaluated for a maximum flood water depth of 50 feet above the base of the storage cask. The flood water velocity is considered to be 15 feet per second. Under these conditions, the NAC-MPC will not float, tip or significantly slide on the storage pad, and the confinement function will be maintained.

2.2.2.2 Phenomena Considered in Design Load Calculations

The occurrence of flooding at an ISFSI site is dependent upon the specific site location and the surrounding geographical features, natural and man-made. Flooding of an ISFSI site is highly improbable because of the extensive environmental impact studies that are performed during the selection of a site for a nuclear facility. Some possible sources of a flood at an ISFSI site are: (1) overflow from a river or stream due to unusually heavy rain, snow-melt runoff, a dam or major water supply line break caused by a seismic event (earthquake); (2) high tides produced by a hurricane; and (3) a tsunami (tidal wave) caused by an underwater earthquake or volcanic eruption.

2.2.2.3 Flood Force Application

The evaluation of the NAC-MPC for a flood condition determines a maximum allowable flood water current velocity and a maximum allowable flood water depth. The criteria employed in the determination of the maximum allowable values are that cask sliding or tip-over will not occur, and that the canister (or overpack, if used) material yield strength is not exceeded. The evaluation of the effects of flood conditions on the NAC-MPC is presented in Section 11.2.6.

The force of the flood water current on the NAC-MPC is calculated as a function of the current velocity by multiplying the dynamic water pressure by the frontal area of the cask that is normal to the current direction. The dynamic water pressure is calculated using Bernoulli's equation relating fluid velocity and pressure. The force of the flood water current is limited such that the overturning moment on the cask will be less than that required to tip the cask over.

2.2.2.4 Flood Protection

The inherent strength of the reinforced concrete cask component of the NAC-MPC provides a substantial margin of safety against any permanent deformation of the cask for a credible flood event at an ISFSI site. Therefore, no special flood protection measures for the NAC-MPC are necessary. The evaluation presented in Section 11.2.6 shows that for the design basis flood, the allowable stresses in the canister (or overpack, if used) are not exceeded.

2.2.3 Seismic Design

The NAC-MPC may be exposed to a seismic event (earthquake) during storage on an unsheltered concrete pad at an ISFSI site. The seismic response spectra experienced by the cask will depend upon the geographical location of the specific site and the distance from the epicenter of the earthquake. The only significant effect of a seismic event on the NAC-MPC would be a possible tip-over; however, tip-over does not occur in the evaluated design basis earthquake. Seismic response of the NAC-MPC is presented in Section 11.2.2. The seismic evaluation of the canister overpack configuration is presented in Section 11.4.1.

2.2.3.1 Input Criteria

The magnitude of the maximum seismic accelerations to which the NAC-MPC may be subjected are site specific. 10 CFR 72.102 defines a 0.10 g horizontal ground motion design earthquake as the minimum allowable seismic design criteria, and 0.25 g is suggested for sites east of the Rocky Mountain front. The NAC-MPC is designed to 0.25 g horizontal and vertical seismic acceleration. This acceleration provides seismic qualification for a predominant number of nuclear facilities within the United States.

2.2.3.2 Seismic - System Analyses

The seismic ground acceleration that will cause the NAC-MPC to tip over is calculated in Section 11.2.2 using quasi-static analysis methods. Both horizontal and vertical acceleration components are considered in the analyses. These components are calculated and combined according to Section 3.7.1 of NUREG-0800. Evaluation of the consequences of a tip over event is provided in Section 11.2.12.

2.2.4 Snow and Ice Loadings

The criterion for determining design snow loads is based on ANSI/ASCE 7-93, Section 7.0. Flat roof snow loads apply and are calculated from the following formula:

$$p_f = 0.7 C_e C_t I p_g$$

Where:

p_f = flat roof snow load (psf)
C_e = Exposure factor = 1.0
C_t = Thermal factor = 1.2
I = Importance factor = 1.2
p_g = ground snow load, (psf) = 100

The numerical values of C_e, C_t, I and p_g are obtained from Tables 18, 19, 20 and Figure 7, respectively, of ANSI/ASCE 7-93.

The exposure factor accounts for wind effects. The NAC-MPC is assumed to have a site location typical for siting Category C, which is defined to be "locations in which snow removal by wind cannot be relied on to reduce roof loads because of terrain, higher structures, or several trees nearby."

The thermal factor accounts for the importance of buildings and structures in relation to public health and safety. The NAC-MPC is conservatively classified as Category III.

Ground snow loads for the contiguous United States are given in Figures 5, 6 and 7 of ANSI/ ASCE 7-93. A worst case value of 100 pounds per square foot was assumed.

Based on the above, the design criterion for snow and ice loads is:

$$\text{Flat Roof Snow Load, } p_f = (0.7)\,(1.0)\,(1.2)\,(1.2)\,(100)$$

$$= 100.8 \text{ psf}$$

This load is bounded by the weight of the loaded transfer cask. The snow load is considered in the load combinations described in Section 3.4.4.2.2.

2.2.5 Combined Load Criteria

Each normal, off-normal and accident condition has a combination of load cases that defines the total combined loading for that condition. The individual load cases considered include thermal, seismic, external and internal pressure, missile impacts, drops, snow and ice loads, and/or flood water forces.

The load conditions to be evaluated for storage casks are identified in 10 CFR 72 and in the "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)" (ANSI/ANS 57.9 - 1992).

2.2.5.1 Load Combinations and Design Strength - Concrete Cask

The load combinations specified in ANSI/ANS 57.9 - 1992 for concrete structures are applied to the concrete casks as shown in Table 2.2-2. The live loads are considered to vary from 0 percent to 100 percent to ensure that the worst-case condition is evaluated. In each case, use of 100 percent of the live load produces the maximum load condition. The steel liner of the concrete cask is a stay-in-place form and it provides radiation shielding. The concrete cask is designed to the requirements of ACI 349.

2.2.5.2 Design Strength Reduction Factors - Concrete

In calculating the design strength of the NAC-MPC concrete body, nominal strength values are multiplied by a strength reduction factor in accordance with Section 9.3 of ACI 349.

2.2.5.3 Load Combinations and Design Strength - Canister/Canister Overpack and Basket

The canister and the canister overpack are designed in accordance with the 1995 edition of the ASME Code, Section III, Subsection NB for Class 1 components. The basket structure is designed per ASME Code, Section III, Subsection NG, and structural buckling of the basket is evaluated per NUREG/CR-6322.

The load combinations for the canister and canister overpack for all normal, off-normal, and accident conditions and corresponding service levels are shown in Table 2.2-3. The overpack is not handled and is not used with the transfer cask. Levels A and D service limits are used for normal and accident conditions, respectively. Levels B and C service limits are used for off-normal conditions. The analysis methods allowed by the ASME Code are employed. Stress intensities caused by pressure, temperature, and mechanical loads are combined before comparing to ASME code allowables, which are listed in Table 2.2-4.

2.2.5.4 Design Strength - Transfer Cask

The transfer cask is a special lifting device and is designed and fabricated to the requirements of ANSI N14.6 and NUREG 0612 for the lifting trunnions and supports and ANSI 57.9 for the remainder of the structure. The criteria are:

The combined shear stress or maximum tensile stress during the lift (with 10 percent dynamic load factor) shall be $\leq S_y/6$ and $S_u/10$ for a nonredundant load path, or shall be $\leq S_y/3$ and $S_u/5$ for redundant load paths.

The ferritic steel material used for the load bearing members of the transfer cask shall satisfy the material toughness requirements of ANSI N14.6, paragraph 4.2.6.

2.2.6 Environmental Temperatures

The normal, long-term design temperature was selected to model the expected average ambient to bound most annual average temperatures seen by a cask over its lifetime. A temperature of 75°F was selected to bound all annual average temperatures in the United States except the Florida Keys and Hawaii.

The 75°F normal temperature was used as the base for thermal evaluations. The evaluation of this environmental condition is discussed along with the thermal analysis models in Chapter 4.0. The thermal stress evaluation for the normal operating conditions is provided in Section 3.4.4. Normal temperature fluctuations are bounded by the severe ambient temperature cases that are evaluated as off-normal and accident conditions.

Off-normal, severe environmental conditions were defined as -40°F with no solar loads and 100°F with solar loads. An extreme environmental condition of 125°F with maximum solar loads is evaluated as an accident case to show compliance with the maximum heat load case required by ANSI-57.9 (Section 11.2.10). Thermal performance was also evaluated assuming half-blockage of the air inlets and the complete blockage of the air inlets and outlets. Thermal analyses for these cases are presented in Sections 11.1.1 and 11.2.8. The evaluation based on ambient temperature conditions is presented in Section 4.4.

The design basis temperatures used in the NAC-MPC analysis are shown below. Solar insolance is as specified in 10 CFR 71.71 and Regulatory Guide 7.8.

Condition	Ambient Temperature	Solar Insolance
Normal	75°F	yes
Off-Normal - Severe Heat	100°F	yes
Off-Normal - Severe Cold	-40°F	no
Accident - Extreme Heat	125°F	yes

Table 2.2-1 Tornado and Wind Loading Criteria

Environmental Condition	Limit
Rotational Wind Speed, mph	290
Transitional Wind Speed, mph	70
Maximum Wind Speed, mph	360
Radius of Max. Wind Speed, ft.	150
Pressure Drop, psi	3.0
Rate of Pressure Drop, psi/sec	2.0

Table 2.2-2 Load Combinations for the NAC-MPC Vertical Concrete Cask

Load Combination	Condition	Dead	Live	Wind	Thermal	Seismic	Tornado/ Missile	Drop/ Impact	Flood
1	Normal	1.4D	1.7L						
2	Normal	1.05D	1.275L		$1.275T_o$				
3	Normal	1.05D	1.275L	1.275W	$1.275T_o$				
4	Off-Normal & Accident	D	L		T_a				
5	Accident	D	L		T_o	E_{ss}			
6	Accident	D	L		T_o			A	
7	Accident	D	L		T_o				F
8	Accident	D	L		T_o		W_t		

Load Combinations are from ANSI 57.9 and ACI 349.

D = Dead Load
L = Live Load
W = Wind
T_o = Normal Temperature
F = Flood
T_a = Off- Normal or Accident Temperature
E_{ss} = Design Basis Earthquake
W_t = Tornado/Tornado Missile
A = Drop/Impact

Table 2.2-3 Load Combinations for the Transportable Storage Canister and Canister Overpack

LOAD		NORMAL			OFF-NORMAL					ACCIDENT					
ASME Service Level		A			B		C			D					
Load Combinations		1	2	3	1	2	3	4	5	1	2	3	4	5	6
Dead Weight	Canister with fuel	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Thermal	In Storage Cask 75° F Ambient	X		X				X		X	X	X	X	X	
	In Transfer Cask[1] 75° F Ambient		X		X		X								X
	In Storage Cask -40°F or 100°F Ambient					X			X						
Internal Pressure	Normal	X	X	X				X		X	X	X	X		
	Off-Normal				X	X	X		X						
	Accident													X	X
Handling Load[1]	Normal		X	X	X										
	Off-Normal						X	X	X						
Drop/Impact	Accident									X					
Seismic	Accident										X				
Flood	Accident											X			
Tornado	Accident												X		

1. The canister overpack is not handled while loaded and is not used with the transfer cask.

Table 2.2-4 Structural Design Criteria for Components Used in the Transportable Storage Canister and Canister Overpack

	Component	Criteria
1.	Normal Operations: Service Level A Canister: ASME Section III, Subsection NB Overpack: ASME Section III, Subsection NB Basket: ASME Section III, Subsection NG	$P_m \leq S_m$ $P_L + P_b \leq 1.5\ S_m$ $P_L + P_b + Q \leq 3S_m$
	Canister Lifting Devices ANSI N14.6 and NUREG 0612	Redundant load path: combined shear or max. tensile stress $\leq S_u/5$ or $S_y/3$
2.	Off-Normal Operations: Service Level B Canister: ASME Section III, Subsection NB Overpack: ASME Section III, Subsection NB	$P_m < 1.1\ S_m$ $P_L + P_b < 1.65\ S_m$
3.	Off-Normal Operations: Service Level C Canister: ASME Section III, Subsection NB Overpack: ASME Section III, Subsection NB Basket: ASME Section III, Subsection NG	Subsection NB Allowables: $P_m < 1.2\ S_m$ or S_y (whichever is greater) $P_L + P_b < 1.8\ S_m$ or $1.5\ S_y$ (whichever is less) Note: Level C allowables for Subsection NG are larger than those for Level C per Subsection NB. Therefore, it is conservative to employ Subsection NB allowables for the basket.
4.	Accident Conditions, Service Level D Canister: ASME Section III, Subsection NB Overpack: ASME Section III, Subsection NB Basket: ASME Section III, Subsection NG	$P_m \leq 2.4\ S_m$ or $0.7\ S_u$ (whichever is less) $P_L + P_b \leq 3.6\ S_m$ or $1.05\ S_u$ (whichever is less)
5.	Basket Structural Buckling	NUREG/CR-6322

2.3 Safety Protection Systems

The NAC-MPC relies upon passive systems to ensure the protection of public health and safety, except in the case of fire or explosion. As discussed in Section 2.3.6, fire and explosion events are effectively precluded by site administrative controls that prevent the introduction of flammable and explosive materials. The use of passive systems provides protection from mechanical or equipment failure.

2.3.1 General

The NAC-MPC is designed for safe, long-term storage of spent nuclear fuel. The NAC-MPC will survive all of the evaluated normal, off-normal, and postulated accident conditions without release of radioactive material or excessive radiation exposure to workers or the general public. The major design considerations that have been incorporated in the NAC-MPC system to assure safe long-term fuel storage are:

1. Continued confinement in postulated accidents.
2. Thick concrete and steel biological shield.
3. Passive systems that ensure reliability.
4. Inert atmosphere to provide corrosion protection for stored fuel cladding.

Each NAC-MPC system storage component is classified with respect to its function and corresponding effect on public safety. In accordance with Regulatory Guide 7.10, each system component is assigned safety classification into Category A, B or C, as shown in Table 2.3-1. The safety classification is based on review of each component's function and the assessment of the consequences of component failure following the guidelines of NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety."

Category A - Components critical to safe operations whose failure or malfunction could directly result in conditions adverse to safe operations, integrity of spent fuel or public health and safety.

Category B - Components with major impact on safe operations whose failure or malfunction could indirectly result in conditions adverse to safe operations, integrity of spent fuel or public health and safety.

Category C - Components whose failure would not significantly reduce the packaging effectiveness and would not likely result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.

As discussed in the following sections, the NAC-MPC design incorporates features addressing the above design considerations to assure safe operation during fuel loading, handling, and storage.

2.3.2 Protection by Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

The radioactivity that the NAC-MPC must confine originates from the spent fuel assemblies to be stored, and residual contamination that may remain inside the canister as a result of contact with the water in the fuel pool where the canister loading is conducted.

The NAC-MPC is designed to confine the radioactive fuel. The canister is closed by welding. The shield lid weld is pressure tested. All of the field-installed welds are liquid penetrant examined following the root and final weld passes. The shield lid weld is leak tested to 1.0×10^{-5} cubic centimeters per second (helium). The closure of the canister structural lid, which provides a redundant closure over the shield lid and port covers, is accomplished by multi-pass welding that is tested by liquid penetrant examination on the root and final pass. The longitudinal and girth welds and bottom welds of the canister shell are full penetration welds that are radiographed or ultrasonically inspected during fabrication.

The canister (and overpack, if used) welds are an impenetrable boundary to the release of fission gas products during the period of storage. There are no evaluated normal, off-normal, or accident conditions that result in the breach of the canister and the subsequent release of fission products. The canister is designed to withstand a postulated drop accident in a transportation

cask without precluding the subsequent removal of the fuel (i.e., the fuel tubes do not deform such that they bind the fuel).

Personnel radiation exposure during handling and closure of the canister is minimized by the following steps:

1. Placing the shield lid on the canister while the transfer cask and canister are under water in the fuel pool.
2. Decontaminating the exterior of the transfer cask prior to draining the canister to preserve the shielding benefit of the water.
3. Using temporary shielding.
4. Using a retaining ring on the transfer cask to ensure that the canister is not raised out of the shield provided by the transfer cask.
5. Placing a shielding ring over the annular gap between the transfer cask and the canister.

2.3.3 Protection by Equipment and Instrumentation Selection

The NAC-MPC is a passive storage system that does not rely on equipment or instruments to preserve public health or safety and to meet its safety functions in long-term storage. The system employs support equipment and instrumentation to facilitate operations. These items and the actions taken to assure performance are described below.

2.3.3.1 Equipment

The only important-to-safety equipment employed in the use and operation of the NAC-MPC is the lifting yoke used to lift the transfer cask. The transfer cask lifting yoke is designed to meet the requirements of ANSI N14.6 and NUREG-0612. It is single failure-proof by design. The lifting yoke is proof load tested to 300 percent of design load when fabricated. The lifting yoke is inspected for visible defects prior to each use and is inspected annually.

Additional handling equipment (such as trailers, skids, air pads, portable cranes, or cask transporters) are not important to safety as the NAC-MPC system is designed to withstand the failure of any of these components.

2.3.3.2 Instrumentation

A remote temperature measuring system is employed to measure the outlet air temperature of the NAC-MPC in long-term storage. The outlet temperature is recorded daily as a check of the thermal performance of the heat rejection capability of the storage cask. The outlet temperature is expected to increase in the unlikely event that one or more inlet or outlet ventilation ports become blocked.

The inlet and outlet ports are visually inspected each day during the same walk-through in which the temperatures are recorded. This visual inspection assists in ensuring that the temperature measuring system is continuing to perform as expected.

The canister (and canister overpack, if used) shield lid weld is helium leak tested during closure. The leak detector is checked against a known helium source immediately prior to, and after, use to preclude unknown leak detector failure.

2.3.4 Nuclear Criticality Safety

The primary nuclear criticality safety design criterion of the NAC-MPC is to provide features that ensure that the cask remains subcritical under normal, off-normal, and accident conditions. Neutron poison sheets (BORAL) are employed in the basket design to capture thermalized neutrons, and preclude uncontrolled fission events. BORAL sheets are attached to each side of each fuel tube. These sheets are mechanically supported by the fuel tube structure to ensure that the poison sheets remain in place during the design basis normal, off-normal, and accident events.

The efficiency of the BORAL sheets in preserving nuclear criticality safety is demonstrated by the Criticality Evaluation presented in Chapter 6.

2.3.4.1 Error Contingency Criterion

The design of the canister and fuel basket is such that, under all conditions, the highest neutron multiplication factor (k_{eff}) will be less than 0.95. The criticality evaluation for the design basis fuel is presented in Section 6.4. Assumptions made in the analyses used to demonstrate conformance to this criterion include:

1. Most reactive Yankee Class fuel assembly type with maximum U^{235} loading;
2. 75 percent of the nominal B^{10} loading in the BORAL;
3. Infinite array of casks in the X-Y (horizontal) plane;
4. Infinite fuel length with no inclusion of end leakage effects;
5. No structural material present in the assembly;
6. No credit taken for boron in the cask cavity or surrounding loading or storage area; and
7. No credit taken for fuel burnup or for the buildup of fission product neutron poisons.

These assumptions demonstrate adequate controls to assure subcriticality in the use of the NAC-MPC system.

2.3.5 Radiological Protection

The NAC-MPC system, in keeping with the As Low As Reasonably Achievable (ALARA) philosophy, is designed to minimize, to the extent practicable, operator radiological exposure.

2.3.5.1 Access Control

Access to an NAC-MPC ISFSI site is controlled by a peripheral fence to meet the requirements of 10 CFR 72 and 10 CFR 20. Access to the storage area, and its designation as to the level of radiation protection required, is established by site procedure. The storage area will be surrounded by a fence, having lockable truck and personnel access gates. The fence will have intrusion-detection features as determined by the site procedure.

2.3.5.2 Shielding

The NAC-MPC is designed to provide an external side surface dose (gamma and neutron) of less than 50 mrem/hr (average) on the storage cask sides, 35 mrem/hr (average) top, and 100 mrem/hr at the air vent inlets. The transfer cask side wall contact dose rate limit is 200 mrem/hr (average). The design maximum dose rate at the top of the canister structural lid, with supplemental shielding, is 200 mrem/hr (average) to limit personnel exposure during canister closure operations.

Sections 72.104 and 72.106 of 10 CFR 72 set whole body dose limits for an individual located beyond the controlled area at 25 millirems per year (whole body) during normal operations and 5 rems (5,000 millirems) from any design basis accident. The analyses showing the actual NAC-MPC doses are included in Sections 5.0 and 11.0.

2.3.5.3 Ventilation Off-Gas

The NAC-MPC is passively cooled by radiant and natural convection heat transfer at the outer surface of the canister and natural convective heat transfer in the canister-concrete cask annulus. The bottom of the cask is conservatively assumed to be an adiabatic surface. The design criterion for the air-flow in the annulus is that the pressure difference due to the buoyancy effect created by the heating of the air is equal to the flow pressure drop. The details of the passive ventilation system design are provided in Section 4.0.

There are no radioactive releases during normal operations. Also, there are no credible accidents that cause significant releases of radioactivity from the NAC-MPC and, hence, there are no off-gas system requirements for the NAC-MPC during normal storage operation. The only time an off-gas system is required is during the canister drying phase. During this operation, the reactor off-gas system or a HEPA filter system will be used.

The surface of the canister is exposed to cooling air when the canister is placed in the storage cask. If the surface is contaminated, the possibility exists that contamination could be carried aloft by the cooling air stream. To ensure that the canister surface is free of contamination, pool water is prevented from contacting the canister exterior by filling the transfer cask/canister annular gap with clean water as the transfer cask is being lowered into the fuel pool.

Clean water is injected into the gap during the entire time the transfer cask is submerged. These steps preclude the intrusion of contaminated water into the canister annular gap.

Once the transfer cask is removed from the pool, a smear survey is taken of the exterior surface of the canister near the top. While no contamination is expected to be found, it is possible that the surface could be contaminated. The allowable upper limit on surface contamination is calculated in Section 12.2.1.4. If this limit is exceeded, then steps to decontaminate the canister surface must be taken and continued until the contamination is less than the allowable limit.

To facilitate decontamination, the canister is fabricated so that its exterior surface is smooth. There are no corners or pockets that could trap and hold contamination.

2.3.5.4 Radiological Alarm Systems

There are no radiological alarms required on the NAC-MPC. Justification for this is provided in analysis in Sections 5.0 (Shielding), 10.0 (Radiological Protection), and 11.0 (Accident Analysis).

Typically, total radiation exposure due to the ISFSI installation is determined by the use of Thermo-Luminescent Detectors (TLDs) mounted at convenient locations on the ISFSI fence. The TLDs are read quarterly to provide a record of boundary dose.

2.3.6 Fire and Explosion Protection

Fire and explosion protection of the NAC-MPC is primarily provided by administrative controls applied at the site, which preclude the introduction of any explosive and any excessive flammable materials into the ISFSI area.

2.3.6.1 Fire Protection

A major ISFSI fire is not considered credible, since there is very little material near the casks that could contribute to a fire. The concrete cask is largely impervious to incidental thermal events. Administrative controls will be put in place to ensure that the presence of combustibles is minimized. A hypothetical fire event is evaluated as an accident condition in Section 11.2.5.

The fire event evaluated is that defined by 10 CFR 71.73c(3), a 1475°F fire of 30 minutes duration, with an assumed emissivity coefficient of 0.9. This condition is considered to be highly conservative.

2.3.6.2 Explosion Protection

The cask and associated systems are analyzed to ensure their proper function under an overpressure condition. As described in Section 11.2.3, in the evaluated 22 psig over pressure condition, stresses in the canister remain below allowable limits and there is no loss of confinement. These results are conservative as the canister is protected from direct over-pressure conditions by the concrete storage cask.

For the same reasons as for the fire condition, a severe explosion on an ISFSI site is not considered credible. The evaluated over-pressure is considered to bound any explosive over pressure resulting from an industrial explosion at the boundary of the owner-controlled area.

Table 2.3-1 Safety Classification of NAC-MPC Components

Drawing Number	Sh	Title	Rev	Item No.	Component	Function	Safety Class
455-861	1	Weldment, Structure	2	26	Baffle	Heat Transfer	B
				-	Outlet (4)	Heat Transfer	B
				20	Shield Plate	Shielding	B
				17	Nelson Stud	Structural	C
				16	Base Plate	Structural	B
				15	Stand	Structural	B
				-	Inlet (4)	Heat Transfer	B
				12	Bottom	Structural	B
				11	Shield Ring	Shielding	B
				10	Cover	Operations	B
				-	Jack (Leveling)	Operations	C
				3	Support Ring	Structural	B
				2	Top Flange	Structural	B
				1	Shell	Structural	B
455-862	1	Loaded Vertical Concrete Cask	1	9	Cover	Operations	B
				8	Insulation	Operations	B
				7	Washer (Lid Bolt)	Operations	C
				6	Lid Bolt	Operations	B
				5	Lid	Operations	B
				4	Shield Plug	Shielding	B
455-866	1	Reinforcing Bar and Concrete Placement	0	18	Name Plate	Operations	C
				17	Outlet Screen	Operations	C
				16	Inlet Screen	Operations	C
				15	Concrete	Shielding/ Structural	B
				13	Liner Weldment	Shielding/ Structural	B

Table 2.3-1 Safety Classification of NAC-MPC Components (continued)

Drawing Number	Sh	Title	Rev	Item No.	Component	Function	Safety Class
455-866 (continued)	1	Reinforcing Bar and Concrete Placement	0	-	Reinforcing Bar	Structural	B
455-870	1	Canister, Shell	3	3	Location Nut	Operations	B
				2	Bottom	Structural/ Confinement	A
				1	Shell	Structural/ Confinement	A
455-871	1	Details, Canister	2	8	Key	Operations	C
				7	Port Cover (Two)	Confinement/ Operations	B
				6	Valved Nipple (Two)	Operations	C
				5	Structural Lid	Structural	A
				3	Shield Lid	Shielding	B
				2	Backing Ring	Structural	C
				1	Lid Support Ring	Structural	B
455-872	1	Assembly, Transportable Storage Canister	4	3	Drain Tube Assembly	Operations	C
455-881	1	PWR Fuel Tube	1	4	Flange	Structural	A
				3	Cladding	Criticality Control	A
				2	BORAL	Criticality Control	A
				1	Tubing	Structural/ Criticality	A
455-887		Drawing Deleted					
455-888		Drawing Deleted					
455-891	1	Bottom Weldment, Fuel Basket	0	-	Support	Structural	B
				2	Circular Pad	Structural	C
				1	Plate	Structural	A

Table 2.3-1 Safety Classification of NAC-MPC Components (continued)

Drawing Number	Sh	Title	Rev	Item No.	Component	Function	Safety Class
455-892	1	Top Weldment, Fuel Basket	1	4	Baffle	Structural	A
				3	Support	Structural	A
				2	Support Ring	Structural	B
				1	Plate	Structural	A
455-893	1	Support Disk and Misc. Basket Details	3	7	Top Spacer	Structural	B
				6	Split Spacer	Structural	B
				5	Tie Rod	Structural	A
				4	Top Nut	Structural	A
				3	Bottom Spacer	Structural	B
				2	Spacer	Structural	A
				1	Plate	Structural	A
455-894	1	Heat Transfer Disk	1	1	Heat Transfer Disk	Heat Transfer	A
455-895	1	Fuel Basket Assembly	2	13	Flat Washer	Structural	B
				4	Drain Tube Sleeve	Operations	C
455-857	1	Assembly Canister Overpack	1	5	Seal	Operations	C
				6	Nipple	Operations	C
455-858	1	Canister Overpack Shell	2	1	Shell	Structural/Confinement	C
				2	Bottom	Structural/Confinement	B
				3	Inner Lid	Structural/Confinement	C
				4	Support Ring	Structural	B
				5	Port Cover	Confinement/Operations	B
				6	Lug	Operations	C
				7	Outer Lid	Structural/Confinement	A
				8	Backing Ring	Structural	C

Table 2.3-1 Safety Classification of NAC-MPC Components (continued)

Drawing Number	Sh	Title	Rev	Item No.	Component	Function	Safety Class
YR-00-060	1	Yankee – Class Reconfigured Fuel Assembly	1	1	Shell Weldment	Structural	A
				2	Top End Fitting Assembly	Structural/ Criticality	A
				3	Bottom End Fitting Assembly	Structural/ Criticality	A
				4	Basket Assembly	Structural/ Criticality	A
				5	Top Nozzle Bolts	Structural/ Criticality	A
				6	Alignment Pin	Operations	C

2.4 Decommissioning Considerations

The principal elements of the NAC-MPC storage system are the vertical concrete cask (storage cask) and the transportable storage canister (canister).

The storage cask provides biological shielding and physical protection for the contents of the canister during long-term storage. The storage cask is not expected to become surface contaminated during use, except through incidental contact with other contaminated surfaces. Incidental contact could occur at the interior surface (liner) of the storage cask, the top surface that supports the transfer cask during loading and unloading operations, and the floor of the storage cask that supports the canister. All of these surfaces are carbon steel, and it is anticipated that these surfaces could be decontaminated as necessary for decommissioning. A layer of insulation and stainless steel is placed on the floor of the storage cask in order to separate the stainless steel canister bottom from the carbon steel storage cask bottom plate. The insulation rests on the storage cask carbon steel pedestal. The insulation is covered by a sheet of stainless steel. Contamination of these surfaces is expected to be minimal since the canister is isolated from spent fuel pool water during loading in the pool, and the transfer cask is decontaminated prior to transfer of the canister to the storage cask. In the unlikely event that the insulation became contaminated, it is not reasonable to expect that it could be decontaminated. Consequently, the insulation would have to be disposed of as surface-contaminated material.

The concrete that provides biological shielding is not expected to become contaminated during the period of use, as it does not come into contact with other contaminated objects or surfaces.

Activation of the carbon steel liner, support plates, and reinforcing bar could occur due to neutron flux from the stored fuel. Since the neutron flux rate is low, only minimal activation of carbon steel in the storage cask is expected to occur.

Decommissioning of the storage cask would involve the removal of the canister, and the subsequent disassembly of the storage cask. It is expected that the concrete would be broken up, and steel components segmented, to reduce volume. Any contaminated or activated items are expected to qualify for near-surface disposal as low specific activity material.

The transportable storage canister is designed and fabricated to be suitable for use as a waste package for permanent disposal in a deep Mined Geological Disposal System, in that it meets the requirements of the DOE MPC Design Procurement Specification. The canister is fabricated from materials having high long-term corrosion resistance, and the canister contains no paints or coatings that could adversely affect the permanent disposal of the canister. Consequently, decommissioning of the canister would occur only if the fuel contained in the canister had to be removed, or if current requirements for disposal were to change. Decommissioning would require that the closure welds at the canister structural lid, shield lid and shield lid port covers be cut, so that the spent fuel [redacted] could be removed. Removal of the contents of the canister would require that the canister be returned to a spent fuel pool or dry unloading facility, such as a hot cell. Closure welds can be cut either manually or with automated equipment, with the procedure being essentially the reverse of that used to initially close the canister.

Following removal of the contents, the canister could have significant internal contamination due to the contents, and may contain "crud" or other residual material in the bottom of the canister. Some effort may be required to remove the surface contamination prior to disposal; however, in practice, it would not be absolutely necessary to decontaminate the canister internals. Any contaminated canister and internal components are expected to qualify for near-surface disposal as low specific activity waste without internal contamination, as the internal contamination would consist only of by-product materials. Should internal decontamination be necessary, the canister and basket surfaces are smooth, and the design precludes the presence of crud traps, thus facilitating any required decontamination. Since the neutron flux rate from the stored fuel is low, only minimal activation of the canister is expected to occur.

The unloaded canister could also qualify as a strong, tight container for other waste. In this case, the canister could be filled, within weight limits, with other qualified waste, closed and transported whole and complete to a near-surface disposal site. Use of the canister for this purpose could reduce decommissioning costs by avoiding decontamination, segmenting and repackaging.

The storage pad, fence and supporting utility fixtures are not expected to require decontamination as a result of use of the NAC-MPC system. The design of the cask and canister precludes the release of contamination from the contents over the period of use of the system. Consequently, these items may be reused or disposed of as locally generated clean waste.

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3.0 STRUCTURAL EVALUATION

This section describes the design and analyses of the principal structural components of the NAC-MPC System under normal operating conditions. It demonstrates that the NAC-MPC System meets the requirements to assure confinement of contents, criticality control, radiological shielding, and contents retrievability as required by 10CFR72 for the design basis operating conditions. Off-normal and accident conditions are evaluated in Chapter 11.

3.1 Structural Design

3.1.1 Discussion

The NAC-MPC System consists of three major components: 1) the vertical concrete cask (storage cask); 2) the transportable storage canister (canister); and 3) the transfer cask. These components are shown in Figure 3.1-1. The principal structural member of the vertical concrete cask is the reinforced concrete shell. The principal structural members of the canister are the shell, structural lid, bottom plate, the welds joining these components, and the basket assembly. The primary structural components of the transfer cask are its trunnions, inner and outer steel walls and the bottom doors and their support rails. All of the components are shown on the license drawings provided in Section 1.5.

The concrete cask is a reinforced concrete cylinder with an outside diameter of 128 inches and an overall height of 160 inches. The internal cavity of the concrete cask is formed by a 3.5-inch thick cylindrical carbon steel liner having an inside diameter of 79 inches. The liner is a stay-in-place form. Its thickness is primarily determined by shielding requirements, but is related to the need to establish a practical limit to the diameter of the concrete shell. The concrete is Type II Portland Cement, having a nominal density of 140 lb./ft^3, and a nominal compressive strength of 4000 psi. The inner and outer reinforcing bar assemblies are formed by vertical hook bars and horizontal hoop bars. The air flow path is formed by channels at the bottom that provide the entrance for cooling air, the air inlet ducts that admit the air to the storage cask interior cavity (i.e., the annular gap between the canister outer surface and the concrete cask liner interior surface, and the air outlet ducts.) A 5-inch thick carbon steel shield plug, that encloses a 1-inch thick layer of NS-4-FR neutron shield material, is installed in the concrete cask cavity above the canister. The plug is supported by a support ring welded to the liner. A 1.5-inch thick carbon steel lid provides a cover to protect the canister from adverse environmental conditions and

postulated tornado driven missiles. The shield plug and lid provide shielding to reduce the skyshine radiation. The lid is bolted in place.

The canister consists of a cylindrical shell assembly closed at its top end by an inner shield lid and an outer structural lid. The canister contains a basket assembly that holds the spent fuel. The canister shell is 122.5 inches long and is fabricated from 304L stainless steel plate. The canister shield lid is 5-inch thick Type 304 stainless steel, and the structural lid is 3.0-inch thick Type 304L stainless steel. Both lids are welded to the canister shell to close the canister. The shield lid is supported from below, prior to welding, by a support ring. The structural lid is supported, prior to welding, by the shield lid. The bottom of the canister is a 1-inch thick, Type 304L stainless steel plate that is welded to the canister shell.

The basket assembly is designed to hold up to 36 Yankee Class fuel assemblies. It incorporates 22 Type 17-4 PH stainless steel support disks and 14 Type 6061-T6 aluminum alloy heat transfer disks. The remaining components of the basket assembly are Type 304 stainless steel. These disks, together with the top and bottom weldments, are positioned by tie rods (with spacers and washers) that extend the length of the basket and clamp the components together. The support disks provide heat removal and support the fuel tubes that pass through the disks. The heat transfer disks provide the heat removal capability but are not considered to be structural components. The fuel tubes have an inside square dimension of 7.8 inches and a composite wall thickness of 0.14 inches. All walls of each fuel tube contains a sheet of BORAL neutron poison material. No structural credit is taken for the BORAL sheet.

A transportable storage canister containing spent fuel may also contain one or more Reconfigured Fuel Assemblies. The Reconfigured Fuel Assembly is designed to contain Yankee Class spent fuel rods, or portions thereof, which are classified as failed, and to maintain the geometric positions of the rods. The assembly has a capacity of 64 full length spent fuel rods in an eight by eight array of tubes. As shown in Figure 1.2-5, the reconfigured fuel assembly consists of a shell (square tube with end fittings), a basket assembly, and 64 fuel tubes. All of the materials are stainless steel.

The Yankee Class Reconfigured Fuel Assembly is designed to contain failed fuel rods, in fuel tubes, during all storage and transport conditions. The Reconfigured Fuel Assembly is designed to the requirements of ASME Boiler and Pressure Vessel Code, Section III, Article NG-3000 and

NUREG/CR-6322, "Buckling Analysis of Spent Fuel Baskets" and using the additional guidance contained in ASME Section III, Article NF-3000 and in ASME Section III, Appendix F. The structural evaluation of the Reconfigured Fuel Assembly is presented in Section 11.5.

The external dimensions of the Reconfigured Fuel Assembly are the same as those of other Yankee Class fuel assemblies. The weight of a loaded reconfigured fuel assembly (approximately 550 pounds) is less than the weight of other Yankee Class fuel assemblies (approximately 850 pounds). The maximum temperature of the Reconfigured Fuel Assembly components are determined by the thermal analyses presented in Section 4.4.

The Reconfigured Fuel Assembly has been evaluated and is capable of withstanding, within code allowable limits (Service Level A/B), a postulated end impact resulting in a deceleration of 20 g. It is also, when located in a fuel slot in the transportable storage container, capable of withstanding, within code allowable limits (Service Level A/B), a postulated side impact resulting in a deceleration of 20 g. This analysis bounds the design conditions of the Reconfigured Fuel Assembly for normal conditions of storage.

The Reconfigured Fuel Assembly has also been evaluated for accident conditions and is capable of withstanding, within code allowable limits (Service Level D), a postulated end impact resulting in a deceleration of 57 g. It is also, when located in a fuel slot in the transportable storage container, capable of withstanding, within code allowable limits (Service Level D), a postulated side impact resulting in a deceleration of 55 g. This analysis bounds the design conditions of the Reconfigured Fuel Assembly for accident conditions of storage.

Therefore, the structural evaluations of the NAC-MPC System containing other Yankee Class fuel assemblies (Chapters 3.0 and 11.0) bound those of the NAC-MPC System containing one or more Yankee Class Reconfigured Fuel Assemblies.

The following components are evaluated in this chapter:

- Canister lifting devices
- Canister shell, bottom, and structural lid
- Canister shield lid support ring
- Basket assembly
- Transfer cask trunnions, shells, retaining ring, bottom doors, and support rails
- Vertical concrete cask body
- Concrete cask steel components (reinforcement, liner, lid, bottom plate, bottom, etc.)

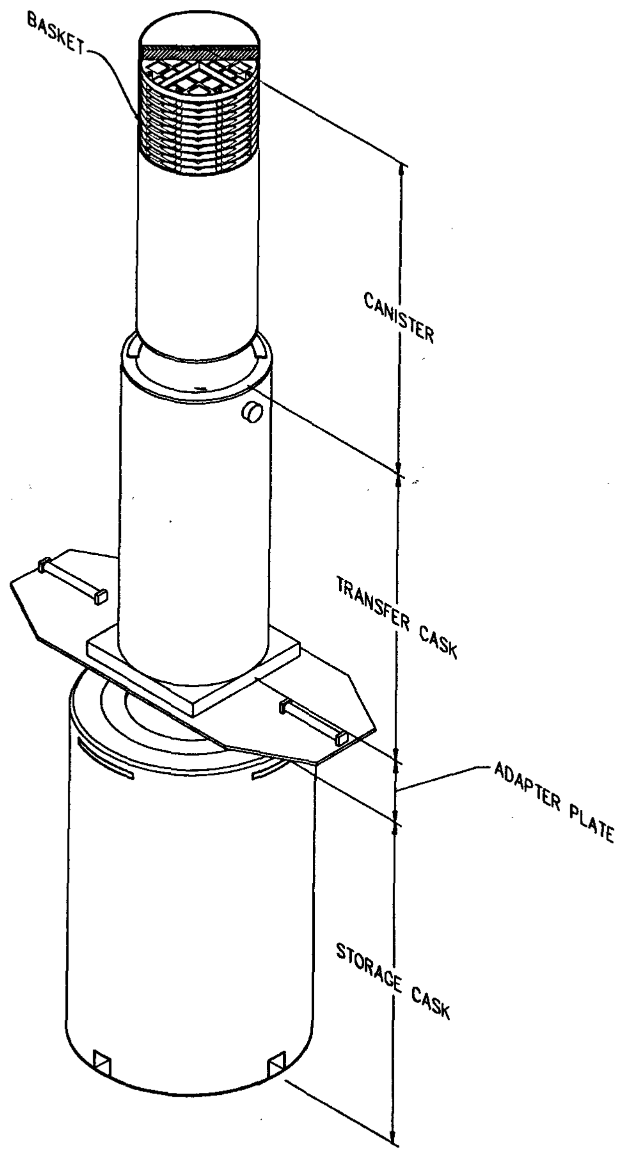
All other NAC-MPC system components shown on the drawings presented in Section 1.5 are either nonstructural or not classified as important to safety. They are appropriately included as loads in the evaluation of the components listed above.

The structural evaluations demonstrate that all of the NAC-MPC components meet their structural design criteria and are capable of safely storing the design basis spent fuel [redacted].

3.1.2 Design Criteria

The NAC-MPC structural design criteria are specified in Section 2.2. The load combinations of normal, off-normal, and accident loadings have been evaluated in accordance with ANSI 57.9 and ACI-349 for the concrete cask (see Table 2.2-[redacted]), and in accordance with the 1995 edition of the ASME Code, Section III, Division I, Subsection NB for Class 1 components for the canister (see Table 2.2-4). The basket is evaluated in accordance with ASME Code, Section III, Subsection NG, and NUREG-6322. The transfer cask and the lifting yoke are lifting devices that are designed to NUREG-0612 and ANSI N14.6.

Figure 3.1-1 Principal Components of the NAC-MPC System



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3.2 Weights and Centers of Gravity

The component weights and centers of gravity for the NAC-MPC system are summarized in Table 3.2-1.

Table 3.2-1 NAC-MPC System Weights and Centers of Gravity

Item Description	Calculated Weight (lbs.)	Center of Gravity (inches above bottom of item)
Concrete Cask Lid	2,838	160.7
Concrete Cask Shield Plug	5,490	153.3
Canister Structural Lid	3,230	121.0
Canister Shield Lid	5,390	116.8
Transfer Adapter Plate	12,659	N/A
Canister (empty, without lid)	15,510	49.7
Canister (loaded with fuel with water and shield lid)	62,270	61.2
Canister (loaded with fuel with lid)	54,730	65.0
Concrete Cask (empty, with shield plug, and without lid)	148,526	80.5
Concrete Cask and Canister (loaded with fuel with lids)	206,094	83.2
Transfer Cask (empty)	80,743	57.0
Transfer Cask and Canister (empty, without lids)	96,253	58.0
Transfer Cask and Canister (loaded with fuel, with water and shield lid)	143,013	63
Transfer Cask and Canister (loaded with fuel, dry with lids)	135,473	64.1
Water in Canister (36 assemblies)	10,618	N/A
Fuel	30,600	55.7
Canister Overpack (empty, with lids)	11,726	89.1
Concrete Cask Lid (for Canister Overpack)	3,521	160.4
Concrete Cask, Canister and Canister Overpack (loaded with fuel, with lids)	213,012	84.1

3.3 Mechanical Properties of Materials

The mechanical properties of steels used in the fabrication of the NAC-MPC components are presented in Tables 3.3-1 through 3.3-8. The primary steels are Type 304 and Type 304L stainless steel, selected because of their high strength, ductility, resistance to corrosion and brittle fracture, and metallurgical stability for long-term storage. The mechanical properties for the 6061-T6 aluminum heat transfer disks in the fuel basket are provided in Table 3.3-9. The mechanical properties of the concrete are presented in Table 3.3-10. The mechanical properties of the neutron shield material, NS-4-FR, are presented in Table 3.3-11.

Table 3.3-1 Mechanical Properties of SA 240, A 479 Type 304 Stainless Steel

	Temperature (°F)							
Property (units)	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	75.0	75.0	75.0	71.0	66.0	64.4	63.5	63.1
Yield Strength[2] (ksi)	30.0	30.0	30.0	25.0	22.5	20.7	19.4	17.3
Design Stress Intensity[3] (ksi)	20.0	20.0	20.0	20.0	20.0	18.7	17.5	15.6
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.275							
Density[8] (lbm/in^3)	0.288							

1 ASME Code, Section II, Part D, Table U.
2 ASME Code, Section II, Part D, Table Y-1.
3 ASME Code, Section II, Part D, Table 2A.
4 ASME Code, Section II, Part D, Table TM-1.
5 ASME Code, Section III, Appendix I, Table I-9.1.
6 ASME Code, Section II, Part D, Table TE-1.
7 Hanford, Volume 1, Design Data, Property Code 2110.
8 Hanford, Volume 1, Design Data, Property Code 3304.

Table 3.3-2 Mechanical Properties of SA 336, Type 304 Stainless Steel

	Temperature (°F)							
Property (units)	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	70.0	70.0	70.0	66.2	61.5	60.0	59.3	58.9
Yield Strength[2] (ksi)	30.0	30.0	30.0	25.0	22.5	20.7	19.4	17.3
Design Stress Intensity[3] (ksi)	20.0	20.0	20.0	20.0	20.0	18.7	17.5	15.6
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.275							
Density[8] (lbm/in^3)	0.288							

1 ASME Code, Section II, Part D, Table U.
2 ASME Code, Section II, Part D, Table Y-1.
3 ASME Code, Section II, Part D, Table 2A.
4 ASME Code, Section II, Part D, Table TM-1.
5 ASME Code, Section III, Appendix I, Table I-9.1.
6 ASME Code, Section II, Part D, Table TE-1.
7 Hanford, Volume 1, Design Data, Property Code 2110.
8 Hanford, Volume 1, Design Data, Property Code 3304.

Table 3.3-3 Mechanical Properties of SA 240, Type 304L Stainless Steel

	Temperature (°F)							
Property (units)	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	70.0	70.0	70.0	66.2	60.9	58.5	57.8	55.9
Yield Strength[2] (ksi)	25.0	25.0	25.0	21.4	19.2	17.5	16.4	14.7
Design Stress Intensity[3] (ksi)	16.7	16.7	16.7	16.7	16.7	15.8	14.8	13.3
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.275							
Density[8] (lbm/in^3)	0.288							

1 ASME Code, Section II, Part D, Table U.
2 ASME Code, Section II, Part D, Table Y-1.
3 ASME Code, Section II, Part D, Table 2A.
4 ASME Code, Section II, Part D, Table TM-1.
5 ASME Code, Section III, Appendix I, Table I-9.1.
6 ASME Code, Section II, Part D, Table TE-1.
7 Hanford, Volume 1, Design Data, Property Code 2110.
8 Hanford, Volume 1, Design Data, Property Code 3304.

Table 3.3-4 Mechanical Properties of SA 705, SA 693 and SA 564, Type 630, H1150, 17-4 PH Stainless Steel

	Temperature (°F)							
Property (units)/	-40	-20	+70	+200	+300	+400	+500	+650
Ultimate Strength[1,2] (ksi)	135.0	135.0	135.0	135.0	135.0	131.4	128.5	125.7[2]
Yield Strength[3] (ksi)	105.0	105.0	105.0	97.1	93.0	89.5	87.0	83.6
Design Stress Intensity[4] (ksi)	45.0	45.0	45.0	45.0	45.0	43.8	42.8	41.9
Modulus of Elasticity[5] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[6] @ 10 cycles (ksi)	401.8	401.8	396.2	386.4	378.0	371.0	361.2	341.6
Alternating Stress[6] @ 10^6 cycles (ksi)	19.1	19.1	18.9	18.4	18.0	17.7	17.2	16.3
Coefficient of Thermal Expansion[7] (in/in/°F)	5.88E-6	5.88E-6	5.89E-6	5.90E-6	5.90E-6	5.91E-6	5.91E-6	5.93E-6
Poisson's Ratio[8]	0.291							
Density[9] (lbm/in³)	0.284							

1 ASME Code, Section II, Part D, Table U.
2 Tabulated value is calculated by ratioing from the Design Stress Intensity.
3 ASME Code, Section II, Part D, Table Y-1.
4 ASME Code, Section II, Part D, Table 2A.
5 ASME Code, Section II, Part D, Table TM-1.
6 ASME Code, Section III, Appendix I, Table I-9.1.
7 ASME Code, Section II, Part D, Table TE-1.
8 ARMCO, Table 7.
9 ARMCO, Table 16.

Table 3.3-5 Mechanical Properties of A36 Carbon Steel

	Temperature (°F)							
Property (units)	100	200	300	400	500	600	650	700
S_u (ksi)[1]	58.0	58.0	58.0	58.0	–	–	–	–
S_y (ksi)[1]	36.0	32.8	31.9	30.8	29.1	26.6	26.1	25.9
S_m (ksi)[2]	19.3	19.3	19.3	19.3	19.3	17.7	17.4	17.3
Modulus of Elasticity[3] (ksi)	29.0E+3	28.8E+3	28.3E+3	27.7E+3	27.3E+3	26.7E+3	26.1E+3	25.5E+3
α (in/in/ °F)[4]	5.53E-6	5.89E-6	6.26E-6	6.61E-6	6.91E-6	7.17E-6	7.30E-6	7.41E-6
Poisson's Ratio[5]	0.31							
Density[6] (lbm/in³)	0.284							

1 Cases of ASME Boiler and Pressure Vessel Code, Case N-71-16, Table 1, 2, 3, 4, 5.
2 ASME Code, Section II, Part D, Table 2A.
3 ASME Code, Section II, Part D, Table TM-1.
4 ASME Code, Section II, Part D, Group C in Table TE-1.
5 ASME Code, Section II, Part D, Table NF-1.
6 Ross.

Table 3.3-6 Mechanical Properties of A615, GR 60, Reinforcing Steel

	Temperature (°F)			
Property (units)	148	328	508	688
S_u (ksi)[1]	58.0	65.3	69.6	53.7
S_y (ksi)[2]	60			
Modulus of Easticity[1](ksi)	29.88E+3			
α (in/in/ °F)[1]	6.1E-6			
Density[1](lbm/in^3)	0.284			

1 Ross.
2 Cases of ASME Code, Case N-71-16, Table 1, 2, 3, 4, 5.

Table 3.3-7 Mechanical Properties of A500 Carbon Steel

	Temperature (°F)							
Property (units)	100	200	300	400	500	600	650	700
S_u (ksi)[1]	58.0	58.0	58.0	58.0	–	–	–	–
S_y (ksi)[1]	42.0	38.3	37.2	35.9	33.9	31.0	30.4	30.2
Modulus of Elasticity[2] (ksi)	29.0E+3	28.8E+3	28.3E+3	27.7E+3	27.3E+3	26.7E+3	26.1E+3	25.5E+3
α (in/in/ °F)[3]	5.53E-6	5.89E-6	6.26E-6	6.61E-6	6.91E-6	7.17E-6	7.30E-6	7.41E-6
Poisson's Ratio[4]	0.31							
Density[5](lbm/in³)	0.284							

1 Cases of ASME Boiler and Pressure Vessel Code, Case N-71-16, Table 1, 2, 3, 4, 5.
2 ASME Code, Section II, Part D, Table TM-1.
3 ASME Code, Section II, Part D, Group C in Table TE-1.
4 ASME Code, Section II, Part D, Table NF-1.
5 Ross.

Table 3.3-8 Mechanical Properties of A588, Type A, B Low Alloy Steel

	Temperature (°F)							
Property (units)	100	200	300	400	500	600	650	700
S_u (ksi)[1]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
S_y (ksi)[1]	50.0	47.5	45.6	43.0	41.8	39.9	38.9	37.9
S_m (ksi)[1]	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3
Modulus of Elasticity[2] (ksi)	29.0E+3	28.8E+3	28.3E+3	27.7E+3	27.3E+3	26.7E+3	26.1E+3	25.5E+3
α (in/in/ °F)[3]	5.53E-6	5.89E-6	6.26E-6	6.61E-6	6.91E-6	7.17E-6	7.30E-6	7.41E-6
Poisson's Ratio[4]	0.31							
Density[5] (lbm/in³)	0.284							

1 Cases of ASME Boiler and Pressure Vessel Code, Case N-71-16, Table 1, 2, 3, 4, 5.
2 ASME Code, Section II, Part D, Table TM-1.
3 ASME Code, Section II, Part D, Group C in Table TE-1.
4 ASME Code, Section II, Part D, Table NF-1.
5 Ross.

Table 3.3-9 Mechanical Properties of 6061-T6 Aluminum Alloy

	Temperature (°F)							
Property (units)	70	100	200	300	400	500	600	700
Ultimate Strength[1, 2] (ksi)	42.0	40.7	38.2	31.5	17.2	6.7	3.4	2.1
Yield Strength (ksi)[1, 2]	35.0	33.9	32.2	26.9	14.0	5.3	2.5	1.4
Design Stress[1](ksi)	10.5	10.5	10.5	8.4	4.4	N/A	N/A	N/A
Modulus of Elasticity[3](ksi)	10.0E+3	9.9E+3	9.6E+3	9.2E+3	8.7E+3	8.1E+3	7.0E+3[5]	N/A
Coefficient of Thermal Expansion[4] (in/in/°F)	---	12.6E-6	12.9E-6	13.22E-6	13.52E-6	13.7E-6[6]	14.3E-6[6]	N/A
Poisson's Ratio[7]	0.33							
Density[8] (lbm/in^3)	0.098							

[1] ASME Code, Section II, Part D, Table 1-B.

[2] Strength at elevated temperatures calculated using the following relationships from MIL-HDBK-5F, Figures 3.6.2.2.1(a) and 3.6.2.2.1(b);

$S_{u\ @temp} = (\%Value)(S_{u\ @70})$

$S_{y\ @temp} = (\%Value)(S_{y\ @70})$

<u>% Value @ Room Temperature</u>

Temp°F	100	200	300	400	500	600	700
S_u	97	91	75	41	16	8	5
S_y	97	92	77	40	15	7	4

[3] ASME Code, Section II, Part D, Table TM-2.

[4] ASME Code, Section II, Part D, Table TE-2.

[5] MIL-HDBK-5F, Figure 3.6.2.2.4.

[6] MIL-HDBK-5F, Figure 3.6.2.0.

[7] ASME Code, Section II, Part D, Table NF-1.

[8] ASME Code, Section II, Part D, Table NF-2.

Table 3.3-10 Mechanical Properties of Concrete

Property (units)	Temperature (°F) 70	100	200	300	400	500
Density[1] (lb/ft^3)	140	140	140	140	140	140
Compressive Strength[1] (psi)	4000	4000	4000	3800	3600	3400
Coefficient of Thermal Expansion[1] (in/in/°F)	5.5×10^{-6}					
Modulus of Elasticity[1] (ksi)	---	3.64×10^6	3.38×10^6	3.09×10^6	3.73×10^6	3.43×10^6

[1] Fintel.

Table 3.3-11 Mechanical Properties of NS-4-FR

Property (units)	Temperature (°F)			
	86	158	212	302
Compressive Modulus of Elasticity[1] (ksi)	← 561 →			
Coefficient of Thermal Expansion[1] (in/in/°F)	2.22E-5	4.72E-5	5.88E-5	5.74E-5
Density[1] (lbm/in^3)	← 0.0607 →			

[1] GESC Product Data.

3.4 General Standards for Casks

3.4.1 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of the NAC-MPC system have been evaluated to determine whether chemical, galvanic, or other reactions among the materials, contents, and environments can occur. All phases of operation—loading, unloading, handling, and storage—have been considered for the environments that may be encountered under normal, off-normal, or accident conditions. Based on the evaluation, there is one potential reaction that could adversely affect the overall integrity of the storage cask, the fuel basket, the transportable storage canister, or the structural integrity and retrievability of the fuel from the canister. That potential reaction, between aluminum and spent fuel pool water, which may produce hydrogen is mitigated by the specific canister loading procedures presented in Section 8.1.1.

3.4.1.1 Component Operating Environment

Most of the component materials of the NAC-MPC are exposed to two typical operating environments: 1) an open canister containing pool water or borated water with a pH of 4.5 and spent fuel or other radioactive material; or 2) a sealed canister containing helium, but with the canister in environs that include air, rain water/snow/ice, and marine (salty) water/air. The spent fuel assemblies consist of zircaloy or stainless steel clad fuel and other fuel assembly components of stainless steel.

Each category of canister component materials is evaluated for potential reactions in each of the operating environments to which those materials are exposed. These environments may occur during fuel loading or unloading, handling or storage, and include normal, off-normal, and accident conditions.

One of the operating environments to which the canister internal component materials are exposed does not provide the conditions necessary for a reaction (corrosion); i.e., both moisture and oxygen must be present for corrosion to occur. This long-term environment is the sealed canister, backfilled with helium. Helium displaces the oxygen in the canister effectively precluding corrosion. Galvanic corrosion (i.e., between dissimilar metals that are in contact) could occur; but only if there is water present at the point of contact and the metals are in

electrical contact with each other (i.e., mechanically held together). NAC's operating procedures provide two helium backfill cycles in series separated by a vacuum-drying cycle for the canister during the preparation of the canister for storage. Therefore, the canister cavity is effectively dry and galvanic corrosion is precluded.

3.4.1.2 Component Material Categories

The component materials evaluated are categorized based on similarity of physical and chemical properties and/or on similarity of component functions. The categories of materials that are considered are stainless/nickel alloy steels, nonferrous metals, and criticality control materials. These categories are evaluated based on the environment to which they could be exposed during operation or use of the canister.

The canister component materials are not reactive among themselves, with the canister's contents, nor with the canister's operating environments, except aluminum, during any phase of normal, off-normal, or accident condition loading, unloading, handling, or storage operations. Therefore, only the potential aluminum reaction with spent fuel pool water is evaluated.

3.4.1.2.1 Stainless Steels

No reaction of the canister component stainless steel is expected in any environment except for the marine environment, where chloride-containing salt spray might initiate pitting of the steels if the chlorides are allowed to concentrate and stay wet for extended periods of time (weeks). Only the external canister surface could be so exposed. The corrosion rate will, however, be so low that no detectable corrosion products or gases will be generated. The NAC-MPC has smooth external surfaces to minimize the collection of such materials as salts.

There is a significant electrochemical potential difference between austenitic (300 series) stainless steel and aluminum. If aluminum is in electrical contact with the austenitic stainless steel, the aluminum could be expected to exhibit corrosion driven by electrochemical EMF when immersed in water. Pressurized Water Reactor (PWR) pool water does provide a conductive potential. The only aluminum components that will be in contact with stainless steel and exposed to the pool water are the heat transfer disks in the fuel basket. Since the fuel basket is

not welded or bolted to the canisters, poor, if any, electrical contact with the stainless steels is present. Therefore, in the absence of electrical contact between the aluminum and the stainless steel, galvanically driven corrosion does not occur.

No coatings are applied to the stainless steels.

Based on the foregoing discussion, there are no potential reactions associated with the stainless steel canister components.

3.4.1.2.2 Nonferrous Metals

Heat transfer disks fabricated from 6061-T6 aluminum alloy are used in the NAC-MPC fuel basket to augment heat transfer from the spent fuel through the basket structure to the canister exterior. Vendor and Nuclear Regulatory Commission safety evaluations of the NUHOMS Dry Spent Fuel Storage System (Docket No. 72-1004) have concluded that combustible gases, primarily hydrogen, may be produced by a chemical reaction and/or radiolysis when aluminum or aluminum flame-sprayed components are immersed in spent fuel pool water. The evaluations further concluded that it is possible, at higher temperatures (above 150 - 160 °F), for the aluminum/water reaction to produce a hydrogen concentration in the cask or canister that approaches or exceeds the Lower Flammability Limit (LFL) for hydrogen of 4 percent. The NRC Inspection Reports No. 50-266/96005 and 50-301/96005 dated July 01, 1996, for the Point Beach Nuclear Plant concluded that hydrogen generation by radiolysis was insignificant relative to other sources.

Thus, it is reasonable to conclude that small amounts of combustible gases, primarily hydrogen, may be produced during NAC-MPC canister loading or unloading operations as a result of a chemical reaction between the 6061-T6 aluminum heat transfer disks in the fuel basket and the spent fuel pool water. The generation of combustible gases stops when the water is removed from the cask or canister and the aluminum surfaces are dry.

A galvanic reaction may occur at the contact surfaces between the aluminum disks and the stainless steel tie rods and spacers in the presence of an electrolyte, like the pool water. The galvanic reaction ceases when the electrolyte is removed. Each metal has some tendency to ionize, or release electrons. A voltage, or electromotive force (emf), associated with this release of electrons is generated between two dissimilar metals in an electrolytic solution. The emf

between aluminum and stainless steel is small and the amount of corrosion is directly proportional to the emf. Loading operations generally take less than 24 hours, a large portion of which has the canister immersed in and open to the pool water after which the electrolyte (water) is drained and the cask or canister is dried and back-filled with helium, effectively halting any galvanic reaction.

The potential chemical or galvanic reactions do not have a significant detrimental effect on the ability of the aluminum heat transfer disks to perform their function for all normal and accident conditions associated with dry storage.

Loading Operations

After the canister is removed from the pool and during canister closure operations, an air space is created inside the canister beneath the shield lid by the drain-down of 50 gallons of water so that the shield-lid-to-canister-shell can be performed. The resulting air space is approximately 70 inches in diameter and 3 inches deep. Although there is some clearance between the inside diameter of the canister shell and the outside diameter of the shield lid, it is possible that gases released from a chemical reaction inside the canister could accumulate beneath the shield lid. A bare aluminum surface oxidizes when exposed to air, reacts chemically in an aqueous solution, and may react galvanically when in contact with stainless steel in the presence of an aqueous solution.

The reaction of aluminum in water, which results in hydrogen generation, proceeds as:

$$2\,Al + 3\,H_20 \Rightarrow Al_2O_3 + 3\,H_2$$

The aluminum oxide (Al_2O_3) produces the dull, light gray film that is present on the surface of bare aluminum when it reacts with the oxygen in air or water. The formation of the thin oxide film is a self limiting reaction as the film isolates the aluminum metal from the oxygen source acting as a barrier to further oxidation. The oxide film is stable in pH neutral (passive) solutions, but is soluble in borated PWR spent fuel pool water. The oxide film dissolves at a rate dependent upon the pH of the water, the exposure time of the aluminum in the water, and the temperatures of the aluminum and water.

PWR spent fuel pool water is a boric acid and demineralized water solution. The pH, water chemistry, and water temperature vary from pool to pool. Since the reaction rate is largely dependent upon these variables, it may vary considerably from pool to pool. Thus, the

generation rate of combustible gas (hydrogen) that could be considered representative of spent fuel pools in general is very difficult to accurately calculate.

To ensure safe loading and/or unloading of the NAC-MPC transportable storage canister, the loading and unloading procedures defined in SAR Chapter 8 are revised to provide for the monitoring of hydrogen gas before and during the welding operations joining the shield lid to the canister shell, and joining the vent and drain port coverplates to the shield lid. The monitoring system shall be capable of detecting hydrogen at 60% of the lower flammability limit for hydrogen (i.e. 0.6 x 4.0 = 2.4%). The hydrogen detector shall be mounted so as to detect hydrogen prior to initiation of the weld, and continuously at a point ahead of the weld head. Detection of hydrogen in a concentration exceeding 2.4% shall be cause for the welding operation to stop. If hydrogen gas is detected at concentrations above 2.4% at any time, the hydrogen gas shall be removed by flushing ambient air into the region below the shield lid or port coverplate. To remove hydrogen from below the shield lid, the vacuum pump is attached to the vent port and operated for a sufficient period of time to remove at least five times the air volume of the space below the lid by drawing ambient air through the gap between the shield lid and the canister shell, thus removing or diluting any combustible gas concentrations.

The vacuum pump shall exhaust to a system or area where hydrogen flammability is not an issue. If hydrogen gas is detected at the port coverplates, the coverplate is removed and service air is used to flush combustible gases from the port. Once the root pass weld is completed there is no further likelihood of a combustible gas burn because the ignition source is isolated from the combustible gas. Once welding of the shield lid has been completed, the canister is drained, vacuum dried and back-filled with helium.

No hydrogen is expected to be detected prior to, or during, the welding operations. The vent port in the shield lid remains open from the time that the loaded canister is removed from the spent fuel pool until the time that the vent port coverplate is ready to be welded to the shield lid. Since the postulated combustible gases are very light, the open vent port provides an escape path for any gases that are generated prior to the time that the canister is vacuum dried. Once the canister is dry, no combustible gases form within the canister. The mating surfaces of the support ring and inner lid are machined to provide a good level fitup, but are not machined to provide a metal to metal seal. Consequently, additional exit paths for the combustible gases exist at the circumference of the shield lid.

Unloading Operations

It is not expected that the canister will contain a measurable quantity of combustible gases during the time period of storage. The canister is vacuum dried and backfilled with helium immediately prior to being welded closed. There are only minor mechanisms by which hydrogen is generated after the canister is dried and sealed.

As shown in Section 8.3, the principal steps in opening the canister are the removal of the structural lid, the removal of the vent and drain port coverplates, and the removal of the shield lid. These steps are performed by cutting or grinding. The design of the canister precludes monitoring for the presence of combustible gases prior to the removal of the structural lid and the vent and drain port coverplates. Following removal of the vent port coverplate, a vent line is connected to the vent port quick disconnect. The vent line incorporates a hydrogen gas detector which is capable of detecting hydrogen at a concentration of 2.4% (60% of its lower flammability limit of 4%). The pressurized gases (expected to be greater than 96% helium) in the canister are expected to carry combustible gases out of the vent port. If the exiting gases in the vent line contain no hydrogen at concentrations above 2.4%, the drain port coverplate weld is cut and the coverplate removed. If levels of hydrogen gas above 2.4% concentration are detected in the vent line, then the vacuum system is used to remove all residual gas prior to removal of the drain port coverplate. During the removal of the drain port coverplate, the hydrogen gas detector is attached to the vent port to ensure that the hydrogen gas concentrations remains below 2.4%. Following removal of the drain port coverplate, the canister is filled with water using the vent and drain ports. Prior to cutting the shield lid weld, 50 gallons of water are removed from the canister to permit the removal of the shield lid. Monitoring for hydrogen would then proceed as described for the loading operations.

3.4.1.2.3 Criticality Control Material

The criticality control material is a sheet consisting of boron carbide mixed in an aluminum alloy. This material is effectively a sheet of aluminum that is in contact with the stainless steel fuel tubes and is completely enclosed by a welded stainless steel cover. This "aluminum" is protected by an oxide layer that formed shortly after fabrication and precludes further oxidation of the aluminum or interaction with the stainless steel. Consequently, there are no potential reactions associated with the aluminum-based criticality control material.

3.4.1.3 General Effects of Identified Reactions

One potential chemical, galvanic, or other reaction has been identified for the NAC-MPC system. A condition, such as the generation of flammable or explosive quantities of combustible gases does not result in an adverse event during any phase of canister operations for normal, off-normal, or accident conditions because specific detection procedures and responses are defined in Section 8.1.1.

3.4.1.4 Adequacy of the Canister Operating Procedures

Based on this evaluation, which resulted in one identified reaction, it is concluded that the NAC-MPC operating controls and procedures presented in Chapter 8.0 are adequate to minimize the occurrence of hazardous conditions.

3.4.1.5 Effects of Reaction Products

One potential chemical, galvanic, or other reaction has been identified for the NAC-MPC. The effects of that reaction are mitigated by the operating procedures described in Section 8.1.1. The overall integrity of the canister and the structural integrity and retrievability of the spent fuel are not adversely affected for the design basis life of the canister. Based on the evaluation, there will be no change in the canister or fuel cladding thermal properties, there will be no binding of mechanical surfaces, no change in basket clearances, and no degradation of any safety components either directly or indirectly.

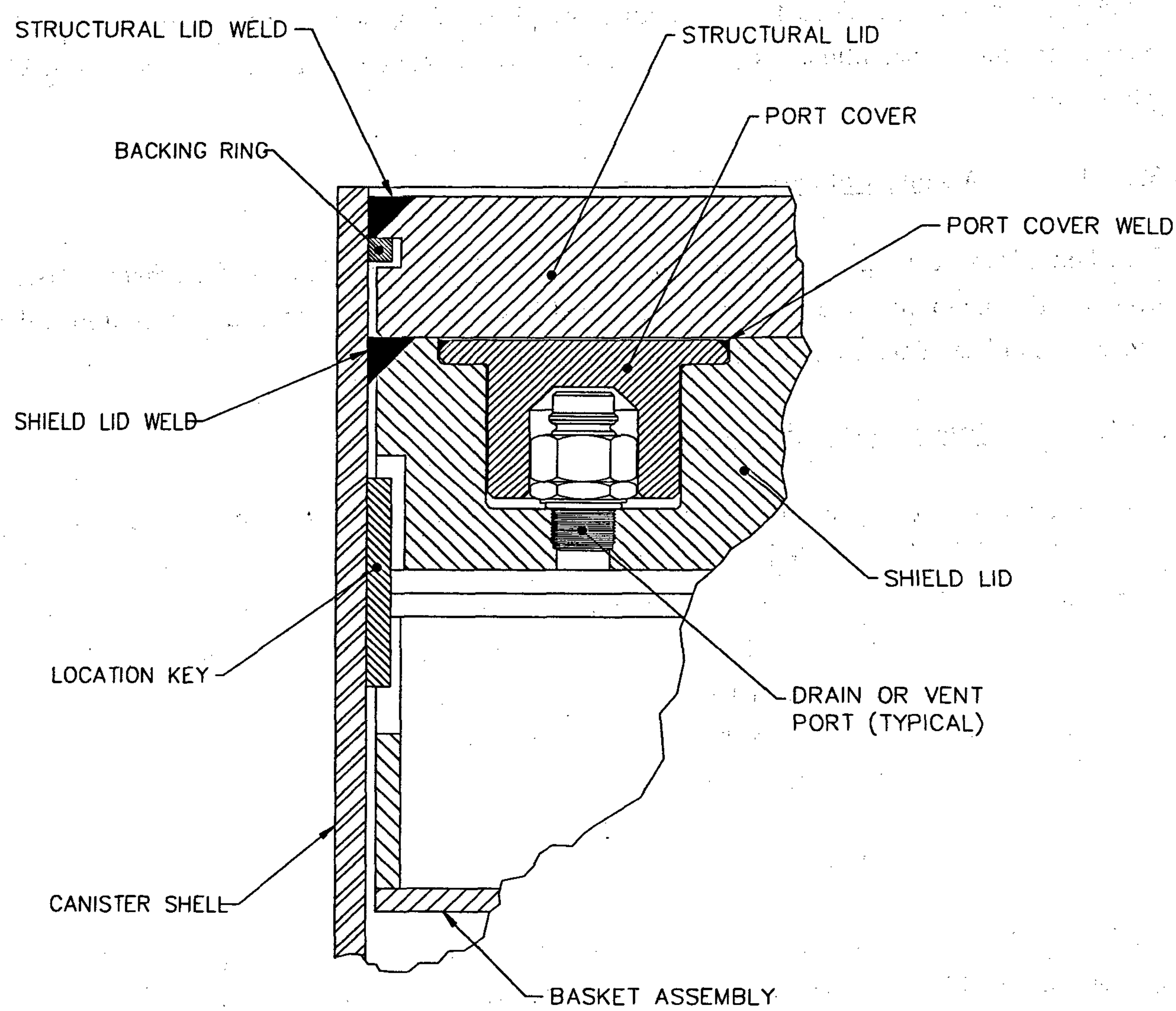
3.4.2 Positive Closure

The NAC-MPC employs a positive closure system that is composed of multipass welds to join the canister shield lid to the shell, and to join the canister structural lid to the shell. The penetrations to the canister cavity through the shield lid are closed by port covers that are welded to the shield lid (see Figure 3.4.2-1).

The welds employed for closing the NAC-MPC canister preclude inadvertent opening of the canister.

The top of the concrete storage cask is closed by a bolted lid. The lid weighs approximately 3,000 lbs. The weight of the lid, its inaccessibility and the presence of the bolts effectively preclude inadvertent opening of the lid.

Figure 3.4.2-1 NAC-MPC Welded Closure System



3.4.3 Lifting Devices

To provide more efficient handling of the components of the NAC-MPC System, different methods of lifting, i.e., trunnions, hoist rings, and jacks and air pads, have been designed for each of the components - the transfer cask, the transportable storage canister, and the storage cask, respectively.

The transfer cask is lifted by two trunnions located near the top of the cask. The 10-inch diameter trunnions extend through the multiwall body to 5.25 inches beyond the outer shell and are full-penetration welded to both the inner and the outer shells (Figure 3.4.3-1). The transfer cask is designed as a heavy-lifting device that satisfies the requirements of NUREG-0612 and ANSI N14.6 for lifting the combined weight of the transfer cask and a fully loaded canister of fuel and water (approximately 143,000 pounds). This is the maximum weight for the transfer cask during a lifting operation.

The transportable storage canister is lifted and handled while supported on the shield doors within the transfer cask during all preparation, loading and cask closure operations and is then moved to the top of the storage cask. Six hoist rings that are threaded into the structural lid are used to lift the loaded and closed canister just off the shield doors of the transfer cask and to lower the canister into the storage cask after the shield doors are opened. The hoist rings are also used for any subsequent lifting of the loaded canister whose weight is approximately 54,730 pounds (Figure 3.4.3-2).

The vertical concrete cask is raised approximately 3 inches by four lifting jacks placed at the jacking pads located near the end of each air inlet. A system of air pads consisting of 4 units is then inserted under the concrete cask. The cask is lowered onto the air pads (uninflated) and the jacks are removed. The air pads are inflated to lift the concrete cask and position it as required on the storage pad or on the transport vehicle. When positioning is complete, the jacks are again used to raise the cask and remove the air pads.

Figure 3.4.3-1 Transfer Cask Lifting Trunnion Design

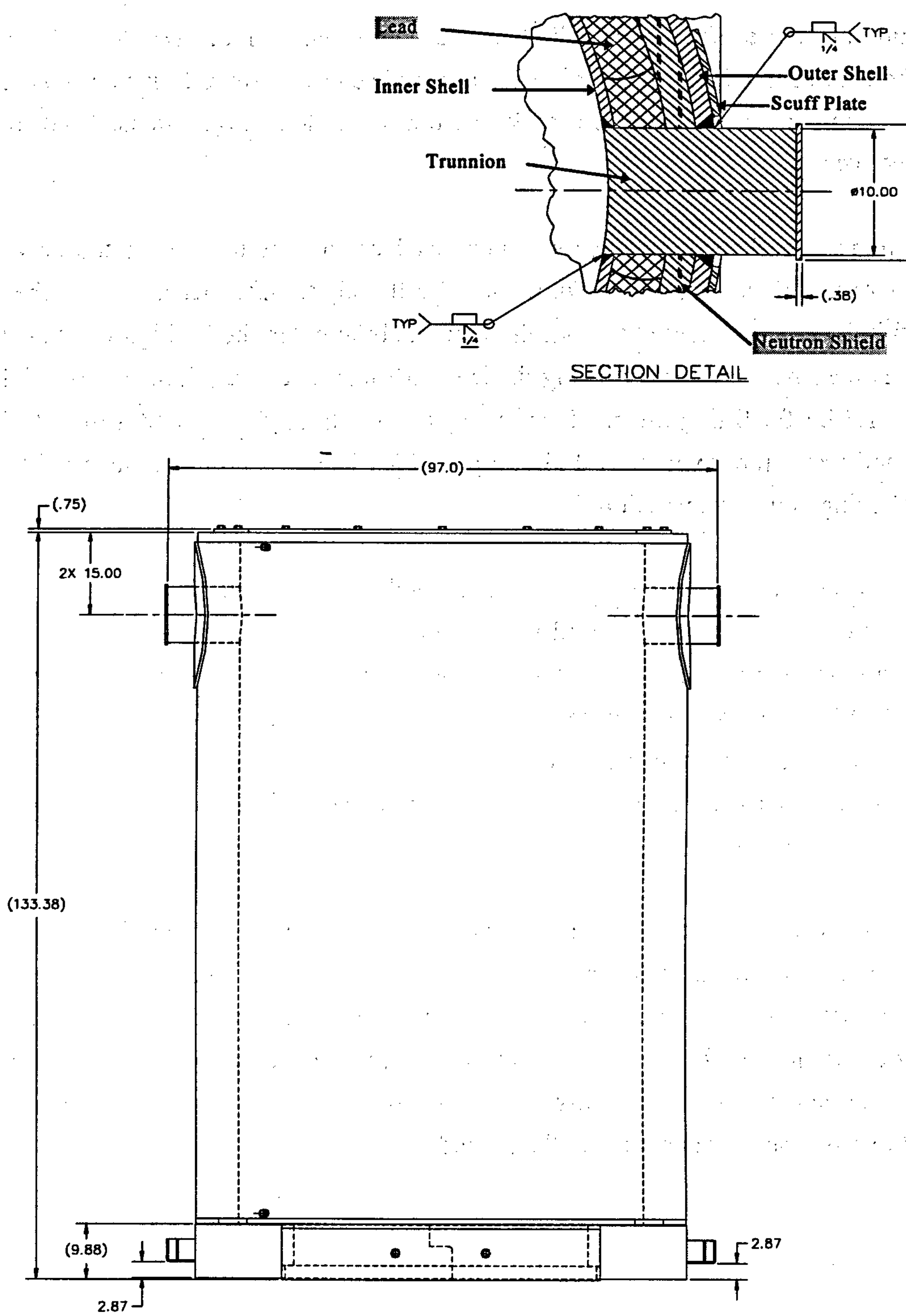
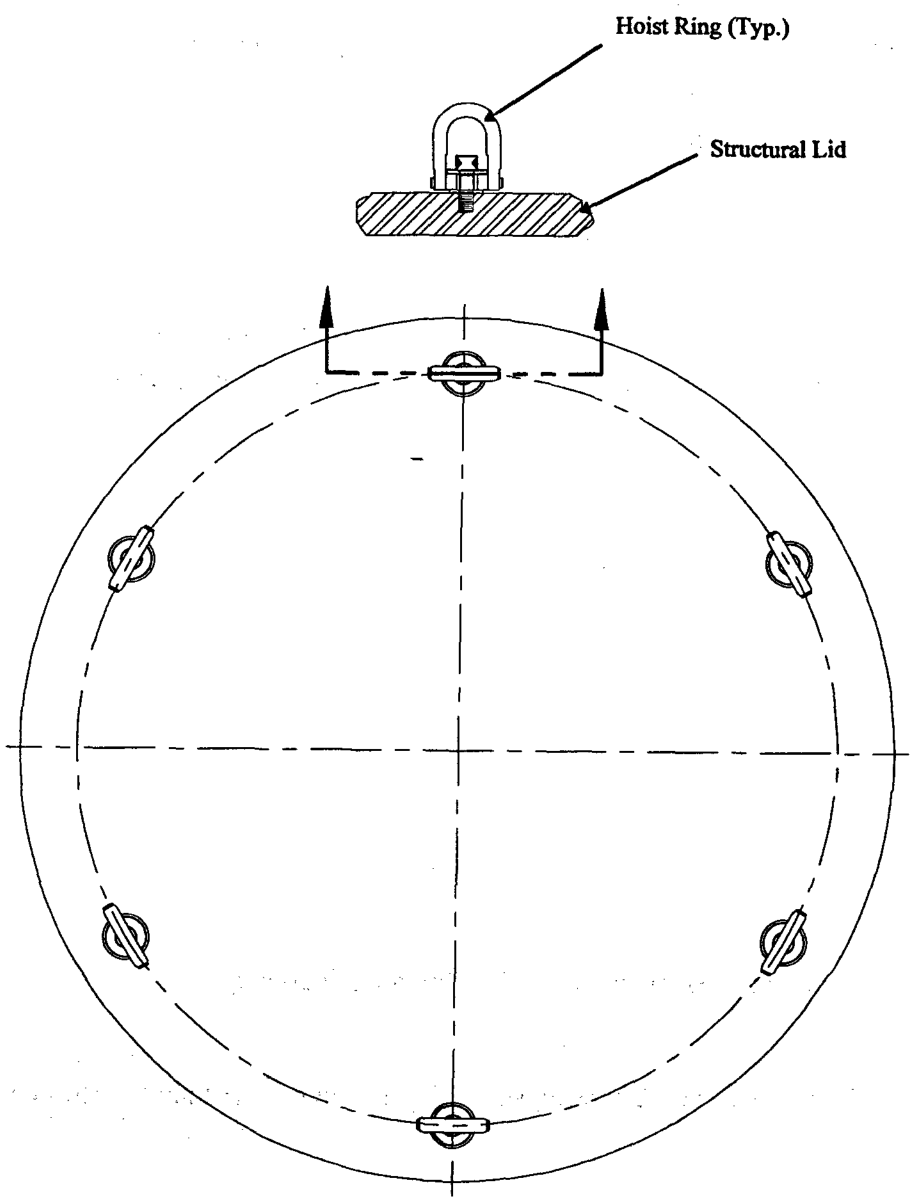


Figure 3.4.3-2 Canister Hoist Ring Design



3.4.3.1 Storage Cask Bottom Lift

The concrete cask is lifted from the bottom via an air pad system. Insertion of the air pad system is made possible by the use of lifting jacks. The current design utilizes a Synchronous Lifting System with four (4) hydraulic jack cylinders. The system is designed to equally distributes hydraulic pressure among four cylinders.

3.4.3.1.1 Bottom Lift By Hydraulic Jack

To ensure the concrete bearing stresses at the jack locations do exceed the allowable stress, the required diameter of the jack piston rod is determined. The concrete allowable bearing capacity (in pounds) at each jack is

$$U_b = \phi f_c' A = \frac{(0.7)(4{,}000)\pi d^2}{4} = 2{,}199.1 d^2,$$

where,

ϕ = 0.7 strength reduction factor for bearing,

f_c' = 4,000 psi concrete compressive strength,

$A = \frac{\pi d^2}{4}$, concrete bearing area (d = bearing area diameter).

For dead load conditions, the concrete bearing strength must be greater than the storage cask weight times a load factor, L_f, of 1.4.

$$2{,}199.1\, d^2 > \frac{L_f \times W}{n} = \frac{1.4(206{,}100)}{4} \Rightarrow d > 5.73 \text{ in.},$$

where,

n = the number of jacks, 4

W = the weight of the VCC, 206,100 lbs.

Lf = the load factor, 1.4

The diameter obtained in the above equation is the maximum permissible area at the surface of the concrete over which the load must be distributed. The force exerted by the jack to lift the storage cask is applied to the bottom surface of the top plate of the air inlet, which is separated from the concrete surface by a one inch thick steel plate. The force exerted by the jack will be distributed over a larger area on the concrete surface. The effective diameter of the load acting on the concrete surface is increased by 2 x tan (45°) x thickness of the steel plate. Therefore, the required hydraulic jack piston diameter is:

5.73 in. - 2 in. = 3.73 in.

The actual hydraulic cylinder to be used has a piston rod diameter of 4 1/8 inch, which is greater than the required 3.73 inch.

Nelson Studs

During the bottom lift of the storage cask with hydraulic jacks the weight of the loaded canister, pedestal and air inlet vent system are transferred to the baseplate of the storage cask (total weight = 63,230 lbs). As the baseplate is loaded, the plate tends to flex, thus separating the concrete from the bottom plate. To prevent this separation, Nelson studs are utilized to bond the concrete to the bottom plate.

Use of the Nelson studs requires proper spacing to prevent overlapping of the shear cones of adjacent Nelson studs (TRW). The term "shear cone" refers to the geometry that a failed concrete section takes when a Nelson stud pulls out of concrete. Overlapping of adjacent shear cones tends to reduce the effectiveness of the Nelson stud. In the case of the storage cask, thirty-two (32), 3/4 × 6 3/16 inch Nelson studs are used. For 4000 psi strength concrete, the minimum

spacing between two studs is 7.984 inches. (2 x 3.992 inch, where, 3.992 inch is surface area diameter of the full concrete shear cone for 3/4 x 6-3/16 inch Nelson studs.) The spacing of the Nelson studs on the storage cask bottom exceeds requirements. The total capacity is:

$$\text{Capacity} = 32\ \text{Anchors} \times 23{,}860\ \text{lb/Anchor} = 763{,}500\ \text{lb}$$

The allowable load, P_u, with a load factor of 2.0, as specified in the TRW design data, is

$$P_u = \frac{763{,}500}{2.0} = 381{,}750\,\text{lb}$$

The total load applied to the storage cask bottom plate (including a 10% dynamic load factor) is

$$63{,}230 \times 1.1 = 69{,}553\ \text{lbs}$$

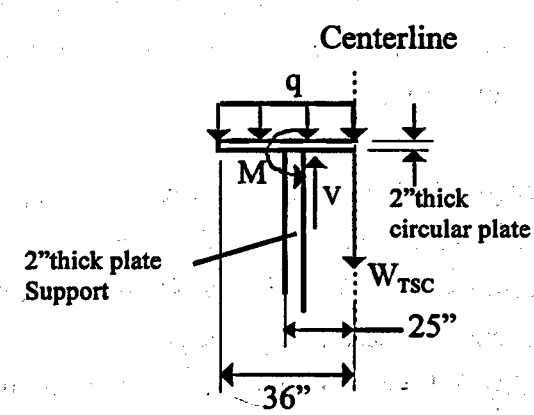
Therefore, the margin of safety is

$$\text{M.S.} = \frac{381{,}750}{69{,}553} - 1 = +4.49$$

Pedestal - Horizontal Plate

The canister weight (54,730 pound) is uniformly distributed over the 2-inch thick horizontal circular plate of the pedestal. The self-weight of the plate is 2,313 pound (0.284 lb/in^3 x π x 36^2 x 2). The equivalent pressure is

$$q = \frac{W}{A} = \frac{54{,}730 + 2{,}313}{\pi(36^2)} = 14.01\ \text{psi}$$



The horizontal plate is supported by the pedestal ring (vertical plate support) at four locations (each has a circumferential length of 16.85 inch). The bending moment at the cross-section of the plate at support location is

$$M = (LF)(q)(A)(P_c) = (1.1)(14.01)\left(\frac{\pi(36^2 - 25^2)}{4}\right)(5.5) = 44{,}670 \text{ in.–lb},$$

where,

A = the area of the pedestal from the plate support to the edge of the circular plate,
P_c = 5.5 in., the location of the resultant force,
LF = 1.1, load factor to account for 10% dynamic load factor

The bending stress is

$$f_b = \frac{6M}{bt^2} = \frac{(6)(44{,}670)}{(16.85)(2)^2} = 3{,}977 \text{ psi}$$

The material of the pedestal horizontal plate is ASTM A36 with a yield stress (Fy) of 36,000 psi. The allowable stress for flexural members per the Manual of Steel Construction (AISC) is

$$F_b = 0.66\, F_y = 23{,}760 \text{ psi},$$

and the resulting margin of safety is

$$M.S. = \frac{23{,}760}{3{,}977} - 1 = +5.0$$

The maximum shear stress at the support location is

$$f_v = \frac{W}{L} = \frac{(54{,}730 + 2{,}313)(1.1)}{4(16.85)(2)} = 465.5 \text{ psi}$$

The allowable shear stress is 14,400 psi (0.4 Fy = 0.4 x 36,000) and the margin of safety is

$$M.S.=\frac{14,400}{465.5}-1=+29.9$$

Pedestal Ring (Vertical Plate)

The pedestal ring is subjected to an axial compressive force and bending moments due to weight of the canister (54,730 lb), weight of the pedestal horizontal plate (2,313 lb) and self-weight of the pedestal ring (0.284 lb/in. × 16.85 × 2 × 6 = 230 lb). The maximum compressive stress at the critical cross-section (2 inch × 1.5 inch, 8 locations) is

$$f_a=\frac{(54,730+2,313+230)(1.1)}{8(1.5)(2)}=2,625\,\text{psi.}$$

The allowable stress, F_a, for compression member is determined per Chapter E of the Manual of Steel Construction (AISC):

$$\frac{KL}{r}=\frac{0.65\times 6}{0.433}=9,$$

where,

K = 0.65, effective-length factor for the end conditions (rotation and translation fixed),

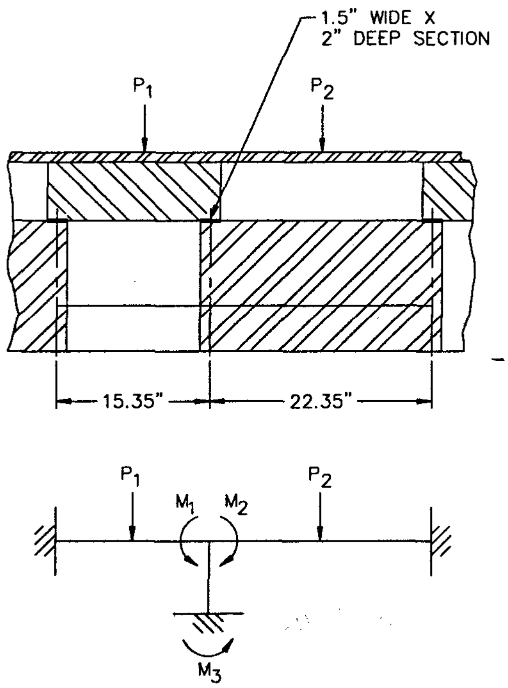
L = 6.0 in., height of pedestal ring (unbraced),

r = $\frac{1.5}{\sqrt{12}}=0.433$, radius of gyration.

Using Chapter E and Tables 3 through 5 of Section 5 of the AISC for A36 material (F_y = 36,000 psi), the allowable stress ,F_a, for compression is determined to be 21,200 psi.

The bending stress at the same cross-section is conservatively calculated below:

P_t = one-fourth of the total load = (54730 + 2,313) / 4 = 14,261 lb. ≈ 14,300 lb.



The pedestal is represented as a combination of beams to describe the load path.

P_1 = 14,300 × (15.35 / 37.7) = 5,822 lb.

P_2 = 14,300 × (22.35 / 37.7) = 8,478 lb.

M_1 and M_2 are conservatively considered to be the fixed-end moments of beams of with a concentrated load at mid-span (with a 10% dynamic load factor). L_1 (15.35 inch) and L_2 (22.35 inch) are the length of the beams. M_3 (the moment at the 2 inch by 1.5 inch cross-section) is considered to be the difference of M_1 and M_2.

$$M_1 = \frac{1.1(P_1L_1)}{8} = \frac{(1.1)(5,822)(15.35)}{8} = 12,288 \text{in.} - \text{lb.}$$

$$M_2 = \frac{1.1(P_2L_2)}{8} = \frac{(1.1)(8,478)(22.35)}{8} = 26,054 \text{ in.} - \text{lb.}$$

$$M_3 = M_2 - M_1 = 13,766 \text{ in-lb.}$$

The maximum bending stress f_b is computed as

$$f_b = \frac{6M_3}{bt^2} = \frac{(6)(13,766)}{(2)(1.5)^2} = 18,355 \text{psi}$$

The allowable stress for bending (F_b) is 23,760 psi (0.66 F_y). Since f_a / F_a is less than 0.15, Equation (H1-3) in the Manual of Steel Construction (AISC), Chapter H, is used to evaluate combined stress:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} = \frac{2,625}{21,200} + \frac{18,355}{23,760} = 0.90 < 1.0$$

Therefore, the pedestal is structurally adequate to support the weight of the loaded canister.

3.4.3.1.2 Bottom Support by Air Pads

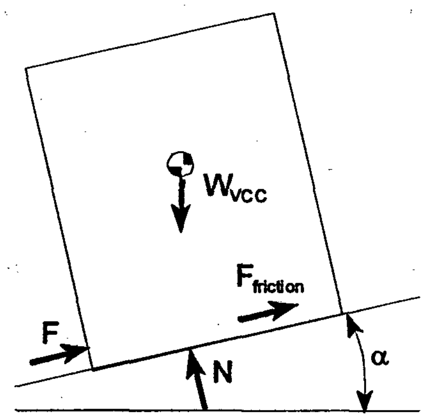
The storage cask is supported by air pads in each of 4 quadrants during transport. The layout of the air pads (four 48 in. × 48 in. square pads) must clear the air inlet locations by approximately 3 inches to allow for hydraulic jack access.

The air pad system maximum lift elevation to the storage cask bottom surface is 5.69 inches (3-inch lift, maximum, plus 2-11/16-inch overall height, when deflated) above the transport surface. The air pad system has a vendor rated lift capacity of 360,000 pounds.

The air pad system must supply sufficient force to overcome the weight of the storage cask under full load with a lift load factor, L.F of 1.1. Assuming a fully loaded weight of 206,100 pounds: the required lift load is 1.1(206,100) = 226,710 pounds. Since the available lift force is greater than the required lift force, the air pads are adequate to lift the storage cask. The lifting force margin of safety = (360,000 / 226,700) -1 = +0.59.

Operational/Handling Requirements

The handling force required to control the storage cask on a sloped surface, assuming minimal friction ($F_{friction}$), is



$$F = W_{VCC} \sin \alpha$$

$$= 206{,}100 \sin \alpha$$

Where W_{VCC} is the weight of the storage cask.

The amount of handling force, F, required on slanted surfaces can be very high. Therefore, the storage cask, while supported by air pads, will be transferred from trailer deck to storage pad site over essentially flat horizontal surfaces.

Once positioned on the storage pad, the storage cask is lifted from the air pads by the jacks for air pad removal. The maximum air pad deflated height plus lift height during all handling and transport is 5.69 inches above the transporter or storage pad surface. Therefore, storage pad handling method limits the potential drop height to 5.69 inches.

3.4.3.2 Canister Lift

The adequacy of the canister lifting devices is demonstrated by considering each of the hoist rings, the canister structural lid, and the weld that joins the structural lid to the canister shell. Lifting of the canister employs redundant 3-legged lifting slings for single failure proof lifting in accordance with NUREG-0612.

When considering a three-point lifting configuration, the load-bearing members of the canister maintain a factor of safety greater than three based on material yield strength. Additionally, the load-bearing members of the canister maintain a factor of safety greater than five based on material ultimate strength. The hoist rings are designed with a 5 to 1 safety factor based on ultimate. Therefore, the lifting requirements are satisfied.

Each lifting device in a three-point lift would experience the following load, F, when lifting the canister (the total load is based on the dead weight of the loaded canister with a dynamic load factor of 10 %):

$$F = \frac{54{,}730 \text{x} 1.1}{3} = 20{,}068 \text{ lb}$$

The hoist rings used to lift the canister have a rated load capacity of 24,000 pounds with a 5 to 1 safety factor based on material ultimate strength [redacted]. The length of the hoist ring bolt is 2.50 inches. The following calculation (using formula from Machinery's Handbook) demonstrates that a thread engagement length of 2.50 inches is satisfactory.

Definition of Terms

D	= basic major diameter of bolt threads = 1.5 inches
n	= number of threads per inch = 6
A_t	= tensile area of the bolt thread (in^2)
L_e	= minimum thread engagement length for mating materials with equal tensile strengths (in.)
$K_n max$	= maximum minor diameter of lid (internal) thread = 1.35 inches
$E_s min$	= minimum pitch diameter of bolt (external) threads = 1.3812 inches
A_s	= shear area of bolt threads (in^2)
A_n	= shear area of lid threads (in^2)
$D_s min$	= minimum major diameter of bolt (external) threads = 1.4794 inches
$E_n max$	= maximum pitch diameter of lid (internal) threads = 1.402 inches
Q	= length of thread engagement required to prevent shearing when the mating thread materials are different tensile strengths (in.)
J	= scale factor for calculation of Q
H	= height of sharp "V" thread = 0.1443 inches

Hoist ring material	= 4140 High strength alloy steel
Tensile strength of 4140	= 180,000 psi
Hoist ring thread	= 1-1/2 - 6 UNC
Structural lid material	= Type 304 L stainless steel
Temperature of structural lid	= 250°F
Tapped hole in structural lid	= 1-1/2 - 6 UNC

For steels up to 100,000 psi tensile strength, the tensile area of the bolt thread is given by:

$$A_t = \pi \left(\frac{E_s \min}{2} - \frac{0.9743}{n} \right) = \pi \left(\frac{1.3812}{2} - \frac{0.9743}{6} \right)$$

$$A_t = 1.405 \text{ in}^2$$

For mating materials having equal tensile strengths, the minimum length of thread engagement is given by:

$$L_e = \frac{2A_t}{3.1416 K_n \max \left[\frac{1}{2} + 0.57735 n (E_s \min - K_n \max) \right]}$$

$$L_e = 1.0898 \text{ inches}$$

For mating materials of differing tensile strengths:

$$J = \frac{A_s \text{ x tensile strength of bolt thread material}}{A_n \text{ x tensile strength of lid thread material}}$$

The shear areas are calculated as follows:

$$A_s = 3.1416 n L_e K_n \max \left[\frac{1}{2n} + 0.57735 (E_s \min - K_n \max) \right]$$

$$A_s = 2.8106 \text{ in}^2$$

$$A_n = 3.1416 n L_e D_s \min \left[\frac{1}{2n} + 0.57735 (D_s \min - E_n \max) \right]$$

$$A_n = 3.8871 \text{ in}^2$$

At a temperature of 250°F, the ultimate strength of Type 304L stainless steel is 63,550 psi.

$$J = \frac{A_s x (S_u)_{bolt}}{A_n x (S_u)_{lid}}$$

$$= 2.048$$

The length of thread engagement necessary to prevent shearing is:

$$Q = JL_e$$

$$Q = (2{,}048)(1.073) = 2.20\,\text{in.} < 2.5\,\text{in.}$$

Therefore, the required length of thread engagement is 2.23 inches, which is less than the hoist ring thread length of 2.5 inches.

The hoist rings are rated at 24,000 lbs with a safety factor of 5. The ultimate capacity of the rings is, therefore, 24,000 lbs x 5 = 120,000 lbs (120 kip).

Because the hoist rings and sling legs must demonstrate a safety factor of 10 when compared to ultimate strength, a design load, F_D = 11.0 kips, is chosen.

$$\frac{\text{Ring Ultimate Capacity}}{\text{Design Load}} = \frac{120\ \text{kip}}{11.0\ \text{kip}} = 10.9 > 10$$

The design load, F_D, is:

$$F_D = \sqrt{F_H^{\,2} + F_V^{\,2}}$$

where

$F_H = (F_V)(\tan\theta)$	horizontal load on the hoist ring, where θ is the angle of the sling with respect to the vertical axis of the canister
$F_V = 10.0$ kip	vertical load on the hoist ring

Given a six-point lift, and applying a dynamic load factor of 10%, each hoist ring sees a vertical load, F_V = 1.1 (54,730 lbs)/6 = 10.0 kip. Since

$$F_D = \sqrt{F_H^{\,2} + F_V^{\,2}} = F_D = \sqrt{(F_V \tan\theta)^2 + F_V^{\,2}}$$

Solving for θ:

$$\theta = \tan^{-1}\frac{\sqrt{(11.0\text{kips})^2 - (10.0\text{kips})^2}}{10.0\text{kip}} = 24.6\text{ degrees}$$

The distance from the center line of the canister to the hoist ring bolt circle is 30.25 inches. The minimum allowable distance, Y, from the top of the canister is:

$$Y = \frac{X}{\tan\theta} = \frac{30.25}{\tan 24.6} = 66.1\text{ inches}$$

Therefore, the minimum allowable distance from the master link of the sling to the top of the canister is 66.1 inches.

The structural adequacy of the canister structural lid and weld was evaluated using a finite element representation of the upper portion of the canister using the ANSYS program. As shown in Figure 3.4.3.2-1, the model represents one-half (180° section) of the upper 50-in. of the canister (including the structural and shield lids). The lids and shell in the model are comprised of SOLID45 elements. CONTACT52 elements are used to model the interaction between the structural lid and the canister shell and between the shield lid and the canister shell, just below the respective lid weld joints. The size of the CONTACT52 gaps was determined from nominal dimensions of contacting components. COMBIN40 elements are used between the structural and shield lids in the axial direction and between the shield lid and the backing ring. These gaps are assigned small gap sizes of 1E-8 inches. All gap/spring elements are assigned a stiffness of 1E8 lb/in.

To enforce symmetry at the boundary of the model (in the x-y plane), all nodes on the x-y symmetry plane were restrained perpendicular to the symmetry plane (UZ). In addition, the nodes in the x-z plane at the bottom of the model were restrained in the axial direction.

Load-bearing members of a lifting device must be capable of lifting three (3) times the combined weight of the shipping container with which it will be used, plus the weight of intervening components of the lifting device without exceeding the tensile yield strength of their materials of construction. In addition, the lifting components must be capable of lifting five (5) times that combined weight without exceeding the ultimate tensile strength of the materials. NUREG 0612 also requires that the lifting loads must be based on the combined maximum static and dynamic loads that could be imparted on the handling device based on characteristics of the crane that will be used. A dynamic load factor of 10% has been applied.

To simulate the lifting of the canister by a three-point lifting device (the lifting configuration is actually two independent 3-point lifting devices), point loads equal to one-third of the total canister and contents weight plus a dynamic loading factor of 10% were applied to the model. Because the model represents a half section of the canister, only two point loads were applied 120° apart as shown in Figure 3.4.3.2-1. Because of the symmetry conditions of the model, the force applied to the node on the symmetry plane was one-half of the value applied at the other location.

The maximum stress intensity generated in the canister model from the applied lifting forces was 3,753 psi, which occurs in the structural lid where the lifting loads were applied (see Figure 3.4.3.2-2).

As stated previously, the maximum stress intensity in the canister lifting model occurs in the structural lid that is constructed of Type 304L stainless steel. The yield strength (S_y) of Type 304L stainless steel at 250°F is 20,300 psi. The ultimate strength (S_u) of Type 304L stainless steel at 250°F is 63,550 psi.

The factor of safety (FS) for the canister lift based on yield strength is:

$$FS = \frac{S_y}{S_{INT}} = \frac{20{,}300\,psi}{3{,}753\,psi} = 5.40 > 3$$

The factor of safety for the canister lift based on ultimate strength is:

$$FS = \frac{S_u}{S_{INT}} = \frac{63{,}550\,psi}{3{,}753\,psi} = 16.93 > 5$$

Figure 3.4.3.2-1 Canister Lift Finite Element Model

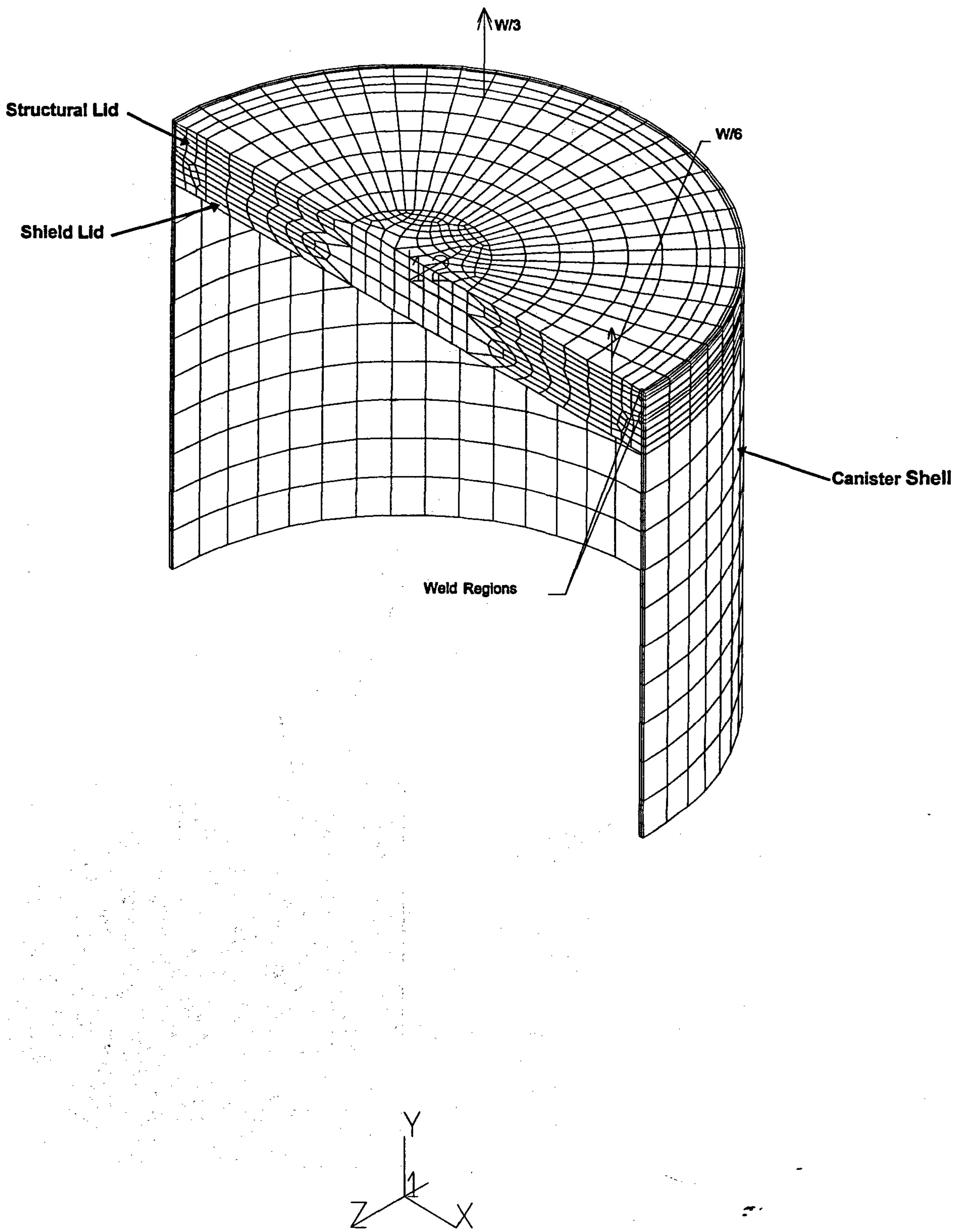
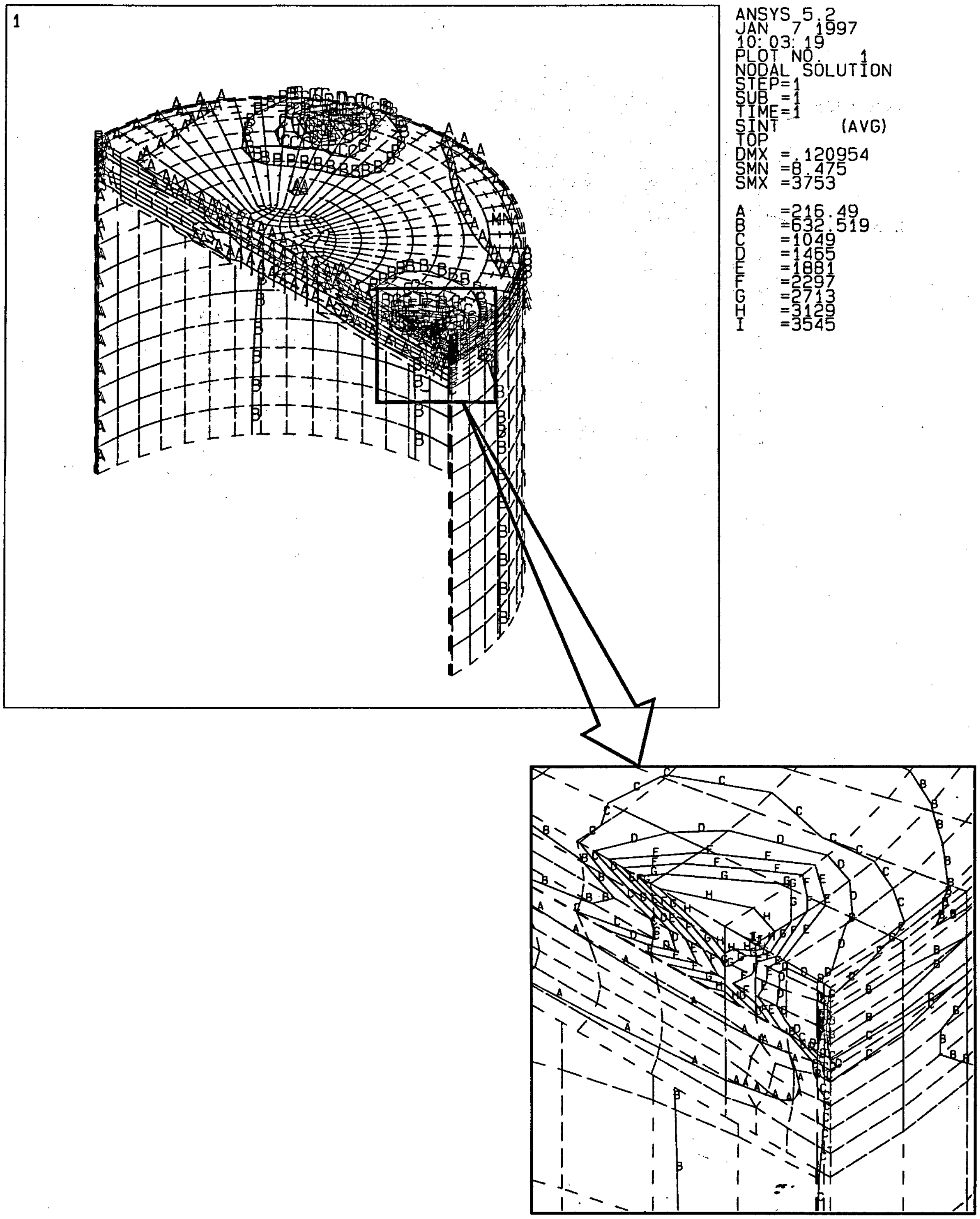


Figure 3.4.3.2-2 Canister Lift Model Stresses Intensity Contours (psi)



3.4.3.3 Transfer Cask Lift

The evaluation of the transfer cask presented here shows that the design meets ANSI N14.6 and NUREG 0612 for heavy lifts. The adequacy of the transfer cask is shown by evaluating the stress levels in all of the load-path components. The maximum weight of the loaded transfer cask is calculated to be 143,013 lbs. (Table 3.2-1). For this analysis, the transfer cask is conservatively assumed to weigh 150,000 lbs. A dynamic load factor of 10 percent is applied to establish a design basis loaded canister weight of 165,000 lbs.

3.4.3.3.1 Transfer Cask Shell and Trunnion

A structural evaluation was prepared for the transfer cask to evaluate the structural adequacy of the cask shell and trunnion during lifting conditions, in accordance with ANSI N14.6 and NUREG 0612.

An ANSYS 3-D model is used to evaluate the lifting of a fully loaded transfer cask. Because of symmetry, the 3D ANSYS model considers one quarter of the transfer cask. The model contains only the upper portion of the transfer cask since the purpose of this calculation is to evaluate the shells at the trunnion region. The lead and NS-4FR between the inner and outer shells of the transfer cask are also neglected since they are not structural components. SOLID95 and SHELL93 elements are used to model the trunnion and shells, respectively. BEAM4 elements are used at the interface of the trunnion and the shells to transfer moments from the SOLID95 elements to the SHELL93 elements. The ANSYS model is shown in Figure 3.4.3.3-1.

The total (design) load for the transfer cask is conservatively assumed to be 165,000 pounds, including a 10% dynamic load factor. The loading applied to the model is (165,000) / 4 = 41,250 lb. The load is applied upward at the trunnion as a "surface load". The location of the load is determined by the lifting yoke dimensions.

Per ANSI N14.6 and NUREG 0612, factors of safety of 6 on material yield strength and 10 on material ultimate strength are required. The maximum temperature in the transfer cask shell/trunnion region is 300°F. For the ASTM A-588 shell material, the yield strength, S_y, is 45.6 ksi, and the ultimate strength, S_u is 70 ksi at 300°F. The trunnions are constructed of ASTM A-350 carbon steel, Grade LF2. From the ASME Code, Section II, Part D, Tables U (S_u) and

Y-1 (S_y), the yield stress, S_y is found to be 31.9 ksi, and the ultimate stress, S_u, is found to be 70 ksi at 300°F.

Tables 3.4.3.3-1 and 3.4.3.3-2 provide a summary of the top 30 maximum stresses for the outer shell and inner shell, respectively (see Figures 3.4.3.3-2 and 3.4.3.3-3 for node locations for outer shell and inner shell, respectively). Stress contours plots for the outer shell and inner shell are shown in Figures 3.4.3.3-4 and 3.4.3.3-5, respectively. As shown in Table 3.4.3.3-1 and 3.4.3.3-2, all stresses, except the local stresses, meet the requirement of ANSI N14.6 and NUREG 0612 with a factor of safety of 6 on material yield strength and 10 on material ultimate strength. Per ANSI N14.6, Section 4.2.1.2, the high local stresses are relieved by slight local material yielding and the stress design factors are not applicable.

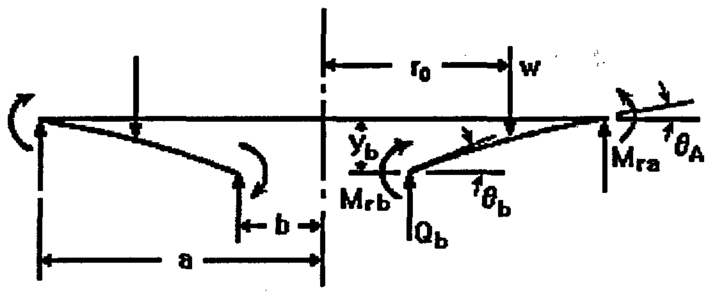
For the trunnion, the maximum bending and shear stress occur at the interface with the outer shell. The linearized stresses through the trunnion is 3,287 psi in bending and 1,221 psi in shear. Comparing to the material yield stress and ultimate stress (A350 carbon steel), the F.S. on yield and ultimate strength are 9.7 (> 6) and 21.3 (> 10), respectively.

3.4.3.3.2 Retaining Ring and Bolts

A retaining ring is bolted on the top of the transfer cask to prevent the inadvertent lifting of the canister out of the transfer cask, which could result in increased radiation exposure to nearby workers. In the event that the loaded transfer cask is inadvertently lifted during handling of the canister, the retaining ring and bolts must have sufficient strength to support the weight of the transfer cask.

Retaining Ring

To qualify the retaining ring, the equations presented in Roark for annular rings are utilized. The retaining ring is represented as shown in the sketch below (Roark, Table 24, Case 1e). The following sketch assists in defining the variables used to calculate the stress in the retaining ring and bolts. The model assumes a uniform annular line load w applied at radius r_o.



The boundary conditions for the model are outer edge fixed, inner edge free.

The material properties and parameters for the analysis are:

Plate dimensions:

thickness:

$t = 0.75$ in

bolt circle:

$a = 39.2$ in

outer radius (outer edge)

$c = 40.4$ in

inner radius:

$b = 34.3$ in

Weight of transfer cask (with 10% dynamic load factor):

$wt = 81{,}000 \text{ lb} \times 1.1$

Radial location of applied load:

$r_o = 35.3$ in

Ring material:

ASTM A588

Modulus of elasticity:

$E = 28.3 \times 10^6$ psi

Poisson's ratio:

$\nu = 0.31$

Number of bolts:

$Nb = 16$

Radial length of applied load:

$L_r = 2\pi r_o$

$L_r = 221.8$ in

Applied unit load:

$$w \equiv \frac{wt}{L_r}$$

$w = 401.7$ psi

The shear modulus is:

$$G = \frac{E}{2 \cdot (1 + \nu)}$$

$= 1.08 \times 10^7$ psi

A plate constant, D, is used in determining boundary values and in the general equations for deflection, slope, moment and shear.

$$D = \frac{E \cdot t^3}{12 \cdot (1 - v^2)}$$

$$D = 1.101 \times 10^6 \text{ lb-in}$$

Tangential shear constants, K_{sb} and K_{sro}, are used in determining the deflection due to shear:

$$K_{sro} = 1.2 \cdot \frac{r_o}{a} \cdot \ln\left(\frac{a}{r_o}\right)$$

$$= -0.113$$

$$K_{sb} = K_{sro}$$

The calculated shear stresses at points b and a (inner and outer radius) are:

$$\tau_b = 0 \text{ psi}$$

$$\tau_a = 482.3 \text{ psi}$$

The calculated radial bending stresses at points b and a (inner and outer radius) are:

$$\sigma_r(b) = 0 \text{ psi}$$

$$\sigma_r(a) = 15{,}220 \text{ psi}$$

The calculated tangential bending stresses at points b and a (inner and outer radius) are:

$$\sigma_t(b) = 828.0 \text{ psi}$$

$$\sigma_t(a) = 4{,}717.9 \text{ psi}$$

The principal stresses at the outer radius are:

$$\sigma_{1a} = \left(\frac{\sigma_r(a) + \sigma_t(a)}{2}\right) + \sqrt{\tau_a^{\,2} + \left(\frac{\sigma_r(a) - \sigma_t(a)}{2}\right)^2}$$

$\sigma_{1a} = 15{,}240$ psi

$$\sigma_{2a} = \left(\frac{\sigma_r(a) + \sigma_t(a)}{2}\right) - \sqrt{\tau_a^{\,2} + \left(\frac{\sigma_r(a) - \sigma_t(a)}{2}\right)^2}$$

$\sigma_{2a} = 4{,}695.8$ psi

$\sigma_{3a} = 0$ psi

The stress intensity at the outer radius ($P_m + P_b$) is:

$SI_a = \sigma_{1a} - \sigma_{3a}$

$SI_a = 15{,}240$ psi

The principal stresses at the inner radius are:

$$\sigma_{1b} = \left(\frac{\sigma_r(b) + \sigma_t(b)}{2}\right) + \sqrt{\tau_b^{\,2} + \left(\frac{\sigma_r(b) - \sigma_t(b)}{2}\right)^2}$$

$\sigma_{1b} = 0$ psi

$$\sigma_{2b} = \left(\frac{\sigma_r(b) + \sigma_t(b)}{2}\right) - \sqrt{\tau_b^{\,2} + \left(\frac{\sigma_r(b) - \sigma_t(b)}{2}\right)^2}$$

$\sigma_{2b} = -828.0$ psi

$\sigma_{3b} = 0$ psi

The stress intensity at the inner radius ($P_m + P_b$) is:

$$SI_b = \sigma_{1b} - \sigma_{2b}$$

$$SI_b = 828.0 \text{ psi}$$

The maximum stress intensity occurs at the outer radius of the retaining ring. For accident conditions, the allowable stress is equal to the lesser of 3.6 S_m and 1.0 S_u. For ASTM A588, the allowable stress at 300°F is S_u = 70 ksi. The calculated stress intensity of 15.24 ksi is less than the allowable stress and the margin of safety is +3.6.

<u>Retaining Ring Bolts</u>

The load on a single bolt, F_F, due to the reactive force caused by inadvertently lifting the canister, is:

$$F_F = \frac{wt}{Nb} \quad = 5{,}569 \text{ lb}$$

The load on each bolt, F_M, due to the bending moment, is:

$$F_M = \left(\frac{2 \cdot \pi \cdot a}{Nb}\right) \cdot \left(\frac{\sigma \cdot t^2}{6 \cdot L}\right)$$

$$F_M = 18{,}304 \text{ lb}$$

where

σ = the radial bending stress at point a (15,220 psi)

L = the distance between the bolt center line and ring outer edge (c - a = 1.2 inches)

The total tension, F, on each bolt is:

$$F = F_F + F_M = 23{,}873 \text{ lb}$$

The bolt cross-sectional area, A_b, is 0.4418 in^2. The bolt tensile stress is:

$$\sigma_t = \frac{F}{A_b} = 54{,}036 \text{ psi}$$

For accident conditions, the allowable stress for primary membrane plus bending stress in a bolt is S_y. S_y for A325 bolts is 73.9 ksi at 200°F. The margin of safety for the bolts is +0.37.

The top plate internal threads are evaluated for resistance to shear pull out. The screw specifications are 3/4-10 UNC (Class 2A external thread and class 2B internal thread):

D = 0.7482 in. (basic major diameter of the bolt threads)
n = 10 (number of bolt threads per inch)
$D_s min$ = 0.7353 in.(minimum major diameter of bolt threads)
$E_n max$ = 0.6927 in. (maximum pitch diameter of lid threads)
L_e = 2.25 - 0.75 = 1.5 in. (minimum thread engagement)

For the top plate (ASTM 588) at a temperature of 200°F, the yield and ultimate stresses are:

S_y = 47.5 ksi
S_u = 70.0 ksi
S_m = 23.3 ksi

The shear area for the internal (top plate) threads (A_n) is:

$$A_n = 3.1416 n L_e D_s min \left[\frac{1}{2n} + 0.57735(D_s min - E_n max)\right] = 2.584 \text{ in}^2$$

The shear stress (τ_n) in the top plate is:

$$\tau_n = \frac{F_y}{A_n} = \frac{23{,}873}{2.584} = 9{,}238 \text{ psi}$$

where

$F_y = F = F_F + F_M$

Conservatively, the shear allowable for normal conditions is used.

$\tau_{allowable} = (S_m)(0.6) = (23.3 \text{ ksi})(0.6) = 13.98$ ksi

The Margin of Safety is: (13,980/9,238) -1 = +0.5

3.4.3.3.3 <u>Rails and Welds – Shield Door</u>

This section demonstrates the adequacy of the shield doors, door rails, and welds in accordance with ANSI N14.6, which requires safety factors of 6 and 10 on material yield strength and ultimate strength, respectively.

The shield door rails support the weight of a wet, fully loaded canister and the weight of the shielding doors themselves. The shield doors are 9.5-inch thick plates resting on top of the bottom section of the door rails. The door rails are 9.88 inches deep by 6.5 inches thick and are welded to the bottom plate of the transfer cask. Both the doors and the rails are constructed of A-350, Grade LF2 carbon steel. The design load for the rails (considering 10% dynamic factor) is conservatively assumed to be:

$$W = 150{,}000 \times 1.1 = 165{,}000 \text{ lbs.}$$

This evaluation shows that the shield doors, door rail structures, and welds are adequate to support a wet, fully loaded canister.

Operating Conditions

Based on the thermal analysis as presented in Chapter 4, the maximum calculated temperature for the transfer cask doors is 257°F. The material allowables are conservatively taken at 300°F.

Material Properties

The material properties for the ASTM A-350, Grade LF2, carbon steel are taken from the ASME Code, Division II, Part D, Tables U (S_u) and Y-1 (S_y).

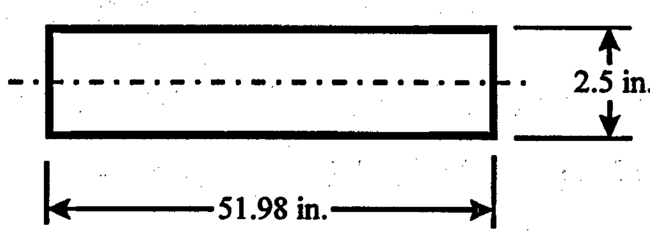
Yield Strength (S_y) = 31.9 ksi at 300° F (ASTM A-350)
Ultimate Strength (S_u)= 70.0 ksi at 300°F (ASTM A-350)

Stress Evaluation for Door Rail

The shear stress in each door rail bottom plate due to the applied load of W is:

$$\tau = \frac{W}{2 \times A_S} = \frac{165}{2 \times 129.95} = 0.64 \text{ ksi}$$

where,



A_s = Shear area

$= L \times t = 129.95 \text{ in}^2$,

and,

L = rail length supporting doors = 2x(45.38-17.39- 4/2) = 51.98 inch,

t = bottom plate thickness = 2.5 inch.

The bending stress in each rail bottom section due to the applied load of W is:

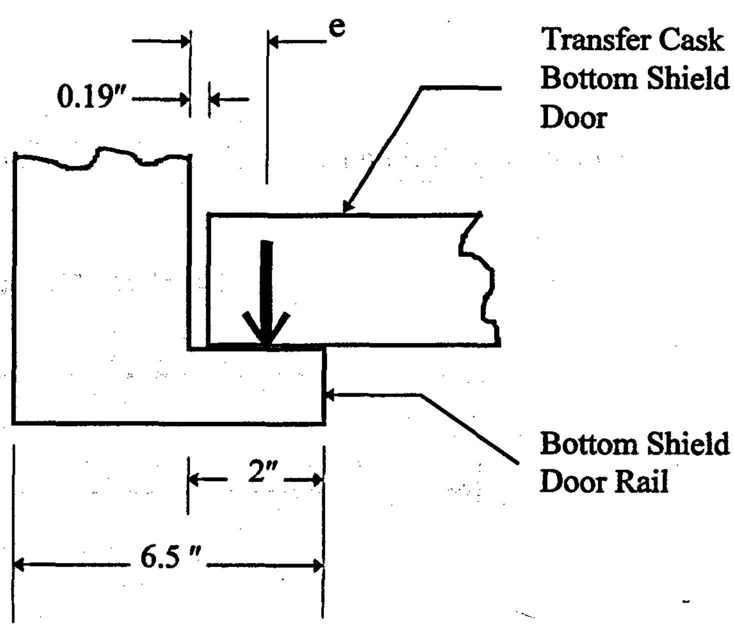
$$\sigma_b = \frac{M}{S} = \frac{90.8}{54.15} = 1.68 \text{ ksi},$$

where,

M = moment at the bottom section ,

$$= \frac{W}{2} \text{ x e} = \frac{165}{2} \times 1.1$$

= 90.8 in-kips,



and,

$$e = \frac{2-0.19}{2} + 0.19 = 1.1 \text{ inch applied load moment arm.}$$

$$S = \frac{b \times d^2}{6} = \frac{51.98 \times 2.5^2}{6}$$

$$= 54.15 \text{ in}^3.$$

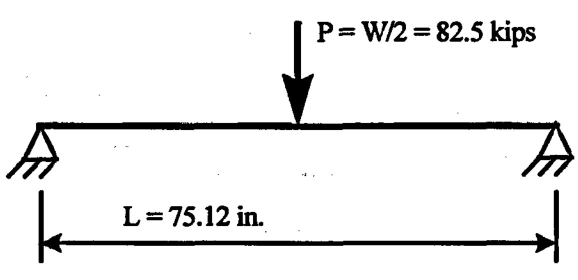
Per ANSI N14.6, Section 4.2.1, shear stress or maximum tensile stress are to be compared with material yield and ultimate strength. The resulting factors of safety are:

$$\varphi_y = \frac{31.9}{1.68} = 19.0 > 6 \qquad \text{(For yield strength criteria)}$$

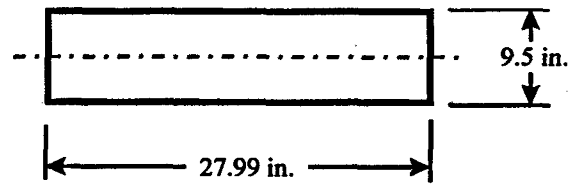
$$\varphi_u = \frac{70}{1.68} = 41.7 > 10 \qquad \text{(For ultimate strength criteria)}$$

<u>Stress Evaluation for the Shield Doors</u>

The shield doors consist of two 9.5-inch thick plates that rest on top of the rails. Stresses can be approximated by modeling the shield door as a simply supported beam with a concentrated load at the center.



The shear stress in each shield door is



(Shield Door Cross Section)

$$\tau = \frac{W}{2 \times A_S} = \frac{165}{2 \times (27.99 \times 9.5)}$$

$$= 0.31 \text{ ksi}$$

and the bending stress in each shield door is

$$\sigma_b = \frac{M}{S} = \frac{1549.35}{421} = 3.68 \text{ ksi},$$

where,

M = moment at the bottom section,

$$= \frac{P \times L}{4} = \frac{82.5 \times 75.12}{4} = 1549.35 \text{ in-kips},$$

S = section modulus

$$= \frac{b \times d^2}{6} = \frac{27.99 \times 9.5^2}{6} = 421 \text{ in}^3$$

The factors of safety are

$$\varphi_y = \frac{31.9}{3.68} = 8.7 > 6$$ (For yield strength criteria)

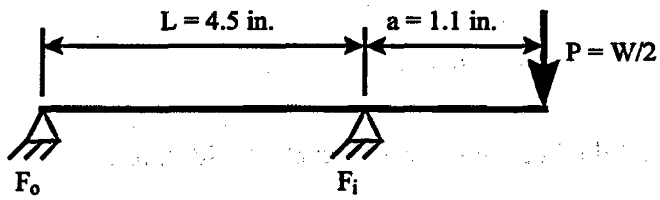
$$\varphi_u = \frac{70}{3.68} = 19.0 > 10$$ (For ultimate strength criteria)

Door Rail Weld Evaluation

The rail welds were evaluated by determining the reactive forces, F_o and F_i, experienced by the outer and inner welds due to applied load, W.

$$F_o = \frac{P \times a}{L} = \frac{165}{2} \times \frac{1.1}{4.5}$$

$$= 20.17 \text{ kips}$$



$$F_i = \frac{165}{2} + 20.17 = 102.67 \text{ kips}$$

Maximum stresses at the groove weld (size = 0.75 inch) are

$$= \frac{102.67}{56.25 \times 0.75} = 2.4 \text{ ksi}$$

The factors of safety are

$$\varphi_y = \frac{31.9}{2.4} = 13.3 > 6$$ (For yield strength criteria)

$$\varphi_u = \frac{70}{2.4} = 29.2 > 10$$ (For ultimate strength criteria)

Figure 3.4.3.3-1 Finite Element Model for Transfer Cask Trunnion and Shells

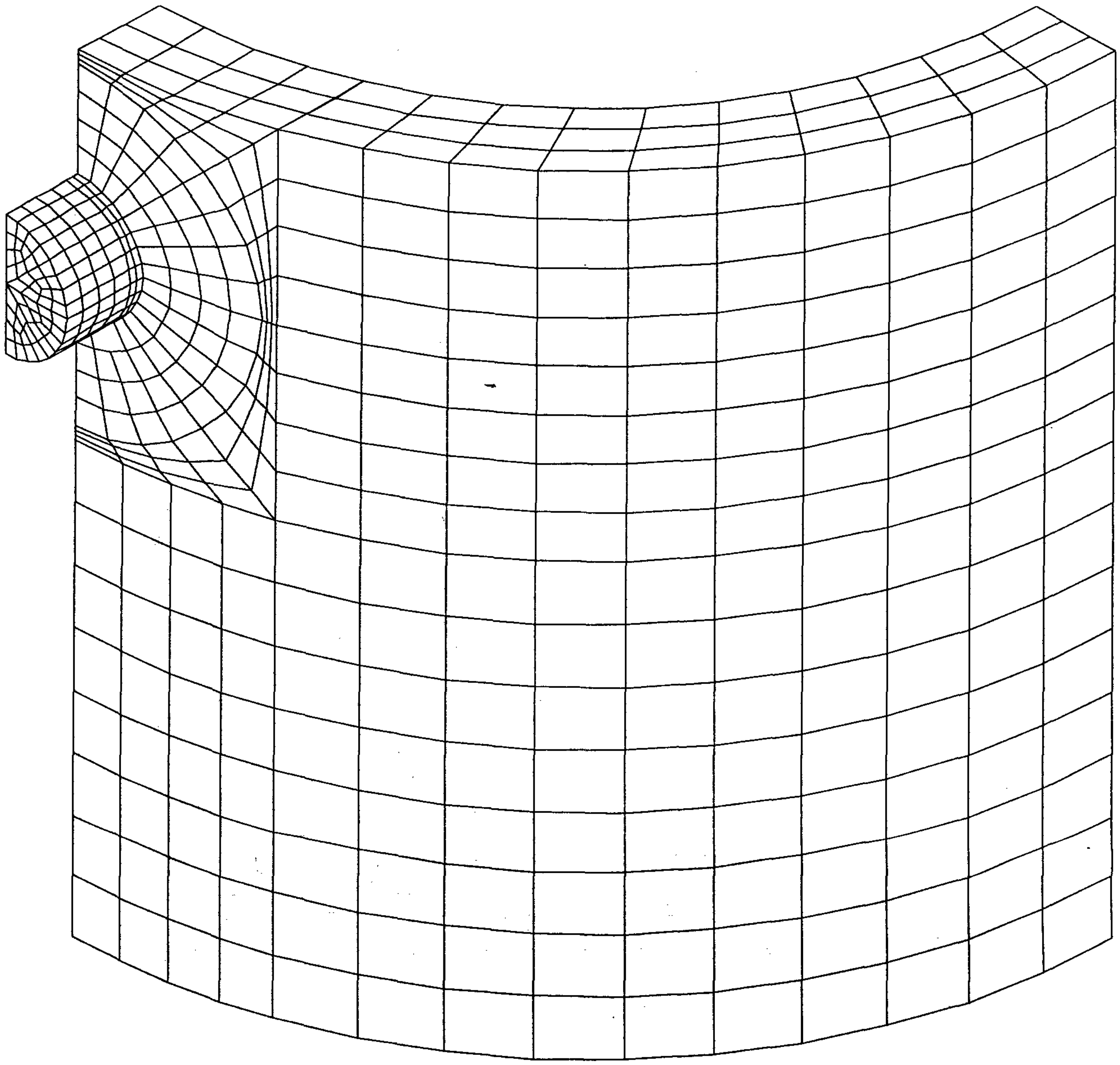


Figure 3.4.3.3-2 Node Locations for Transfer Cask Outer Shell Adjacent To Trunnion

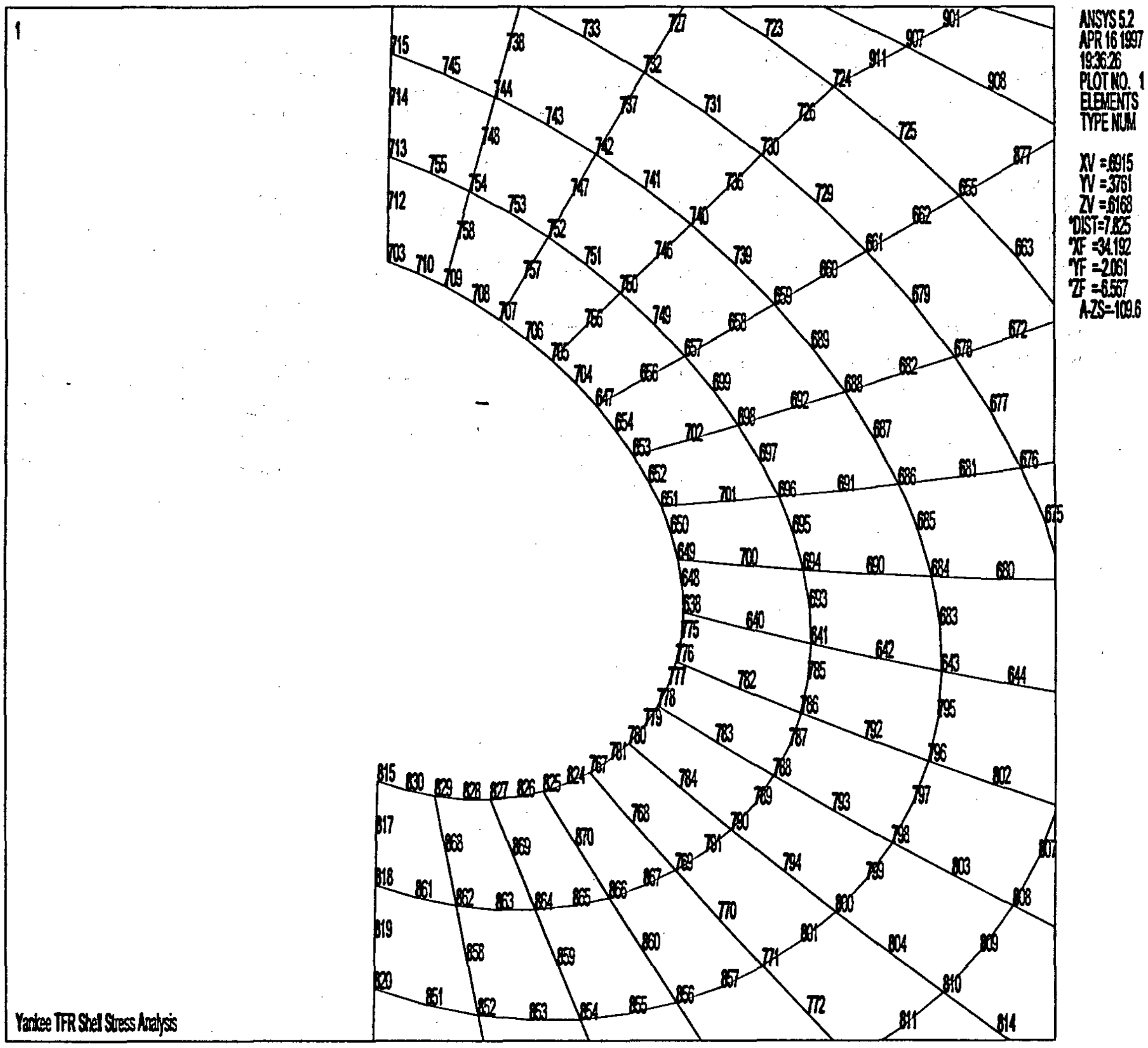


Figure 3.4.3.3-3 Node Locations for Transfer Cask Inner Shell Adjacent To Trunnion

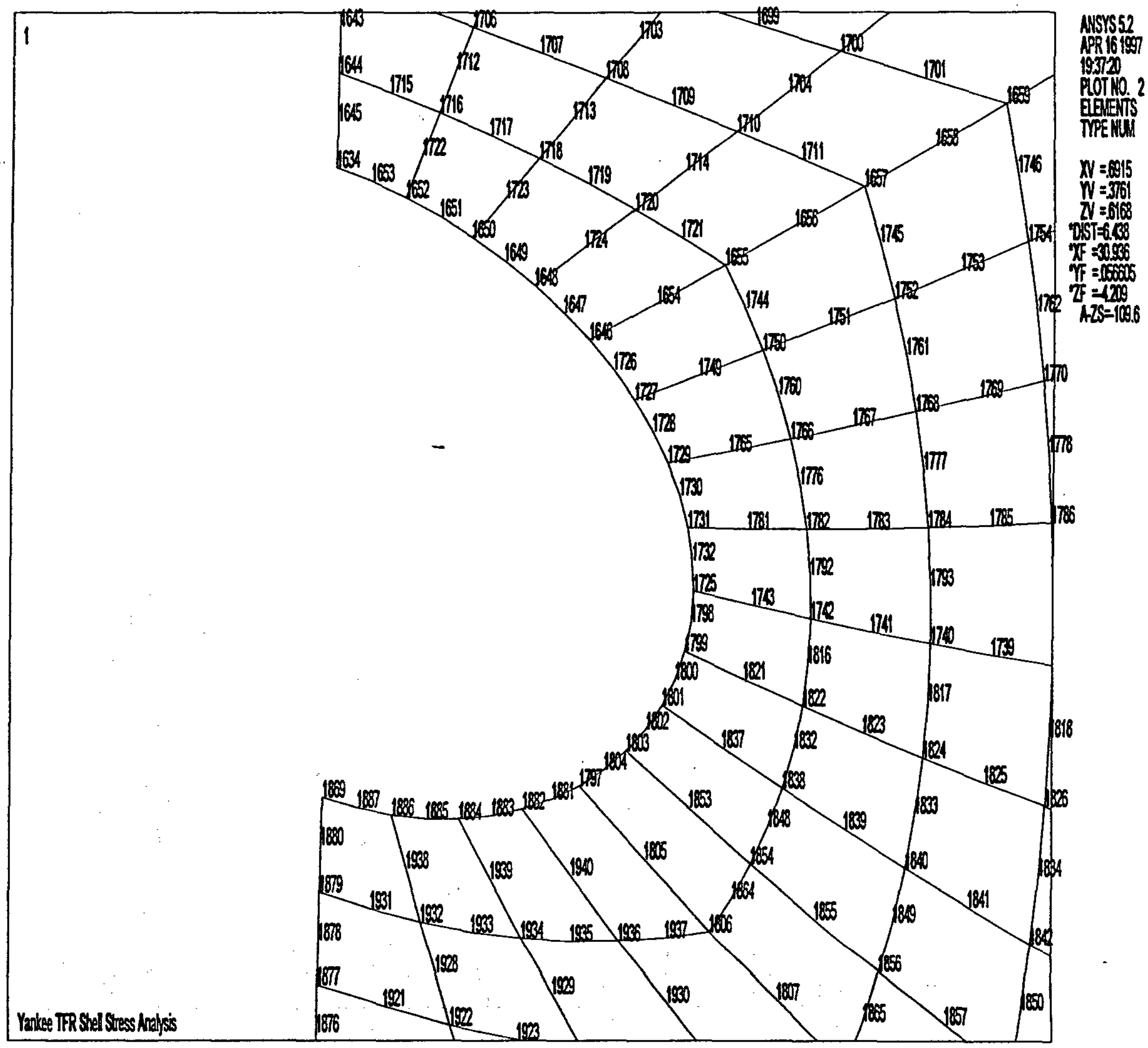


Figure 3.4.3.3-4 Stress Contours for Transfer Cask Outer Shell

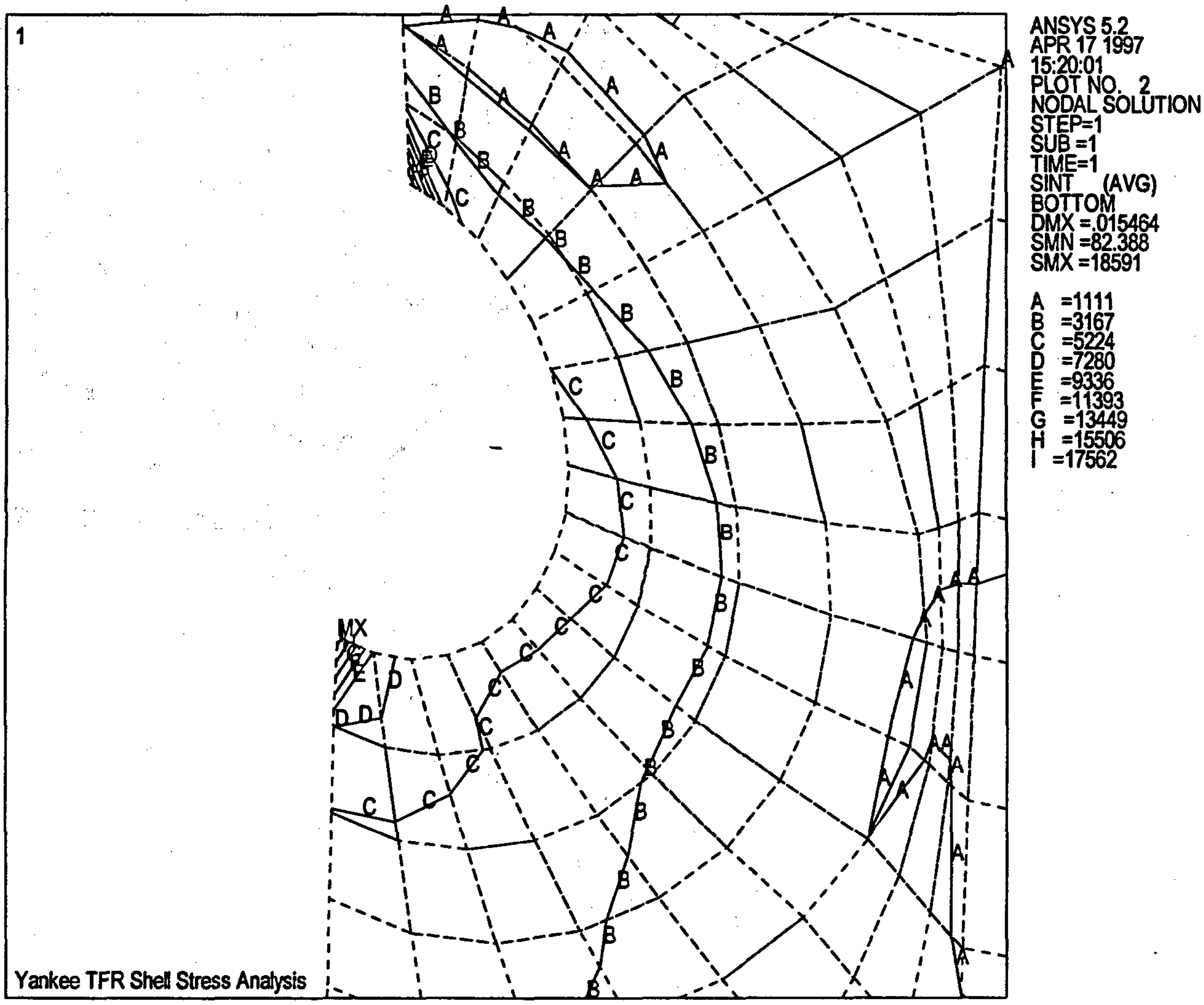


Figure 3.4.3.3-5 Stress Contours for Transfer Cask Inner Shell

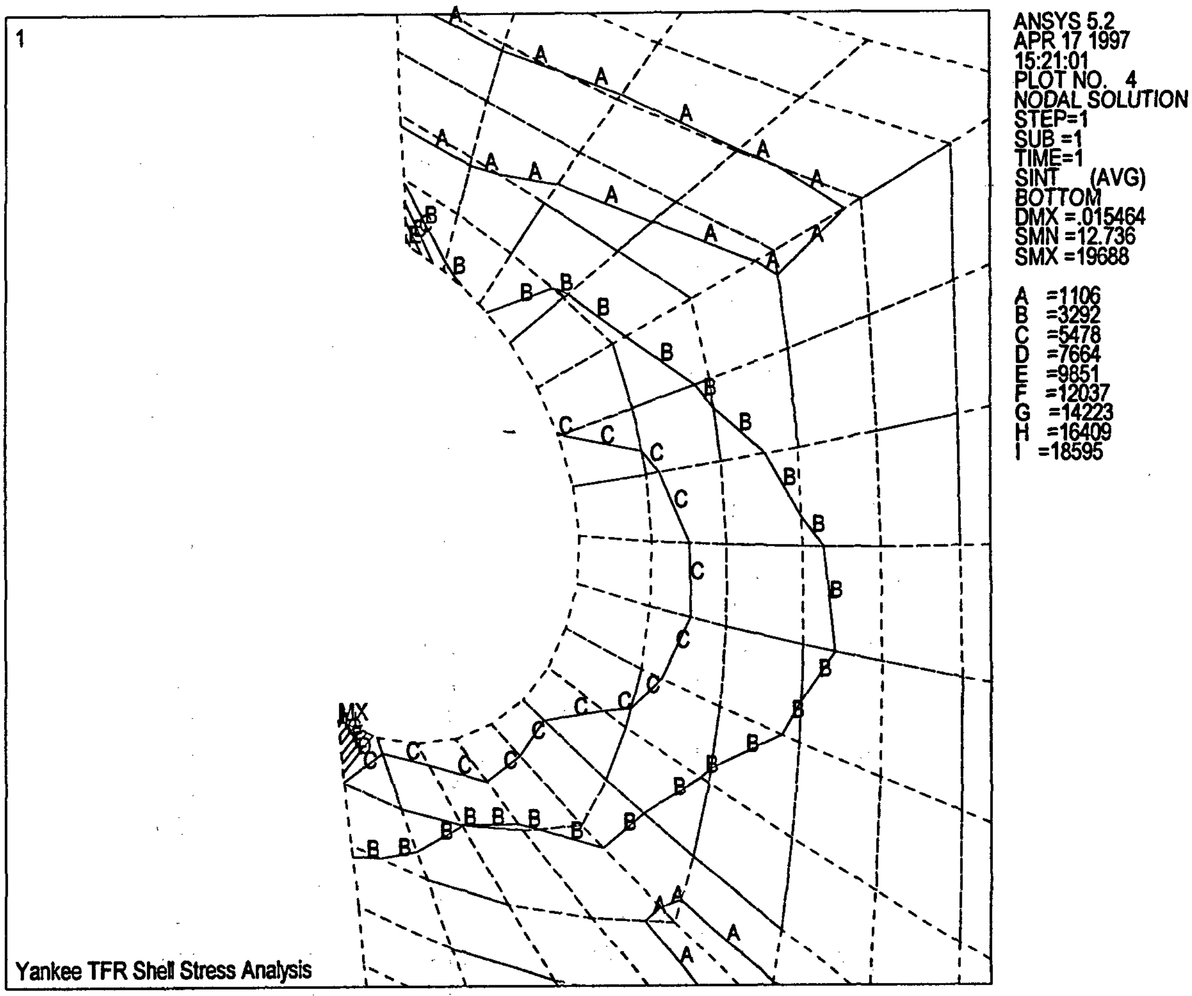


Table 3.4.3.3-1 Top 30 Stresses for Transfer Cask Outer Shell

Node[1]	Principal Stresses (psi) S1	S2	S3	Nodal S.I. (psi)	F.S. on Yield[2] (S_y/S.I.)	F.S. on Ultimate[2] (S_u/S.I.)
815	18395	1593.7	-195.14	18591[3]	N/A	N/A
703	512.98	-1170.3	-16452	16965[3]	N/A	N/A
829	8895.7	4797.9	-20.588	8916.2[3]	N/A	N/A
818	7296.6	1839.7	-7.8552	7304.4[3]	N/A	N/A
862	6536.6	2745.7	-9.4784	6546	7.0	10.7
638	3595.9	-19.633	-2848.4	6444.3	7.1	10.9
776	4756.4	314.84	-1459.5	6215.9	7.3	11.3
871	18.466	-866.71	-6128.8	6147.2	7.4	11.4
709	93.408	-5325.4	-6033.2	6126.6	7.4	11.4
649	2094.5	-385.96	-3988.5	6083	7.5	11.5
827	5931.4	3499.1	-24.444	5955.9	7.7	11.8
778	5262.6	1098.1	-595.23	5857.9	7.8	11.9
864	5725.4	2444.8	-5.0196	5730.4	8.0	12.2
873	17.86	-668.51	-5669.4	5687.3	8.0	12.3
780	5345.3	2320.7	-313.59	5658.9	8.1	12.4
651	1052.3	-1275.6	-4516.8	5569.1	8.2	12.6
767	5246.3	3215.3	-188.33	5434.6	8.4	12.9
825	5317.3	3368.9	-91.577	5408.9	8.4	12.9
875	17.578	-482.15	-5250.6	5268.2	8.7	13.3
883	29.511	-789.43	-5198.3	5227.8	8.7	13.4
653	670.82	-2716.1	-4540.7	5211.5	8.7	13.4
866	5135.7	1721.4	0.66016	5135	8.9	13.6
820	5118.7	2375.9	-1.6525	5120.3	8.9	13.7
893	30.529	-567.18	-4905	4935.5	9.2	14.2
852	4898.5	2243.8	-2.5875	4901.1	9.3	14.3
769	4816.4	1032.1	-1.2375	4817.7	9.5	14.5
647	505.55	-3770.9	-4172.3	4677.9	9.7	15.0
641	2895.5	1.2697	-1776.8	4672.3	9.8	15.0
694	2169.8	4.4459	-2469.6	4639.4	9.8	15.1
903	32.924	-362.76	-4599.4	4632.4	9.8	15.1

Notes:
1. See Figure 3.4.3.3-2 for node locations
2. S_y = 45,600 psi, S_u = 70,000 psi
3. Local stresses that are relieved by local material yielding. Therefore, stress design factors of 6 and 10 on material yield and ultimate strength are not applicable (ANSI N14.6, Section 4.2.1.2)

Table 3.4.3.3-2 Top 30 Stresses for Transfer Cask Inner Shell

	Principal Stresses (psi)			Nodal S.I.	F.S. on Yield[2]	F.S. on Ultimate[2]
Node[1]	S1	S2	S3	(psi)	(S_y/S.I.)	(S_u/S.I.)
1869	17689	436.58	-1999.3	19688[3]	N/A	N/A
1634	9754.8	619.16	-759.58	10514[3]	N/A	N/A
1882	7096.9	803.79	-559.18	7656[3]	N/A	N/A
1731	2629	-50.822	-4142.7	6771.7	6.7	10.3
1725	1528.8	-289.56	-5044.6	6573.4	6.9	10.6
1884	5878.7	463.76	-401.23	6279.9	7.3	11.1
1729	3436.2	79.26	-2823.1	6259.4	7.3	11.2
1742	2276.9	0.49938	-3877.4	6154.4	7.4	11.4
1782	2681.2	0.15472	-3465.3	6146.5	7.4	11.4
1797	936.56	190.95	-5161.7	6098.2	7.5	11.5
1801	499.98	-2533.2	-5548.2	6048.1	7.5	11.6
1799	674.7	-1179.9	-5362.4	6037.1	7.6	11.6
1886	5937.1	2421.9	-85.981	6023.1	7.6	11.6
1803	469.31	-3500.1	-5469.9	5939.2	7.7	11.8
1822	1911.9	5.7018	-4006.7	5918.5	7.7	11.8
1766	2791.3	-1.7689	-2991.6	5783	7.9	12.1
1727	3960.6	331.95	-1535.6	5496.2	8.3	12.7
1879	5014.2	118.74	-303.37	5317.6	8.6	13.2
1838	1675.8	22.011	-3579.3	5255.1	8.7	13.3
1646	4023.3	708.54	-1131	5154.4	8.8	13.6
1750	2409.6	-7.2699	-2506.8	4916.4	9.3	14.2
1740	2413.9	-1.0861	-2489.3	4903.3	9.3	14.3
1784	2271.4	-0.2874	-2557.6	4829	9.4	14.5
1824	2217	-0.4888	-1981.1	4198.1	10.9	16.7
1854	1463.1	39.789	-2681.4	4144.5	11.0	16.9
1806	3183.2	68.412	-943.43	4126.6	11.1	17.0
1768	1787.3	-0.4604	-2229.5	4016.7	11.4	17.4
1648	3076.7	1254.1	-849.56	3926.2	11.6	17.8
1932	3633.4	1174.9	-9.7208	3643.1	12.5	19.2
1738	2162.3	1.0241	-1473.5	3635.8	12.5	19.3

Notes:
1. See Figure 3.4.3.3-3 for node locations
2. S_y = 45,600 psi, S_u = 70,000 psi
3. Local stresses that are relieved by local material yielding. Therefore, stress design factors of 6 and 10 on material yield and ultimate strength are not applicable (ANSI N14.6, Section 4.2.1.2)

3.4.4 NAC-MPC Components Under Normal Operating Loads

The NAC-MPC system is evaluated using individual finite element models for the fuel basket, canister, and vertical concrete cask. Since the individual components are free to expand without interference, the structural finite element models need not be connected.

3.4.4.1 Canister and Basket Analyses

3.4.4.1.1 Canister Thermal Stress Analysis

A three-dimensional finite element model of the canister was constructed using ANSYS SOLID45 elements. By taking advantage of the symmetry of the canister, the model represents one-half (180° section) of the canister including the canister shell, bottom plate, structural lid, and shield lid. The model uses gap/spring elements to simulate contact between adjacent components. Specifically, contact between the structural and shield lids was modeled using COMBIN40 combination elements in the axial (UY) degree of freedom. Simulation of the backing ring is accomplished using a ring of COMBIN40 gap/spring elements connecting the shield lid and the canister in the axial direction at the lid lower outside radius. In addition, CONTAC52 elements were used to model the interaction between the structural lid and the canister shell and between the shield lid and canister shell, just below the respective lid weld joints. The size of the CONTAC52 gaps was determined from 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 were assigned a stiffness of 1E+8 lb/in. The three-dimensional ANSYS model of the canister used in the thermal stress evaluation is shown in Figure 3.4.4.1-1 through Figure 3.4.4.1-3.

The ANSYS thermal stress analysis was performed with canister temperatures that enveloped the canister temperature gradients for normal storage (100°F and -40°F ambient temperatures) and transfer conditions. Prior to performing the thermal stress analysis, the steady-state temperature distribution was determined using temperature information from the storage and transfer thermal analyses (Chapter 4). This was accomplished by converting the SOLID45 structural elements of the canister model to SOLID70 thermal elements and using the material properties from the thermal analyses. Nodal temperatures were applied at six key locations (i.e., top-center of the structural lid, top-outer diameter of the structural lid, bottom-center of the shield lid, bottom-

center of the bottom plate, bottom-outer diameter of the bottom plate, and mid-elevation of the canister shell). The temperatures of the key locations used in the analysis were as follows:

Top center of the structural lid	=	140°F
Top outer diameter of the structural lid	=	100°F
Bottom center of the shield lid	=	165°F
Bottom center of the bottom plate	=	250°F
Bottom outer diameter of the bottom plate	=	130°F
Mid-elevation of the canister shell	=	500°F

The temperatures for all nodes in the canister model were obtained by the solution of the steady state thermal conduction problem.

These temperatures were selected to envelope the temperature differences experienced by the canister for storage and transfer conditions as calculated in the thermal analysis presented in Chapter 4. The following table shows the temperature differences (ΔT) of the canister in the radial and axial directions for the storage and transfer conditions and those used in the canister thermal stress analysis:

	Maximum ΔT (°F)		
Condition	Top of Structural Lid (Radial)	Bottom Plate (Radial)	Canister Shell (Axial)
Storage, Normal 75°F ambient	17	113	223
Storage, Off-Normal 100°F ambient	17	115	225
Storage, Off-Normal, -40°F ambient	15	104	213
Storage, Off-Normal Half Inlets Blocked	16	115	221
Transfer, 75°F ambient	5	21	386
Canister Thermal Stress Analysis	40	120	400

Additionally, canister temperatures used for determining allowable stress values were selected to envelope the maximum temperatures experienced by the canister during storage and transfer conditions. Specifically, allowable stresses were selected at temperatures of 250°F, 550°F, and 250°F for the structural/shield lid region, the canister shell, and the bottom plate region, respectively.

After solving for the canister temperature distribution, the thermal stress analysis was then performed by converting the SOLID70 elements back to SOLID45 structural elements. A single node at the centerline of the bottom plate is restrained in the axial direction (UY) to eliminate rigid body translation in the Y-direction. The nodes along the centerline of the structural and shield lids and the bottom plate were restrained in the x-direction (UX) to prevent rigid body motion in the x-direction. The nodes on the symmetry boundary face were restrained in the direction normal to the symmetry plane (UZ). A linear solution was performed to obtain the stresses due to thermal expansion.

The resulting maximum (secondary) thermal stresses in the canister are summarized in Table 3.4.4.1-1. The sectional stresses at 15 axial locations were obtained for each angular division of the model (a total of 21 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4.

3.4.4.1.2 Canister Dead Weight Load Analysis

The canister was structurally analyzed for dead weight load using the ANSYS model described in Section 3.4.4.1.1. The canister temperature distribution discussed in Section 3.4.4.1.1 was used in the dead load structural analysis to evaluate the material allowable stresses at temperature. The fuel and fuel basket assembly contained within the canister were not explicitly modeled but were included in the analysis by applying a uniform pressure load representing their combined weight to the top surface of the canister bottom plate. The nodes on the bottom surface of the bottom plate were restrained in the axial direction in conjunction with the constraints described in Section 3.4.4.1.1. An acceleration of 1g was applied to the model in the axial direction (Y) to simulate the dead load.

The resulting maximum canister dead load stresses are summarized in Tables 3.4.4.1-2 and 3.4.4.1-3 for primary membrane and primary membrane plus bending stresses, respectively. The sectional stresses at 15 axial locations were obtained for each angular division of the model (a total of 21 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4.

The lid support ring is evaluated for the dead load condition using classical methods. The lid support ring is welded to the inner surface of the canister shell, under the shield lid. The lid support ring is made of ASTM A-479, Type 304 stainless steel. A temperature of 600°F is conservatively used to determine the material allowable stress. The total weight, W, imposed on the lid support ring is conservatively considered to be the weight of the structural lid (3234 lbs), the shield lid (5389 lbs) and the weight of the backing ring (16 lbs). The stresses on the support ring are the bearing stresses and shear stresses at its weld to the canister shell.

The bearing stress $\sigma_{bearing}$ is calculated as follow:

$$\sigma_{bearing} = \frac{W}{area}$$

$$= \frac{8639}{108}$$

$$= 80 \text{ psi}$$

where,

$W = 3234 + 5389 + 16$

$= 8639$ lbs

area $= \pi \times D \times t$ $= 108\ in^2$

D = lid support ring average diameter = 68.89 inch
t = radial thickness of support ring = 0.5 inch

The yield strength (S_y) for A-479, Type 304 stainless steel is 18,600 psi @ 600°F. The allowable bearing stress is 1.0 S_y per ASME Section III, Subsection NB.

Margin of Safety = (18,600/80) -1

= + Large

The weld for the lid support ring is a 3/8 inch partial penetration groove weld. The total shear force on the weld is considered to be the weight of the structural and shield lids, the backing ring, and the lid support ring (8,655 lbs). The shear stress on the weld is calculated as follows:

$$\sigma_w = \frac{W}{area}$$

$$= \frac{8655}{81.32}$$

$$= 106 \text{ psi}$$

where,

area	$= \pi \times D \times t_w$	=	81.32 in^2
D	= shield lid diameter	=	69.03 inch
t_w	= weld size	=	0.375 inch

The yield strength (S_y) for A-479, Type 304 stainless steel is 18,600 psi @ 600°F. In accordance with ASME Section III, Subsection NB, the allowable shear stress is 0.6 x S_m.

Margin of Safety = (0.6 x (2/3) x 18,600) / 106 -1

= + large

3.4.4.1.3 Canister Maximum Internal Pressure Analysis

The canister was structurally analyzed for a maximum internal pressure load using the ANSYS model and temperature distribution and restraints described in Section 3.4.4.1.1. A maximum internal pressure of 11.5 psi was applied as a surface force to the elements along the internal surface of the canister shell, bottom plate, and shield lid.

The resulting maximum canister stresses for maximum internal pressure load are summarized in Tables 3.4.4.1-4 and 3.4.4.1-5 for primary membrane and primary membrane plus primary bending stresses, respectively. The sectional stresses at 15 axial locations were obtained for each angular division of the model (a total of 21 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4.

3.4.4.1.4 Canister Handling Analysis

The canister was structurally analyzed for handling loads using the ANSYS model and conditions described in Section 3.4.4.1.1. Normal handling of the canister was simulated by restraining the model at three lift points and applying a 1.1g acceleration load to the model in the axial direction, which includes a 10% dynamic load factor. The canister is lifted at six points; however, the handling analysis considers only a three-point lifting configuration. Since the model represents a one-half section of the canister, the three-point lift was simulated by restraining two nodes 120° apart (one node at the symmetry plane and a second node 120° from the first) along the bolt diameter at the top of the structural lid in the axial direction. Additionally, the nodes along the centerline of the lids and bottom plate were restrained in the radial direction, and the nodes along the symmetry face were restrained in the direction normal to the symmetry plane.

The resulting maximum stresses in the canister for the handling load are summarized in Tables 3.4.4.1-6 and 3.4.4.1-7 for primary membrane and primary membrane plus primary bending stresses, respectively. The sectional stresses at 15 axial locations were obtained for each angular division of the model (a total of 21 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4.

3.4.4.1.5 Canister Load Combination

The canister was structurally analyzed for the combined thermal, dead, maximum internal pressure, and handling loads using the ANSYS model and conditions described in Section 3.4.4.1.1. Loads were applied to the model as discussed in Sections 3.4.4.1.1 through 3.4.4.1.4. A maximum internal pressure of 11.5 psi was used in conjunction with a positive axial acceleration of 1.1g. Two nodes 120° apart (one node at the symmetry plane and a second node 120° from the first) were restrained along the bolt diameter at the top of the structural lid in the axial direction. Additionally, the nodes along the centerline of the lids and bottom plate were restrained in the radial direction, and the nodes along the symmetry face were restrained in the direction normal to the symmetry plane.

The resulting maximum stresses in the canister for combined loads are summarized in Tables 3.4.4.1-8, 3.4.4.1-9, and 3.4.4.1-10 for primary membrane, primary membrane plus primary bending, and primary membrane plus primary bending plus secondary stresses, respectively. The sectional stresses at 15 axial locations were obtained for each angular division of the model (a total of 21 angular locations for each axial location). The locations for the stress sections are shown in Figure 3.4.4.1-4. As shown in Tables 3.4.4.1-8 through 3.4.4.1-10, the canister maintains positive margins of safety for the combined load condition.

3.4.4.1.6 Canister Fatigue Evaluation

The purpose of this section is to evaluate the effects of thermal and mechanical cyclic loading conditions on the canister during storage conditions using the criteria presented in ASME Code, Section III, Subsection NB-3222.4 for the canister and Subsection NG-3222.4 for the fuel basket.

During storage conditions, the canister is housed in the vertical concrete storage cask. The storage cask is a shielded reinforced concrete overpack designed to hold a canister during long-term storage conditions. The storage cask is constructed of a thick inner steel liner surrounded by twenty-one inches of reinforced concrete. Because the carbon steel inner liner will be subjected to a number of temperature/stress loading cycles (1 cycle x 365 days x 50 years = 18,250 cycles) that is less than the minimum number (20,000 cycles) specified for evaluation in Table A-K4.1 of the AISC Manual of Steel Construction, no further fatigue evaluation of the inner liner is required.

Fatigue effects on the canister are addressed using the criteria presented in ASME Section III, Subsection NB-3222.4 and NG-3222.4.

In accordance with these subsections, fatigue analysis need not be performed provided the conditions of six cases are met. The six cases are as follows:

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

Evaluation of these conditions is presented in the following sections.

Condition 1 — Atmospheric to Service Pressure Cycle

The ASME code requires that the specified number of times that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during normal service does not exceed the number of allowable cycles for the material. In the case of the canister and basket, the cycle from atmospheric to service pressure happens only twice. Since this operation occurs only twice during the 50-year life of the canister (once when the canister is sealed and once when it is opened), atmospheric to service pressure cycle loading of the canister and basket does not cause fatigue failure.

Condition 2 — Normal Service Pressure Fluctuation

To prevent fatigue failure of the canister, the specified full range of pressure fluctuations during normal service must not exceed:

$$P_f = \frac{1}{3} \times P_d \times \left(\frac{S_a}{S_m}\right) = \frac{20 \times 28.2}{3 \times 16.7} = 11.3 \text{ psi},$$

where,

S_a = 28.2 ksi, the value obtained from the design fatigue curve for service cycles < 10^6,

S_m = 16.7 ksi, the allowable stress intensity,

P_d = 20 psi, the design pressure (bounds maximum pressure of 17.93 psi for transfer conditions).

The maximum pressure differential for the canister occurs between transfer and storage conditions. For normal and transfer conditions the maximum pressure differential is

$$\Delta P = 17.93 - 11.32 = 6.61 \text{ psi} < 11.3 \text{ psi}.$$

Therefore, the effective number of cycles is zero.

Condition 3 — Temperature Difference — Startup and Shutdown

This condition is not applicable. It is only required for power plant startup and shutdown processes.

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

Canister Evaluation

The ASME Code specifies that temperature excursions are not significant if the temperature difference between two adjacent points does not change by more than the quantity:

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

where,

S_a = 28,200 psi, the value obtained from the fatigue curve for service cycles < 10^6,

E = 27×10^6 psi, modulus of elasticity at 300 °F,

α = 9×10^{-6} in./in./°F.

For surface temperature differences on surfaces of revolution in the meridional (axial) direction, adjacent points are defined as points that are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface, from the axis of rotation to the midwall and t is the thickness of the part at the point under consideration. For surface temperature differences on surfaces of revolution in the circumferential direction and on flat parts, such as flanges and flat heads, adjacent points are defined as any two points on the same surface.

The greatest cyclic temperature difference will occur between the off-normal, severe hot (ambient temperature = 100°F) and the off-normal, severe cold (ambient temperature = -40°F) conditions as evaluated in the thermal evaluation. Accident temperature conditions are not applicable.

At the hot condition the canister bottom plate temperature varies from 237°F at its center to 123°F at its extreme radial point, a ΔT of 114°F. At the cold condition, the canister bottom plate temperature varies from 78.3°F at its center to -24.6°F at its extreme radial point, a ΔT of 102.9°F. Therefore, in cycling from 100°F ambient to -40°F ambient conditions, the ΔT between adjacent points changes by 11.1°F, which is less than the 58°F ΔT and is not considered to be a significant excursion. Heat transfer is uniform around the circumference therefore, no cyclic ΔT exists in adjacent points on a circumference of the shell.

At the hot condition the canister shell temperature varies from 347.5°F at its center to 121.9°F at its top, a ΔT of 225.6°F. At the cold condition, the canister shell temperature varies from 187.4°F at its center to -25.6°F at its top, a ΔT of 213°F. The distance between adjacent points is

$$d_p = 2\sqrt{Rt} = 9.35 \text{ in.},$$

where,

R = 70.64/2 - 0.625/2 = 35.0 in, the mean radius of the canister shell,

t = 0.625 in., the wall thickness of the canister shell.

At T_{amb}=100 °F, the ΔT between center of canister and end of canister = (347.5°F - 121.9°F) = 225.6°F. The ΔT of adjacent points is (225.6°F / 61.25 in.)(9.35 in.) = 34.4°F.

At T_{amb} = -40 °F, the ΔT between center of canister and end of canister = [187.4°F - (-25.6°F)] = 213°F. The ΔT of adjacent points is (213.0°F / 61.25 in.)(9.35 in.) = 32.5°F.

Therefore, in cycling from 100°F ambient to -40°F ambient conditions, the ΔT between adjacent points changes by 1.9°F, which is less than the 58°F ΔT and is not considered to be a significant excursion.

Basket Evaluation

In storage, the basket is isolated from the influence of environmental temperature excursions by the canister. Any temperature differences within the basket structure are bounded by the evaluation of the temperature differences evaluated for the canister.

Condition 5 — Temperature Difference Between Dissimilar Materials

The canister is constructed of 304L stainless steel and does not contain dissimilar materials. The basket is constructed of several materials. However, all materials except the support disks are free to expand, thus relieving any thermal stress concentration. As noted under the Condition 4 discussion, the temperature differences within the basket are bounded by the temperature differences evaluated for the canister.

Condition 6 — Mechanical Loads

Mechanical loads are not applied to the storage cask and canister during storage conditions. Therefore, no further evaluation is required.

3.4.4.1.7 Canister Pressure Test

The canister is tested using an air over water pressure test in accordance with ASME Code Section III, NB-6221 through NB-6223. The normal pressure for design basis conditions is calculated to be 17.93 psig. This pressure could occur during the time the loaded canister is in the transfer cask. A normal conditions design basis pressure of 20 psig is conservatively applied. In accordance with NB-6221, the test pressure applied is 25 psig (20 x 1.25). The stress resulting from the pressure test is evaluated in accordance with the requirements of NB-3226. The test pressure slightly exceeds 1.2 × design pressure (1.2 × 20 psig = 24 psig). The canister is not reused, and the pressure test is conducted only once. Therefore, the pressure test is not considered in the fatigue analysis.

NB-3226 requires that P_m not exceed $0.9S_y$ at the test temperature. To show that the canister air over water pressure test meets this condition, the stress intensities calculated for the canister due to an operating pressure of 11.5 psig (Section 3.4.4.1.3), are ratioed to account for the 25 psig test pressure. From Table 3.4.4.1-4, the maximum primary stress intensity, P_m, is 4.60 ksi. The canister material is ASME SA-240, Type 304L stainless steel, and the material temperature is conservatively taken to be 250°F (Tables 3.4.4.1-4 and 3.4.4.1-5). Therefore:

$$(P_m)_{test} = (25/20) \times (4.60 \text{ ksi}) = 5.75 \text{ ksi, which is} < .9S_y = 18.3 \text{ ksi } (.9 \times 20.3 \text{ ksi})$$

Thus, the criteria is met.

NB-3226 requires that for $P_m < 0.67S_y$ the primary membrane plus bending stress intensity, $P_m + P_b$, be $\leq 1.35S_y$. From Table 3.4.4.1-5, $P_m + P_b = 10.02$ ksi. Therefore:

$$(P_m + P_b)_{test} = (25/20) \times (10.02 \text{ ksi}) = 12.5 \text{ ksi, which is} \leq 1.35S_y = 27.4 \text{ ksi } (1.35 \times 20.3 \text{ ksi})$$

Therefore, the criteria is met.

The exterior of the canister is at atmospheric pressure at the time the pressure test is conducted, and no external pressure is applied to the canister. Consequently, the evaluation of NB-3133 is not required.

Finally, since the test pressure is equal to the 1.25 times the design pressure, no additional stress calculations are required in accordance with NB-3226, Subparagraph e.

3.4.4.1.8 Fuel Basket Support Disk Evaluation

The response of the fuel basket support disks to storage and handling conditions was evaluated using an ANSYS finite element model that represented a one-quarter section of a single support disk. These loads consist of dead load, handling, and thermal. During storage (dead load) and handling, each support disk supports its own weight and is supported at eight locations by the tie-rod spacers (represented as nodal point restraints in the model). Since all of the support disks experience the same loading conditions during storage and handling, only one support disk was modeled. The support disk model, shown in Figure 3.4.4.1-5 with boundary conditions, was constructed of ANSYS SHELL63 three-dimensional, six degree-of-freedom, elastic shell elements.

The structural analyses of the ANSYS support disk model were performed with temperatures that envelope those experienced by the support disk during storage and handling conditions (100°F and -40°F ambient temperatures). Prior to performing the structural analyses, the steady-state temperature distribution in the support disk model was determined using temperature information from the storage and transfer thermal analyses. This was accomplished by converting the SHELL63 structural elements to SHELL57 thermal elements. The maximum support disk temperature (450°F) was applied to the nodes at the center slot and the minimum support disk temperature (100°F) was applied to the nodes around the outer circumferential edge. All other nodal temperatures were obtained by a steady state conduction solution.

The structural analyses were performed using the SHELL63 structural elements. Since the model represents a one-quarter section of the support disk, in-plane translations and rotations were restrained at the two symmetry faces. Two nodes at the locations of the tie-rod spacers were restrained in the axial direction. The dead load stresses were then calculated by applying a 1.1g acceleration to the entire model in the axial direction, and the handling stresses were calculated by applying a 1.1g acceleration to the entire model in the axial direction. Thermal stresses were also evaluated in addition to both dead load and handling load. The results of the support disk structural analyses for dead load, handling load, and thermal load are presented in

Table 3.4.4.1-11. As shown in Table 3.4.4.1-11, the support disk maintains positive margins of safety for the conditions analyzed.

3.4.4.1.9 Fuel Basket Weldments Evaluation

The response of the fuel basket top and bottom weldments to storage and handling conditions was analyzed using ANSYS finite element models representing one-quarter section of a top and a bottom weldment. These loads consist of the dead weight and handling loads and thermal expansion. During storage (dead load) and handling, the top weldment plate supports its own weight, the weight of eight structural ribs, and the weight of a circumferential ring, which is welded to the plate. The top weldment plate is supported at eight locations by the tie-rod spacers (represented as nodal point restraints in the model). During storage (dead load) and handling, the bottom weldment plate supports its own weight plus the weight of 36 fuel tubes applied as sets of nodal forces around the slot locations. The bottom weldment plate is supported at eight locations by the tie-rod spacers and at twelve locations by structural ribs (represented as nodal point restraints in the model). The top and bottom weldments are both constructed of SA240, Type 304 stainless steel. The top and bottom weldments model, shown in Figures 3.4.4.1-6 and 3.4.4.1-7, respectively, with boundary conditions, were constructed of ANSYS SHELL63 three-dimensional, six degree-of-freedom, elastic shell elements.

The structural analyses of the ANSYS weldment models were performed using the methodology described in Section 3.4.4.1.8. Temperatures employed for the thermal conduction analysis of the weldments are shown below:

Weldment	Maximum Temperature (°F) (at center)	Minimum Temperature (°F) (at circumference)
Top	400	380
Bottom	150	100

Since the ANSYS finite element models represent a one-quarter section of each weldment, in-plane translations and rotations were restrained at the plane of symmetry face. In each weldment model, two nodes at the locations of the tie-rod spacers were restrained in the axial direction. In addition, for the bottom weldment model, two nodes at the location of the support pads were restrained in the axial direction. The dead load stresses were then calculated by applying a 1g acceleration to the entire model in the axial direction, and the handling stresses were calculated

by applying a 1.1g acceleration to the entire model in the axial direction. Thermal stresses were also evaluated in addition to dead load and handling load. The results of the weldment structural analyses for dead load, handling load, and thermal load are presented in Table 3.4.4.1-11. To account for the hottest temperatures experienced by the weldments during storage and handling, the allowable stresses are taken at 658°F for the top weldment and 662°F for the bottom weldment. As shown in Table 3.4.4.1-11, the weldments maintain positive margins of safety for the combined load conditions.

3.4.4.1.10 Fuel Tube Analysis

The fuel tube provides a sealed cavity to mount BORAL poison plates within the fuel basket structure but the fuel tube does not provide structural support of the fuel assembly. The fuel tube design is presented in Figure 3.4.4.1-8. The thickness of the tube wall is 0.048 inch. A structural evaluation of the tube has been performed for the dead load and handling load conditions. The thermal stress is considered to be negligible since the tube is free to expand in both axial and radial directions. The handling load is considered to be 10% of the dead load.

During storage, the fuel assemblies are in contact with the bottom weldment, which is supported by the canister bottom plate. In the vertical position, the fuel assembly load is not carried by the fuel tubes. The fuel tubes are supported by the bottom weldment. Therefore, evaluation of the fuel tube is performed considering the weight of the fuel tube, with a g-load of 1.1 (to account for both the dead load and handling load) carried by the tube cross-section. From the dimensions of the tube shown in Figure 3.4.4.1-8, the cross sectional area is:

$$\text{Area} = (7.8 + 2 \times 0.048)^2 - 7.8^2$$
$$= 1.507 \text{ in}^2$$

The weight of a fuel tube, including the BORAL plates, is 78 pounds. Considering a g-load of 1.1, the maximum compressive and bearing stress in the fuel tube is 57 psi (78 x 1.1 / 1.507). Limiting the compressive stress level in the tube to the material yield strength ensures the tube remains in position in storage conditions. The yield strength of Type 304 stainless steel is 17,300 psi at a conservatively high temperature of 750°F.

$$\text{Margin of Safety} = 17{,}300/57 - 1$$
$$= +\text{Large}$$

Figure 3.4.4.1-1 Canister ANSYS Finite Element Model

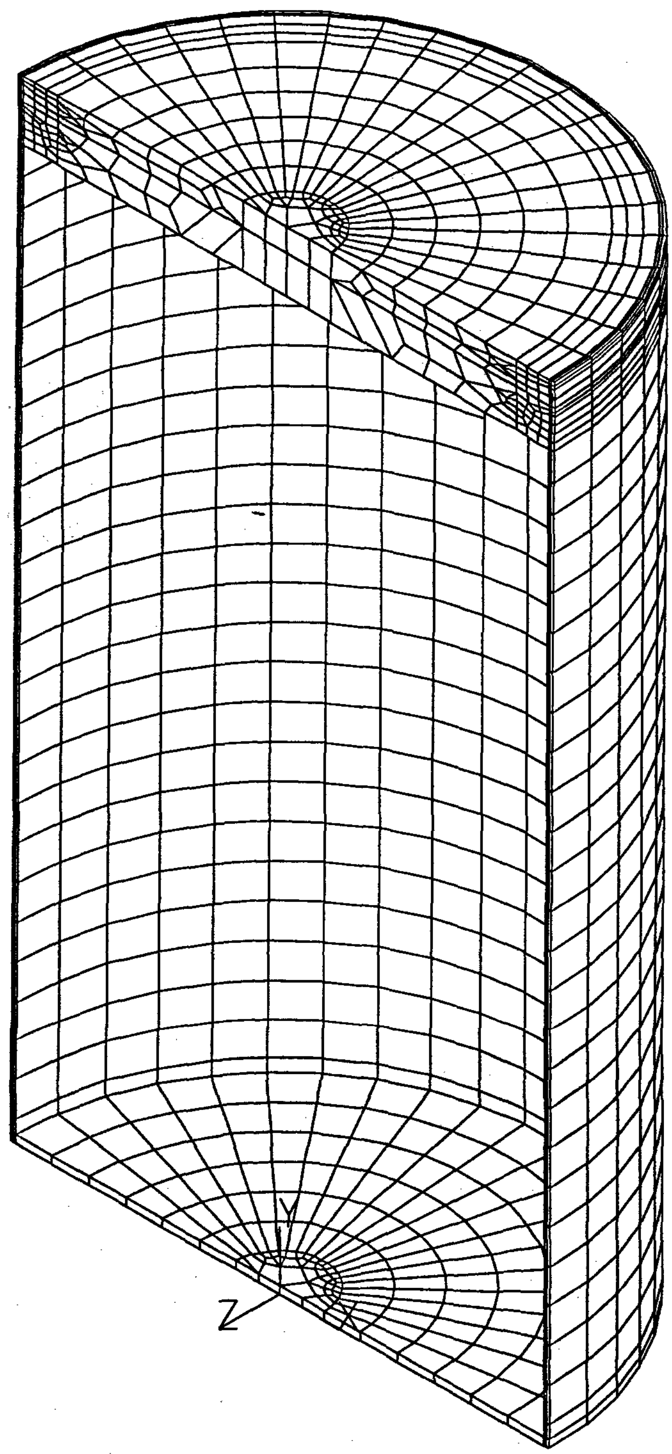


Figure 3.4.4.1-2 Weld Regions of Canister ANSYS Finite Element Model at Structural and Shield Lids

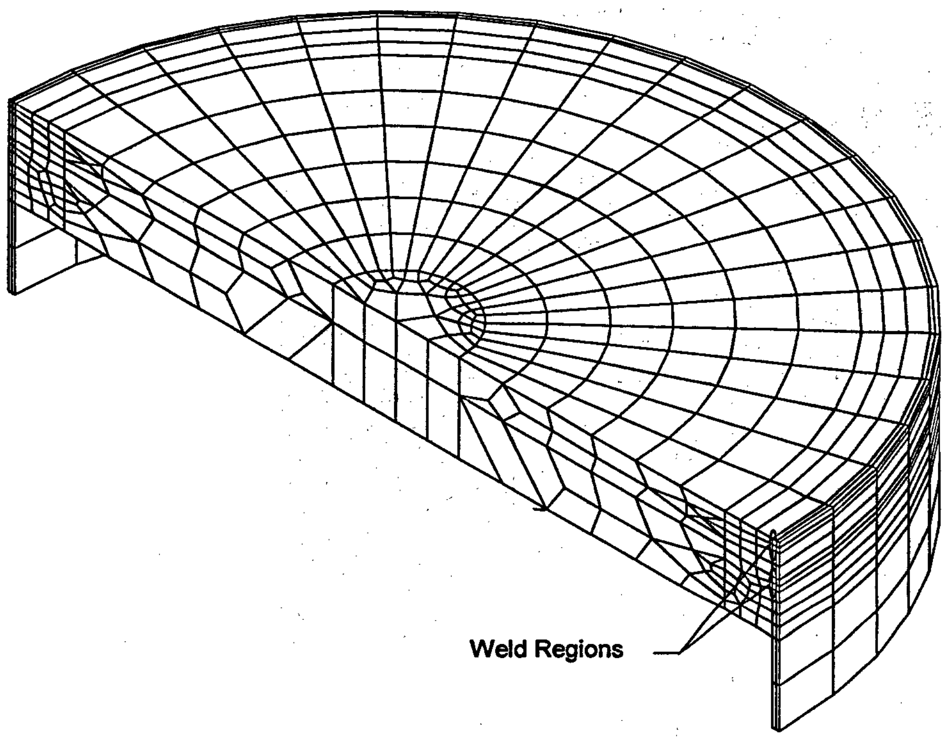


Figure 3.4.4.1-3 Bottom Plate of the Canister ANSYS Finite Element Model

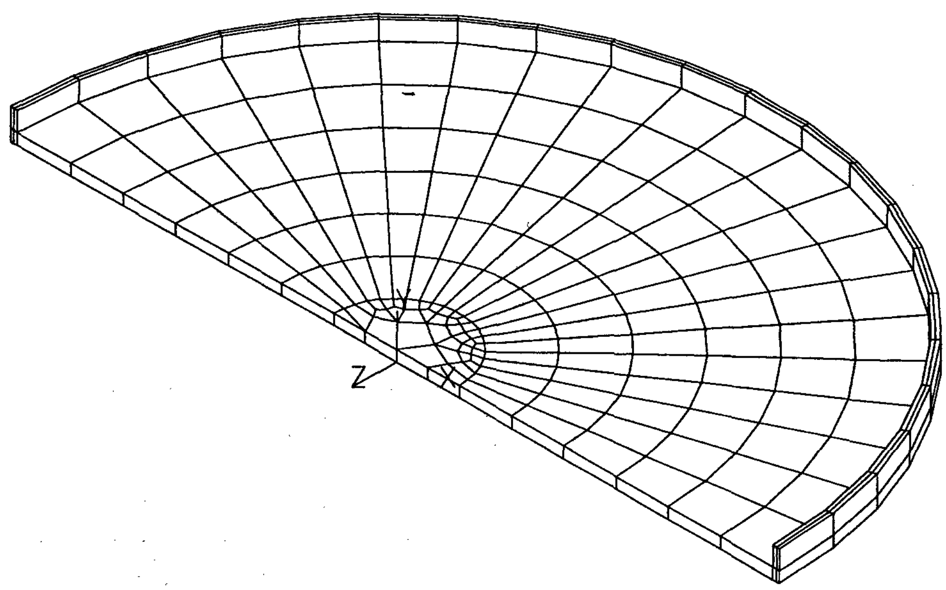
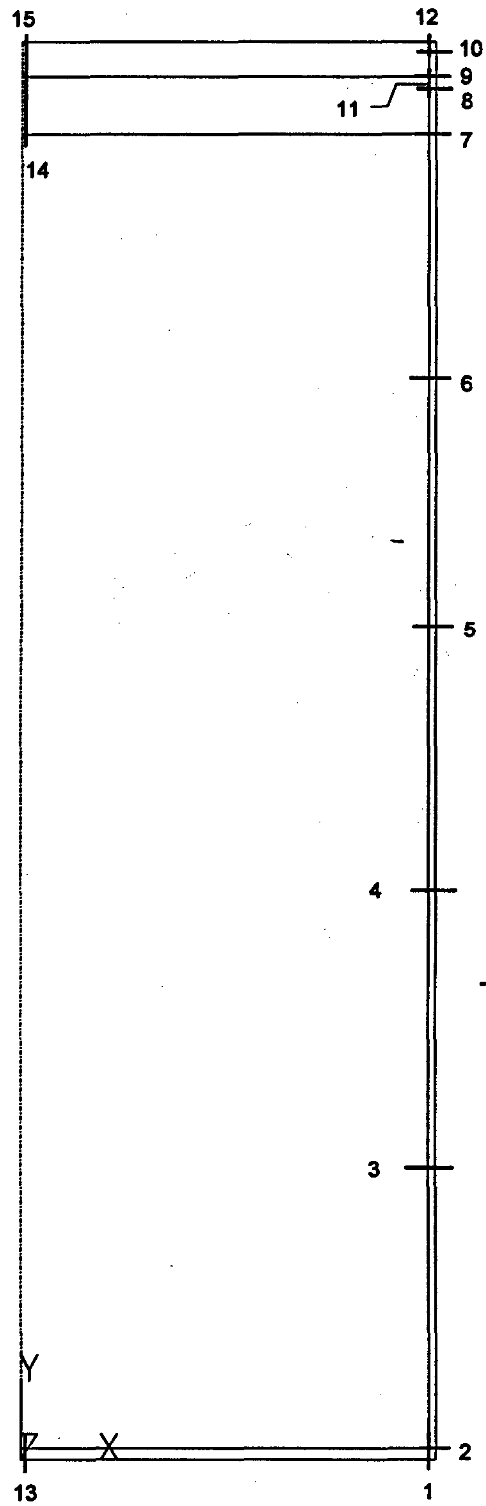
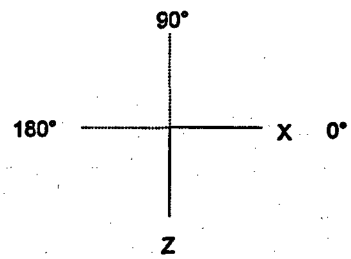


Figure 3.4.4.1-4 Locations for Section Stresses in the Canister ANSYS Finite Element Model





Top View of Axis

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

	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	119.5	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

Figure 3.4.4.1-5 Fuel Basket Support Disk ANSYS Finite Element Model

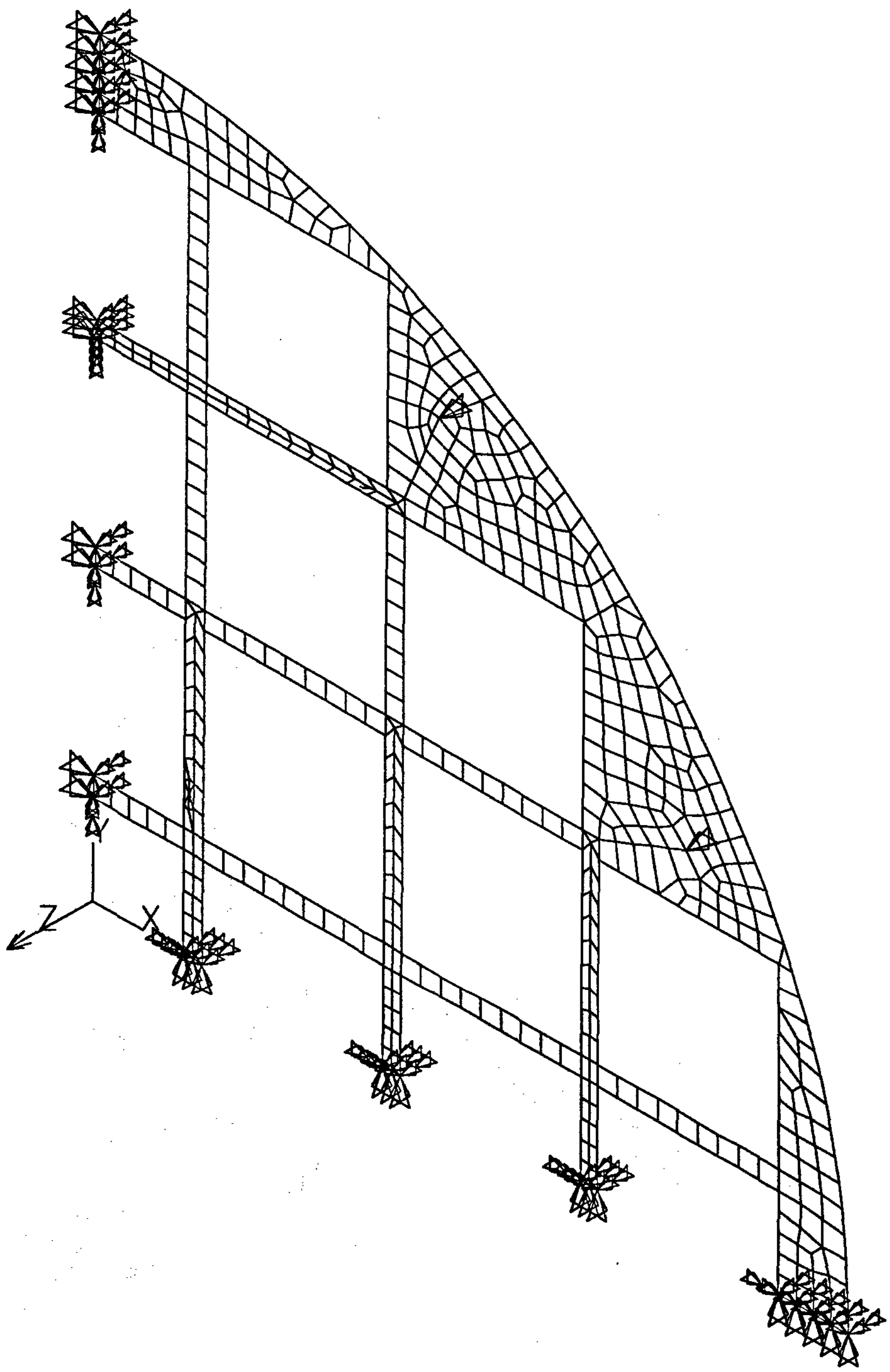


Figure 3.4.4.1-6 Fuel Basket Top Weldment ANSYS Finite Element Model

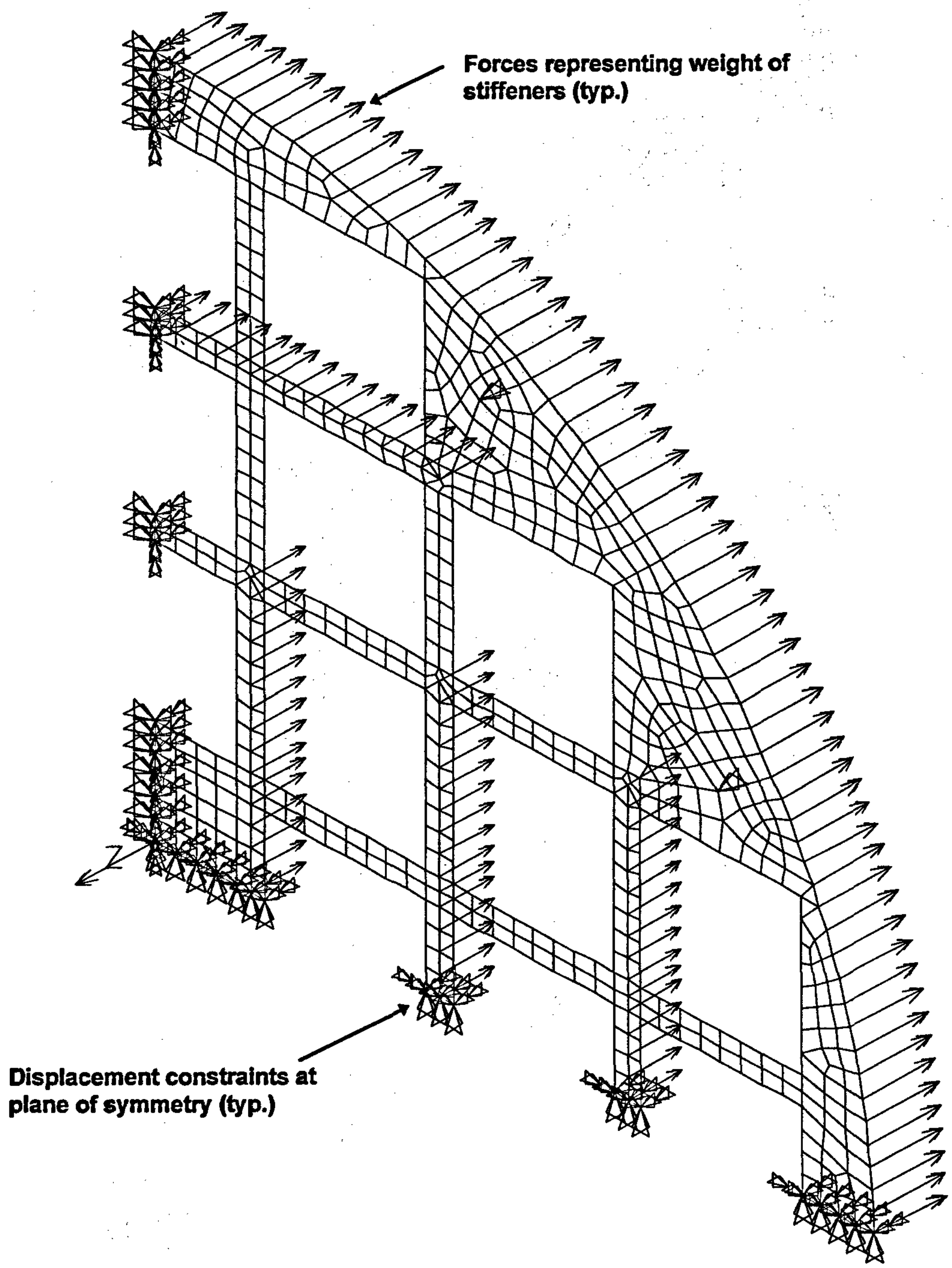


Figure 3.4.4.1-7 Fuel Basket Bottom Weldment ANSYS Finite Element Model

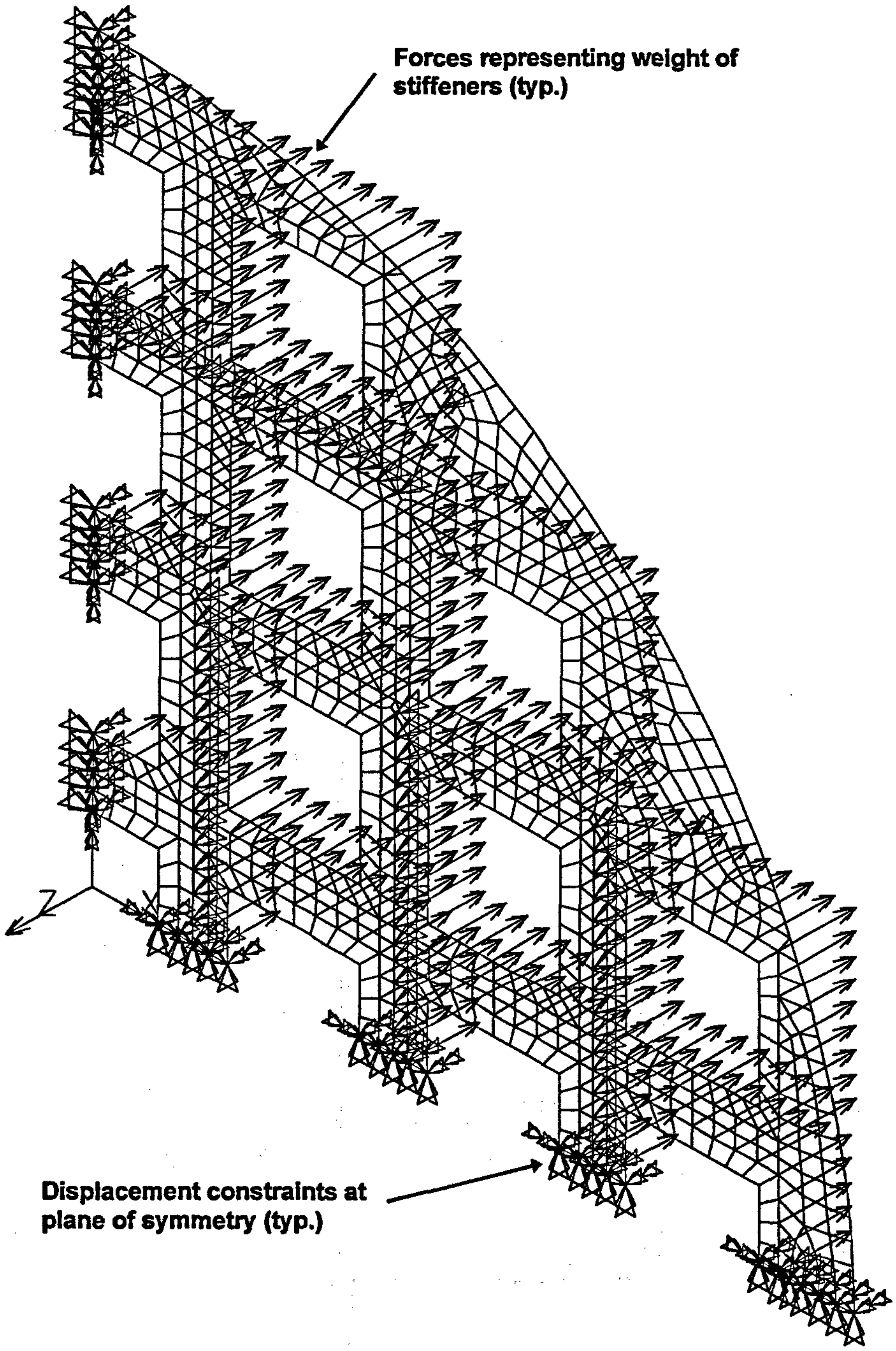


Figure 3.4.4.1-8 Fuel Tube Configuration

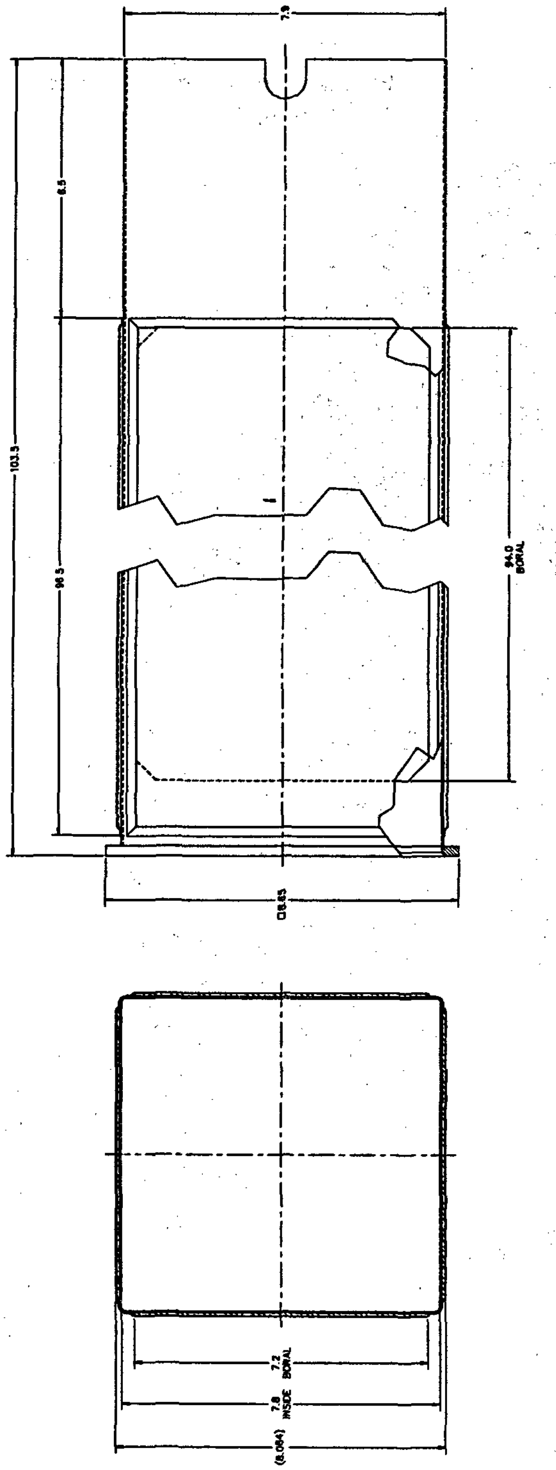


Table 3.4.4.1-1 Summary of Maximum Canister Thermal Stresses (ksi)

Location No.[1]		SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	[redacted]	0.2	0.9	3.2	0.1	< 0.1	-0.2	3.08
2	[redacted]	-0.3	-1.8	2.0	-0.1	< 0.1	0.2	3.73
3	[redacted]	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.04
4	[redacted]	-0.1	0.1	0.3	< 0.1	< 0.1	< 0.1	0.34
5	[redacted]	< 0.1	-0.1	0.1	< 0.1	< 0.1	< 0.1	0.26
6	[redacted]	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.04
7	[redacted]	< 0.1	0.5	-0.8	-0.1	< 0.1	-0.1	1.37
8	[redacted]	1.2	-2.7	-0.7	1.1	-0.1	-0.1	4.43
9	[redacted]	-2.0	9.7	2.2	0.4	< 0.1	0.3	11.78
10	[redacted]	2.5	-10.7	-1.6	0.7	-0.1	-0.3	13.29
11	[redacted]	-4.7	-5.1	-2.7	-0.7	< 0.1	0.1	2.90
12	[redacted]	-4.3	1.6	< 0.1	-0.8	-0.1	-0.3	6.12
13	[redacted]	-19.5	-6.2	-18.8	< 0.1	-0.6	< 0.1	13.35
14	[redacted]	2.4	4.0	2.5	< 0.1	-0.2	< 0.1	1.64
15	[redacted]	-7.1	-5.0	-6.9	< 0.1	0.3	< 0.1	2.17

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

Table 3.4.4.1-2 Summary of Maximum Canister Dead Load Primary Membrane (P_m) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.04
2	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
3	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
4	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
5	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.08
6	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.07
7	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.05
8	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.03
9	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.08
10	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.07
11	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.04
12	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.06
13	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.01
14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.02
15	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.01

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

Table 3.4.4.1-3 Summary of Maximum Canister Dead Load Primary Membrane Plus Primary Bending ($P_m + P_b$) Stresses (ksi)

Location No.[1]	[redacted]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	[redacted]	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.06
2	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.12
3	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
4	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
5	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.08
6	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.07
7	[redacted]	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.07
8	[redacted]	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.05
9	[redacted]	< 0.1	-0.2	-0.1	< 0.1	< 0.1	< 0.1	0.20
10	[redacted]	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.18
11	[redacted]	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.08
12	[redacted]	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.09
13	[redacted]	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.01
14	[redacted]	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	0.09
15	[redacted]	-0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	0.06

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

Table 3.4.4.1-4 Summary of Maximum Canister Internal Pressure Load Primary Membrane (P_m) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	-0.6	3.0	0.9	0.7	0.3	-0.1	3.92
2	1.6	-1.2	-1.0	0.6	0.1	0.1	3.02
3	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.62
4	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.64
5	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.64
6	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.64
7	< 0.1	0.3	0.3	< 0.1	< 0.1	< 0.1	0.33
8	0.1	0.2	0.2	0.1	< 0.1	< 0.1	0.18
9	-0.2	0.2	0.1	< 0.1	< 0.1	< 0.1	0.41
10	0.2	-0.1	0.1	< 0.1	< 0.1	< 0.1	0.35
11	< 0.1	-0.1	0.1	< 0.1	< 0.1	< 0.1	0.20
12	< 0.1	0.3	0.2	< 0.1	< 0.1	< 0.1	0.31
13	0.7	< 0.1	0.7	-0.7	-2.2	< 0.1	4.60
14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.06
15	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.07

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

Table 3.4.4.1-5 Summary of Maximum Canister Internal Pressure Load Primary Membrane Plus Primary Bending ($P_m + P_b$) Stresses (ksi)

Location No.[1]		SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	[redacted]	-4.2	0.3	0.6	1.0	0.4	-0.2	5.29
2	[redacted]	0.7	-9.2	-3.4	0.7	< 0.1	0.3	10.02
3	[redacted]	< 0.1	0.4	0.6	< 0.1	< 0.1	-0.1	0.66
4	[redacted]	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.65
5	[redacted]	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.65
6	[redacted]	< 0.1	0.3	0.6	< 0.1	< 0.1	< 0.1	0.65
7	[redacted]	< 0.1	0.4	0.3	< 0.1	< 0.1	< 0.1	0.39
8	[redacted]	0.1	0.1	0.2	-0.1	< 0.1	< 0.1	0.21
9	[redacted]	-0.1	0.9	0.4	< 0.1	< 0.1	< 0.1	1.03
10	[redacted]	0.2	-0.7	-0.1	< 0.1	< 0.1	< 0.1	0.92
11	[redacted]	-0.3	-0.4	< 0.1	0.1	< 0.1	< 0.1	0.42
12	[redacted]	-0.3	0.1	0.1	-0.1	< 0.1	< 0.1	0.47
13	[redacted]	10.3	1.8	10.0	-0.7	-2.2	< 0.1	9.40
14	[redacted]	-0.6	-0.1	-0.5	< 0.1	< 0.1	< 0.1	0.44
15	[redacted]	0.3	< 0.1	0.3	< 0.1	< 0.1	< 0.1	0.31

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

Table 3.4.4.1-6 Summary of Maximum Canister Dead Load + Handling Load Primary Membrane (P_m) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	-0.7	3.1	0.9	-0.7	0.3	0.1	4.11
2	1.6	-1.3	-1.1	-0.6	0.1	-0.2	3.15
3	< 0.1	0.4	< 0.1	< 0.1	< 0.1	< 0.1	0.41
4	< 0.1	0.4	< 0.1	< 0.1	< 0.1	< 0.1	0.45
5	< 0.1	0.5	< 0.1	< 0.1	< 0.1	< 0.1	0.52
6	< 0.1	0.6	< 0.1	< 0.1	< 0.1	< 0.1	0.64
7	< 0.1	0.9	< 0.1	< 0.1	0.1	< 0.1	0.94
8	< 0.1	0.9	0.2	< 0.1	0.1	< 0.1	0.90
9	-0.2	1.2	0.3	< 0.1	0.1	< 0.1	1.34
10	-0.3	0.6	0.6	-0.3	0.1	0.1	1.08
11	-0.1	0.8	0.2	< 0.1	0.1	< 0.1	0.90
12	0.2	< 0.1	0.8	-0.3	< 0.1	0.1	1.07
13	0.7	< 0.1	0.7	-0.7	-2.3	< 0.1	4.86
14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.03
15	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.05

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

Table 3.4.4.1-7 Summary of Maximum Canister Dead Load + Handling Load Primary Membrane Plus Primary Bending ($P_m + P_b$) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	-4.3	0.3	0.7	-1.0	0.4	0.2	5.50
2	0.7	-9.7	-3.6	-0.8	< 0.1	-0.3	10.51
3	< 0.1	0.5	-0.1	< 0.1	< 0.1	< 0.1	0.53
4	< 0.1	0.4	-0.1	< 0.1	< 0.1	< 0.1	0.52
5	< 0.1	0.5	-0.1	< 0.1	< 0.1	< 0.1	0.62
6	< 0.1	0.6	-0.2	< 0.1	< 0.1	< 0.1	0.74
7	< 0.1	1.0	< 0.1	< 0.1	< 0.1	< 0.1	1.01
8	< 0.1	1.1	0.3	0.1	0.1	< 0.1	1.08
9	0.2	1.5	-0.1	< 0.1	-0.1	-0.3	1.73
10	-0.4	0.9	0.6	-0.5	0.1	0.1	1.70
11	0.2	1.2	-0.1	< 0.1	< 0.1	-0.2	1.37
12	0.7	-0.4	1.0	-0.1	-0.1	0.2	1.56
13	10.9	1.9	10.5	-0.7	-2.3	< 0.1	9.91
14	-0.2	< 0.1	-0.2	< 0.1	< 0.1	< 0.1	0.18
15	0.2	< 0.1	0.2	< 0.1	< 0.1	< 0.1	0.18

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

Table 3.4.4.1-8 Summary of Maximum Canister Combined Load Primary Membrane (P_m) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	-1.3	6.1	1.9	-1.4	0.6	0.2	8.02	16.70	1.08
2	3.2	-2.5	-2.1	-1.2	0.2	-0.3	6.16	16.70	1.71
3	< 0.1	0.7	0.6	< 0.1	< 0.1	< 0.1	0.71	14.50	19.42
4	< 0.1	0.8	0.6	< 0.1	< 0.1	< 0.1	0.76	14.50	18.08
5	< 0.1	0.8	0.6	< 0.1	< 0.1	< 0.1	0.84	14.50	16.26
6	< 0.1	0.9	0.6	< 0.1	< 0.1	0.1	0.94	14.50	14.43
7	< 0.1	1.2	0.3	< 0.1	0.1	< 0.1	1.23	16.70	12.63
8	0.1	1.1	0.4	0.1	0.1	< 0.1	1.06	16.70	14.77
9	-0.3	1.3	0.4	< 0.1	0.1	0.1	1.67	16.70	9.00
10	< 0.1	0.5	0.8	-0.2	< 0.1	0.1	0.86	16.70	18.31
11	-0.1	0.9	0.3	< 0.1	0.1	0.1	0.98	16.70	15.97
12	0.1	0.3	1.1	-0.3	< 0.1	0.1	1.19	16.70	13.09
13	1.4	0.1	1.3	-1.5	-4.5	< 0.1	9.47	16.70	0.76
14[3]	-0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	0.09	20.00	221.22
15	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	0.14	16.70	121.34

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

2 Allowable stresses for bottom plate region (location no. 1-2, 13) taken at 250°F; allowable stresses for canister shell region between shield lid and bottom plate (location no. 3-6) taken at 550°F; allowable stresses for structural/shield lid region (location no. 7-12, 14-15) taken at 250°F.

3 The allowable stress for SA240, Type 304 stainless steel was used for location no. 14. The allowable stress for SA240, Type 304L stainless steel was used for all other locations.

Table 3.4.4.1-9 Summary of Maximum Canister Combined Load Primary Membrane Plus Primary Bending ($P_m + P_b$) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	-8.5	0.7	1.3	-2.0	0.8	0.4	10.77	25.05	1.33
2	1.4	-18.8	-7.0	-1.5	< 0.1	-0.6	20.50	25.05	0.22
3	< 0.1	0.9	0.6	< 0.1	< 0.1	< 0.1	0.92	21.75	22.64
4	< 0.1	0.8	0.7	< 0.1	< 0.1	0.1	0.79	21.75	26.53
5	< 0.1	0.9	0.8	< 0.1	< 0.1	0.1	0.88	21.75	23.72
6	< 0.1	1.0	0.8	< 0.1	< 0.1	0.1	1.00	21.75	20.75
7	< 0.1	1.3	0.3	< 0.1	< 0.1	< 0.1	1.31	25.05	18.14
8	0.1	1.2	0.4	0.1	0.1	< 0.1	1.17	25.05	20.45
9	-0.4	1.4	0.4	< 0.1	0.1	0.1	1.85	25.05	12.53
10	-0.1	1.7	1.1	-0.5	0.1	0.1	2.06	25.05	11.14
11	-0.4	1.0	0.3	< 0.1	0.1	0.1	1.45	25.05	16.26
12	0.3	-0.3	1.3	-0.1	-0.1	0.2	1.66	25.05	14.10
13	21.2	3.7	20.5	-1.4	-4.5	< 0.1	19.33	25.05	0.30
14[3]	-0.5	-0.1	-0.5	< 0.1	< 0.1	< 0.1	0.43	30.00	68.77
15	0.8	0.1	0.8	< 0.1	0.1	< 0.1	0.67	25.05	36.12

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

2 Allowable stresses for bottom plate region (location no. 1-2, 13) taken at 250°F; allowable stresses for canister shell region between shield lid and bottom plate (location no. 3-6) taken at 550°F; allowable stresses for structural/shield lid region (location no. 7-12, 14-15) taken at 250°F.

3 The allowable stress for SA240, Type 304 stainless steel was used for location no. 14. The allowable stress for SA240, Type 304L stainless steel was used for all other locations.

Table 3.4.4.1-10 Summary of Maximum Canister Combined Load Primary Membrane Plus Primary Bending Plus Secondary ($P_m + P_b + Q$) Stresses (ksi)

Location No.[1]	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	-9.1	0.6	3.6	2.1	0.8	-0.6	13.38	50.10	2.74
2	2.1	-22.9	-5.4	-1.5	0.1	-0.5	25.20	50.10	0.99
3	< 0.1	0.9	0.6	< 0.1	< 0.1	< 0.1	0.90	43.50	47.33
4	-0.1	0.7	1.0	< 0.1	< 0.1	-0.1	1.11	43.50	38.19
5	-0.1	0.7	0.9	< 0.1	< 0.1	-0.1	1.01	43.50	42.07
6	< 0.1	1.0	0.8	< 0.1	< 0.1	0.1	1.02	43.50	41.65
7	< 0.1	1.8	-0.6	-0.1	0.1	-0.1	2.43	50.10	19.59
8	1.2	-2.3	-0.5	-1.2	-0.1	0.1	4.22	50.10	10.86
9	-2.3	10.8	2.6	0.3	0.1	0.3	13.14	50.10	2.81
10	2.8	-12.4	-1.8	-0.8	-0.2	0.7	15.32	50.10	2.27
11	-5.0	-5.5	-2.8	0.9	< 0.1	-0.1	3.34	50.10	14.01
12	-4.9	1.8	< 0.1	-0.9	-0.1	-0.3	6.99	50.10	6.17
13	-26.4	0.5	-25.2	-1.4	-4.0	< 0.1	27.74	50.10	0.81
14[3]	1.7	3.9	1.8	< 0.1	-0.1	0.1	2.21	60.00	26.15
15	1.7	3.9	1.8	< 0.1	-0.1	0.1	2.21	50.10	21.68

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

[2] Allowable stresses for bottom plate region (location no. 1-2, 13) taken at 250°F; allowable stresses for canister shell region between shield lid and bottom plate (location no. 3-6) taken at 550°F; allowable stresses for structural/shield lid region (location no. 7-12, 14-15) taken at 250°F.

[3] The allowable stress for SA240, Type 304 stainless steel was used for location no. 14. The allowable stress for SA240, Type 304L stainless steel was used for all other locations.

Table 3.4.4.1-11 Summary of Maximum Stresses for the Fuel Basket Weldments and Support Disks

Component	Load Condition	Stress Intensity		Allowable Stress		Margin of Safety
		Reported	Value (psi)	Criteria	Value (psi)	
Top Weldment	Dead Load	P_m	0	S_m	16,299	—
		$P_m + P_b$	3,297	$1.5S_m$	24,449	6.42
	Dead Load + Thermal	$P_m + P_b + Q$	32,364	$3.0S_m$	48,898	0.51
	Dead Load + Handling	P_m	0	S_m	16,299	—
		$P_m + P_b$	3,626	$1.5S_m$	24,449	5.74
	Dead Load + Handling + Thermal	$P_m + P_b + Q$	32,521	$3.0S_m$	48,898	0.50
Bottom Weldment	Dead Load	P_m	0	S_m	16,269	—
		$P_m + P_b$	857	$1.5S_m$	24,403	27.47
	Dead Load + Thermal	$P_m + P_b + Q$	44,094	$3.0S_m$	48,806	0.11
	Dead Load + Handling	P_m	0	S_m	16,269	—
		$P_m + P_b$	942	$1.5S_m$	24,403	24.89
	Dead Load + Handling + Thermal	$P_m + P_b + Q$	44,119	$3.0S_m$	48,806	0.11
Support Disks	Dead Load	P_m	0	S_m	41,528	—
		$P_m + P_b$	870	$1.5S_m$	62,292	70.60
	Dead Load + Thermal	$P_m + P_b + Q$	35,427	$3.0S_m$	124,584	2.52
	Dead Load + Handling	P_m	0	S_m	41,528	—
		$P_m + P_b$	958	$1.5S_m$	62,292	64.02
	Dead Load + Handling + Thermal	$P_m + P_b + Q$	35,495	$3.0S_m$	124,584	2.51

3.4.4.2 Vertical Concrete Storage Cask - Concrete Stress Analysis

This section evaluates the stresses in the storage cask concrete for normal conditions of storage. The evaluation for the steel pedestal at the bottom of the cask is presented in Section 3.4.3.1. The stresses in the concrete due to dead load, live load, and thermal load are calculated below. The evaluations for off-normal and accident loading conditions are presented in Chapter 11. Summary of calculated stresses for the load combinations defined in Table 2.2-2 is presented in Table 3.4.4.2-1. The maximum stress in the concrete and the maximum force in the reinforcing bars and the comparison to their allowable limits are summarized in Table 3.4.4.2-2. As shown in Table 3.4.4.2-2, the storage cask meets the structural requirements of ACI-349-85.

3.4.4.2.1 Dead Load

The dead load of the storage cask concrete is reacted by the lower concrete surface only. The concrete compression stress due to the self-weight of the storage cask is:

$$\sigma_v = -W/A = -21.44 \text{ psi (compression)}$$

Where

W	=	151,364 lb concrete cask dead weight
D	=	128 in. concrete exterior diameter
ID	=	86 in. concrete interior diameter
A	=	$\pi (D^2 - ID^{2)} / 4 = 7{,}059.2 \text{ in.}^2$

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

3.4.4.2.2 Live Load

The storage cask is subjected to two live loads: (1) the snow load and (2) the weight of the fully loaded transfer cask resting atop the storage cask. These loads are conservatively assumed to be applied to the concrete portion of the storage cask. No loads are assumed to be taken by the steel liner. The loads from the canister and its contents are transferred to the steel support inside the

storage cask and are not applied to the concrete. The stress in the steel support is evaluated in Section 3.4.3.1. Under these conditions, the only stress component is the vertical compression stress.

Snow Load

The snow load on the storage cask is determined in accordance with ANSI/ASCE 7-93 as follows:

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

$$P_f = 0.70\ C_e\ C_t\ I\ P_g = 100.8\ \text{lbf/ft}^2 \text{ (Section 2.2.4)}$$

The storage cask top area,

$$A_{top} = \pi\ (D/2)^2 = 12{,}868\ \text{in.}^2 = 89.36\ \text{ft}^2$$

The maximum snow load, F_s, is,

$$F_s = P_f \times A_{top} = 100.8\ (89.36) = 9{,}007\ \text{lbf.}$$

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

The live load of the transfer cask is 135,473 lbs, which is much greater than the weight of the snow. Consequently, the stress due to the snow load is bounded by the weight of the transfer cask.

W	= 135,473 lb-transfer cask weight (fully loaded)
D	= 128 in.-concrete exterior diameter
ID	= 86 in.-concrete interior diameter
A	$= \pi\ (D^2 - ID^2)/4$
	$= 7{,}059.2$ in.^{2}

Compression stress at the base of the concrete is:

σ_v = W/A = -19.2 psi (compressive)

3.4.4.2.3 Thermal Load

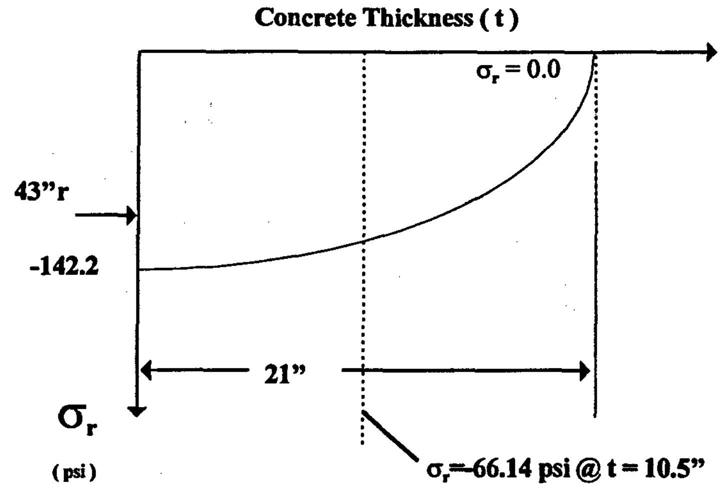
An axisymmetric finite element model consisting of two-dimensional solid elements for the steel liner and concrete shell was developed to calculate the thermal stresses in the concrete (see Fig. 3.4.4.2-1). The nodes at the steel liner/concrete interface are coincident and are connected analytically by coupling the degrees of freedom. Overall shell height is 160 in., the inner radius of the 3.5-in. thick carbon steel liner is 39.5 in., and the outer concrete radius is 64.0 in. The model obtains first a thermal solution (temperatures) and then a structural solution (stresses).

The steady-state, two-dimensional heat transfer conduction solution uses the surface temperature boundary conditions as calculated by the thermal analysis for normal conditions as presented in Section 4.4.1.1. These temperatures were applied without load factor along the steel liner interior and concrete exterior. The coincident nodes located along the steel and concrete interface were coupled with the temperature degree of freedom.

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

Analysis with these boundary conditions provides the magnitude of three stress states σ_r, σ_y, σ_θ, which are denoted radial, vertical, and circumferential stresses respectively (these designations correspond to the x, y, and z axes, respectively, in the model). Stress magnitudes are calculated at various points along the concrete wall mid span to determine the critical bounding cross sections.

The radial stress (σ_r) varies through the concrete wall as shown in the following diagram.



The maximum interior stress of -142.2 psi is a bearing (compressive) stress due to thermal expansion of the steel liner.

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

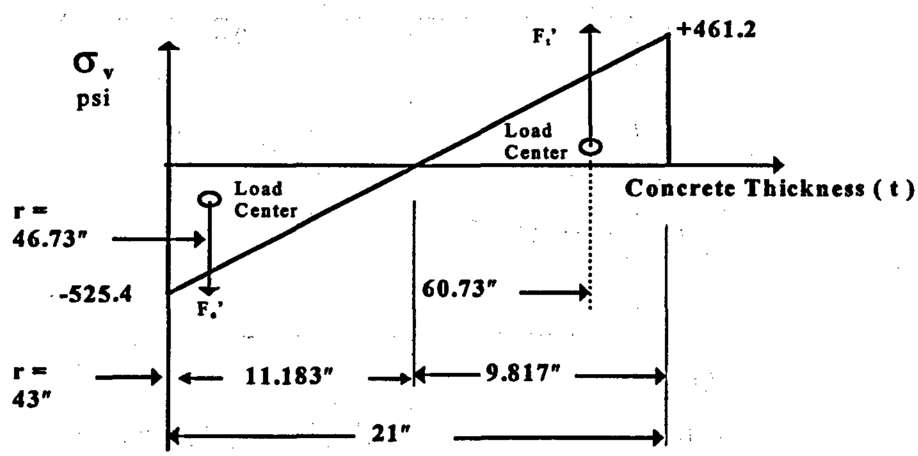
$$\phi = 0.70$$

$$f_c' = 4{,}000 \text{ psi}$$

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

The maximum 75°F normal operating thermally induced stress of -142.2 psi, when factored by the 1.275 load factor (see Table 2.2-2 in Chapter 2), represents a peak potential stress of -181.3 psi at the inner concrete shell surface. As shown in the diagram above, the radial compressive stress decreases through the wall thickness. This stress is considered to be insignificant.

Vertical membrane and bending stress varies through the concrete wall as shown in the diagram below.



A linear equation describes the stress as a function of wall thickness.

σ_v $= 46.98\,t - 525.4$, where $t = r - 43$ and r is the radius from the centerline of the storage cask to the external surface of the concrete. Substituting for t:

$= 46.98r - 2{,}545.54$

Integration of vertical tensile stress over the area in the plane r- θ gives the tensile loads acting in the vertical direction.

$$F_v' = \int \sigma_v \ da = \int \int (46.98\,r - 2{,}545.54)\,r\,dr\,d\theta$$

$$= 863{,}706 \text{ lbf}$$

56 outer vertical reinforcing bars are equally spaced at a 60.63 in. radius, which is close to the 60.73 in. radius tensile load center. The maximum tensile load applied to the reinforcing bar is:

$F_{v\,applied} = F_v' / 56 = 15{,}423$ lbf per vertical reinforcing bar.

Using a 1.275 load factor for normal operating loads:

$1.275\ F_{v\,applied} = 1.275(15{,}423) = 19{,}664$ lbf

Calculating the allowable load for the reinforcing bar:

$$\sigma_{\theta\ allowable} = U_c = \phi\ S_y = 0.90\ (60) = 54\ ksi$$

where

S_y = Reinforcing bar Yield Strength = 60 ksi

ϕ = 0.9 for axial and bending tension loading (strength reduction factor in accordance with ACI 349-85, Section 9.2)

The reinforcing bar tensile load capacity is:

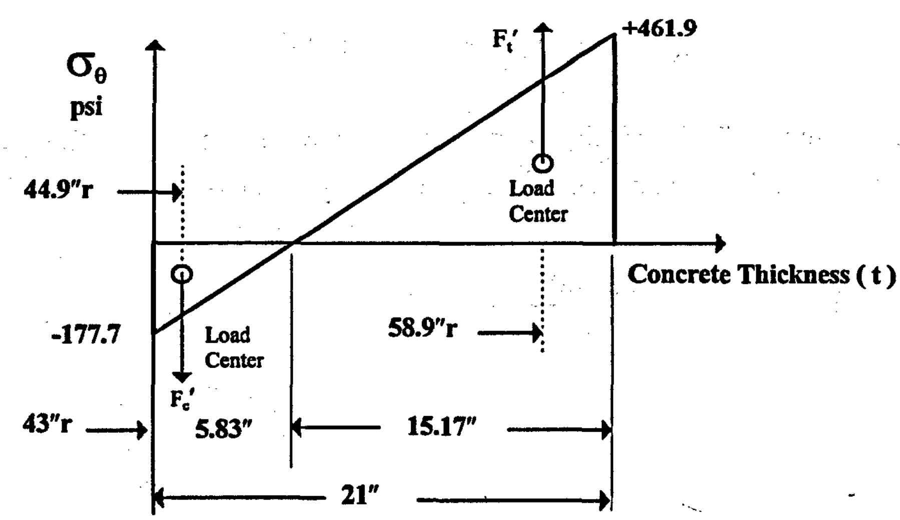
$$F_\theta = (\sigma_{\theta\ allowable})(A_{\#6}) = (54{,}000)\ (.44) = 23{,}760\ lb$$

where, $A_{\#6}$ = #6 reinforcing bar area = 0.44 in.^{2}

The calculated load of 19,664 lb. is less than the allowable reinforcing bar load of 23,760 lb. Therefore, the design is adequate with a margin of safety equal to:

$$M.S. \quad = \quad \frac{23{,}760}{19{,}664} - 1 = +0.21$$

The circumferential membrane and bending stress varies through the concrete wall. The maximum values occur at 92.6 in. from the concrete cask lower surface as shown in the following diagram.



A linear equation describes the stress as a function of wall thickness

$$\sigma_\theta = 30.457\,t - 177.7$$

Integration of circumferential stress over the area in plane r-y gives the load acting in the circumferential (θ) direction. Integration of this stress over the concrete wall thickness provides the distributed load per unit height.

Circumferential tensile loads are found by integrating the stress function (using integration limits for wall thickness of 5.83 to 21 in).

$$\begin{aligned} F_t' &= \int \sigma_\theta \, dt = \int (30.457\,t - 177.7)\,dt \\ &= (15.23\,t^2 - 177.7t)\Big|_{t=5.83}^{t=21} \\ &= 3{,}503.5 \text{ lb/in} \end{aligned}$$

Outer hoop reinforcing bars are spaced on 4-in. centers at a 60.63 in. radius. The maximum circumferential tensile load acting on an outer hoop reinforcing bar in this spacing is:

$$F_{t\theta\,applied} = F_t' \times 4 = 14{,}014 \text{ lb}$$

Using a 1.275 load factor for normal operating loads

$$1.275\,F_{t\theta\,applied} = 1.275(14{,}014) = 17{,}868 \text{ lbf}$$

The calculated load of 17,868 lbf is less than the reinforcing bar allowable of 23,760 lbf. Therefore, the design is adequate with a margin of safety equal to:

$$M.S. = \frac{23{,}760}{17{,}868} - 1 = +0.33$$

Figure 3.4.4.2-1 Concrete Cask Axisymmetric Thermal Stress Model

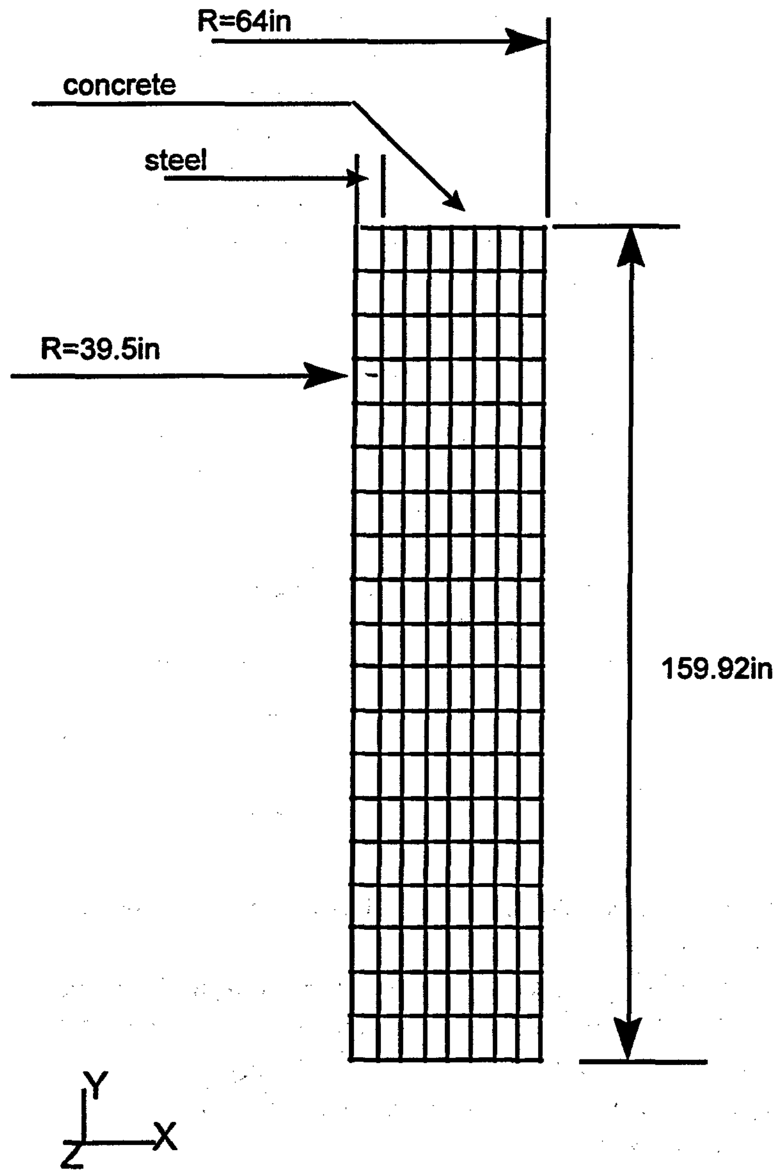


Table 3.4.4.2-1 Stress Summary for Concrete Cask Load Combinations

Load Comb[1]	Stress Direction	Stress[2] (psi)							
		Dead	Live	Wind[3]	Thermal[4]	Seismic[5]	Tornado[6]	Flood[7]	Total
Concrete Outside Surface:									
1	Vertical	-30.0	-32.6	---	---	---	---	---	-45.2
2	Vertical	-22.5	-24.5	---	---	---	---	---	-47.0
3	Vertical	-22.5	-24.5	-14.7	---	---	---	---	-61.7
4	Vertical	-21.4	-19.2	---	---	---	---	---	-40.6
5	Vertical	-21.4	-19.2	---	---	-42.9	---	---	-83.5
7	Vertical	-21.4	-19.2	---	---	---	---	-10.6	-51.2
8	Vertical	-21.4	-19.2	---	---	---	-11.5	---	-52.1
Concrete Inside Surface:									
1	Vertical	-30.0	-32.6	---	---	---	---	---	-62.2
	Circumferential	---	---	---	---	---	---	---	---
2	Vertical	-22.5	-24.5	---	-669.9	---	---	---	-716.9
	Circumferential	---	---	---	-226.6	---	---	---	-226.6
3	Vertical	-22.5	-24.5	-9.9	-669.9	---	---	---	-726.8
	Circumferential	---	---	---	-226.6	---	---	---	-226.6
4	Vertical	-21.4	-19.2	---	-660.1	---	---	---	-700.7
	Circumferential	---	---	---	-127.5	---	---	---	-127.5
5	Vertical	-21.4	-19.2	---	-525.4	-31.2	---	---	-597.2
	Circumferential	---	---	---	-177.7	---	---	---	-177.7
7	Vertical	-21.4	-19.2	---	-525.4	---	---	-7.1	-573.1
	Circumferential	---	---	---	-177.7	---	---	---	-177.7
8	Vertical	-21.4	-19.2	---	-525.4	---	-7.7	---	-573.7
	Circumferential	---	---	---	-177.7	---	---	---	-177.7

[1] Load Combinations are defined in Table 2.2-2. See Section 11.2.11 and 11.2.12 for Evaluations of Drop/Impact Conditions for Load combination No. 6.

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

[3] Stress results from Section 11.2.13 (Tornado) are conservatively used with a load factor of 1.275.

[4] Tensile stresses (at concrete outside surface) are taken by the steel reinforcing bars and therefore are not shown in this Table. Stress Results for T_a (Load Comb. #4) are obtained from Section 11.2.10.

[5] Stress results are obtained from Section 11.2.2.

[6] Stress results are obtained from Section 11.2.13 (Tornado Wind).

[7] Stress results are obtained from Section 11.2.6.

Table 3.4.4.2-2 Maximum Concrete Stress and Reinforcing Bar Forces

	Calculated	Allowable[1]	Margin of Safety
Concrete	727 psi	28,000 psi	+37.51
Reinforcing Bar			
Normal - vertical	19,664 lb.	23,760 lb.	+0.21
- hoop	17,868 lb.	23,760 lb.	+0.33
Accident[2] - vertical	19,380 lb.	23,760 lb.	+0.22
- hoop	23,196 lb.	23,760 lb.	+0.02

[1] Allowable stress for concrete is (0.7)(4,000 psi)=28,000 psi, where 0.7 is the strength reduction factor per ACI 349-85, Section 9.3; 4,000 psi is the concrete strength
Allowable for Reinforcing Bar is determined based on No. 6 Reinforcing Bar as shown in the calculation in this Section.

[2] Results are obtained from Section 11.2.10

3.4.5 Cold

Severe cold environments are analyzed and reported in Section 11.1.4. As shown in that section, the temperature of the structures with a full heat load will not fall to levels where brittle fracture would become an issue. Furthermore, an analysis has been performed for the cask in severe cold conditions after 50 years of storage. The required material toughness is 12.6 ft-lb at -30°F. For conservatism 15 ft-lb at -50°F is stated in the fabrication specification so that the NAC-MPC system can be handled, even during extreme temperatures.

3.5 Fuel Rods

The NAC-MPC system is designed to limit fuel cladding temperatures to levels below those where zircaloy degradation is expected to lead to fuel clad failure. As shown in Chapter 4, fuel cladding temperature limits have been established to be 380°C for 5-year cooled fuel and 340°C for 10-year cooled fuel for normal conditions of storage and 570°C for short term off-normal and accident conditions. As shown in Table 4.1-3, the calculated maximum fuel cladding temperatures are well below the temperature limits for all design conditions of storage.

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4.0 THERMAL EVALUATION

4.1 Discussion

This section presents the thermal analysis of the NAC-MPC system for normal conditions of storage. The significant thermal design feature of the NAC-MPC system is the passive convective air flow up along the side of the canister. Cool (ambient) air enters at the bottom of the storage cask through four inlet vents. Heated air exits through the four outlets at the top of the storage cask. Radiant heat transfer also occurs from the canister shell to the concrete cask liner. Consequently, the liner also heats the convective air flow. Conduction does not play a substantial role in heat removal from the canister surface. This natural circulation of air inside the vertical concrete cask (storage cask), in conjunction with radiation from the canister surface, maintains the fuel cladding temperature and all of the storage cask component temperatures below their design limits.

The thermal evaluation considers normal, off-normal, and accident conditions of storage. Each of these conditions can be described in terms of the environmental temperature, use of solar insolance, and the condition of the air inlet and outlet vents, as shown in Table 4.1-1. The design conditions for transfer are defined in Table 4.1-2.

This evaluation applies different component temperature limits and different material stress limits for long-term (steady-state) conditions and for short-term (transient) conditions. Normal storage is considered to be a steady-state condition. Off-normal and accident events, as well as the vacuum condition that temporarily occurs during the preparation of the canister while it is in the transfer cask and the time the canister is in the transfer cask while filled with helium, are evaluated as transient conditions. The maximum allowable material temperatures for long-term and for transient conditions are provided in Table 4.1-3. The maximum component temperatures are provided in Table 4.1-4.

The NAC-MPC system is designed to store Yankee class spent fuel with a maximum heat load of 12.5 kW and reconfigured fuel assemblies with a maximum heat load of 0.102 kW per assembly. The temperature effects on the NAC-MPC storage cask and the canister due to the reconfigured fuel assemblies are bounded by the temperatures produced in the cask by the design basis fuel. Table 4.1-4 summarizes the results of the thermal evaluation. As shown in this table, the calculated temperatures are well below the allowable component temperatures for normal (long-term) storage conditions and for short-term events.

Table 4.1-1 Summary of Thermal Design Conditions for Storage

CONDITION	ENVIRONMENTAL TEMPERATURE (°F)	SOLAR INSOLANCE [1]	CONDITION OF STORAGE CASK VENTS
Normal	75	Yes	All vents open
Off-Normal - Half Air Inlets Blocked	75	Yes	Two inlets blocked
Off-Normal - Severe Heat	100	Yes	All vents open
Off-Normal - Severe Cold	-40	No	All vents open
Accident - Extreme Heat	125	Yes	All vents open
Accident - All Air Inlets and Outlets Blocked [2]	75	Yes	All vents blocked
Accident - Cask Burial Under Debris [3]	75	No	All vents blocked

[1] Solar Insolance per 10CFR71:
Curved Surface: 400 g cal/cm^2 (1475 Btu/ft^2) for a 12-hour period.
Flat Horizontal Surface: 800 g cal/cm^2 (2950 Btu/ft^2) for a 12-hour period.

[2] This condition bounds the case in which all inlets are blocked, with all outlets open.

[3] In the burial under debris condition, the inlets/outlets are blocked and, in addition, the debris is considered not to permit any heat transfer from the surface of the concrete. This is a highly conservative assumption.

Table 4.1-2 Summary of Thermal Design Conditions for Transfer

CONDITION(1)	DURATION (Hours)
Water Filled	20
Vacuum Drying(2)	10
Canister filled with Helium	36

(1) The canister is inside the Transfer Cask, with an ambient temperature of 75°F.

(2) The canister is filled with water for a maximum of 20 hours before the start of the vacuum drying process. The initial water temperature is considered to be 100°F.

Table 4.1-3 Maximum Allowable Temperature Limits (°F)

MATERIAL[1]	LONG TERM	SHORT TERM	REFERENCE
Concrete	150(B)/200(L)[2]	350	ACI 349
Fuel Clad	644[3]	1,058	PNL-6189 PNL-4835
Aluminum Disk	650	700	MIL-HDBK-5F
NS-4-FR	300	300	Genden
Lead	600	600	Baumeister
SA693 Type 630 Stainless Steel	650	800	ASME B & PV Armco
SA240 Type 304 Stainless Steel	800	800	ASME B & PV
SA240 Type 304L Stainless Steel	800	800	ASME B & PV
ASTM A588 Carbon Steel	700	700	ASME Code Case N-71-16
ASTM A36 Carbon Steel	700	700	ASME Code Case N-71-16
BORAL Composite Sheet	850	1000	AAR Advanced Structures

1 The minimum allowable temperature limit for all materials is -40°F.

2 B and L refer to bulk temperatures and local temperatures, respectively. The local temperature allowable applies to a restricted region where the bulk temperature allowable may be exceeded.

3 The temperature limits for 5-year and 10-year-cooled fuel are 380°C and 340°C, respectively. The lower value (340°C) is used.

Table 4.1-4 Summary of Thermal Evaluation for NAC-MPC Storage System

Design Conditions	Material Temperature (°F) Concrete[1]	Fuel Clad	6061-T6 Al Alloy[2]	NS-4-FR[3]	Lead[3]	SA693 630 SS[2]	SA240 304 SS[4]	SA240 304L SS[4]	A588 Steel[3]	A36 Steel[1]
Allowable										
Long-Term	150(Bulk) 200(Local)	644	650	300	600	650	800	800	700	700
Short-Term	350	1058	700	300	600	800	800	800	700	700
Long-Term Conditions										
Normal (75°F Ambient)	133(Bulk) 165(Local)	563	527	N/A	N/A	529	183	319	N/A	165
Short-Term Conditions										
Off-Normal -Half Inlets Blocked (75°F Ambient)	168	565	529	N/A	N/A	531	192	318[5]	N/A	169
Off-Normal -Severe Heat (100°F Ambient)	196	587	552	N/A	N/A	554	213	347	N/A	196
Off-Normal -Severe Cold (-40°F Ambient)	5	453	411	N/A	N/A	412	44	187	N/A	5
Accident -Extreme Heat (125°F Ambient)	228	607	574	N/A	N/A	575	241	372	N/A	229
Transfer -Vacuum Drying	N/A	424	339	98	98	339	100	274	103	N/A
Transfer -Backfilled with Helium	N/A	597	569	188	191	570	140	430	237	N/A

1. Concrete cask components: Concrete cask and steel liner (A36).
2. Fuel basket components: Heat transfer disks (6061-T6) and support disks (SA 693, Type 630 stainless steel).
3. Transfer cask components: Shells and bottom doors (A588); neutron shield (NS-4-FR); and, gamma shield (lead).
4. Canister components: Shield lid (SA 240, Type 304 stainless steel) and shell, bottom plate and structural lid (SA 240 Type 304L stainless steel).
5. Although the maximum canister temperature is 1 degree lower than that of the normal condition, the overall canister temperature for the half inlet blocked condition is higher than that of the normal condition, which results in higher temperatures inside of the canister (fuel clad and disks).

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4.2 Summary of Thermal Properties of Materials

The thermal properties used in the thermal analyses are shown in Tables 4.2-1 through 4.2-11. The derivation of the effective conductivities is described in Sections 4.4.1.3 and 4.4.1.4

Table 4.2-1 Thermal Properties of Solid Neutron Shield (NS-4-FR)

Property[1] (units)	Value
Conductivity (Btu/hr-in-°F)	0.0311
Density (lbm/in^3) (borated)	0.0589
Density (lbm/in^3) (nonborated)	0.0607
Specific Heat (Btu/lbm-°F)	0.39

[1] Data developed by BISCO Products. (NS-4-FR is now supplied by Genden Engineering Services and Construction Company. Genden has established a maximum continuous service temperature of 300°F.)

Table 4.2-2 Thermal Properties of Stainless Steels

Type 304 and Type 304L

Property (units)	Temperature (°F)[5]			
	212	392	572	752
Conductivity[1] (Btu/hr-in-°F)	0.7800	0.8592	0.9333	1.0042
Density[1] (lbm/in^3)	0.2888	0.2872	0.2855	0.2839
Specific Heat[1] (Btu/lbm-°F)	0.1207	0.1272	0.1320	0.135
Emissivity[2]	0.36 at 300°F			

17-4PH, Type 630

Property (units)	Temperature (°F)[6]			
	100	200	500	700
Conductivity[3] (Btu/hr-in-°F)	0.8417	0.8833	1.0167	1.1000
Density[4] (lbm/in^3)	0.284	0.284	0.284	0.284
Specific Heat[4] (Btu/lbm -°F	0.11	0.11	0.11	0.11
Emissivity[2]	0.58	0.58	0.58	0.58

1 Hanford
2 Bucholz
3 "ASME Code Section II, Part D"
4 ARMCO
5 Maximum Service Temperature: 800°F
6 Maximum Service Temperature: 650°F long term and 800°F short term

Table 4.2-3 Thermal Properties of Chemical Lead

Property (units)	Temperature (°F)[3]			
	209	400	581	630
Conductivity[1] (Btu/hr-in-°F)	1.6308	1.5260	1.2095	1.0079
Density[1] (lbm/in^3)	0.411	0.411	0.411	0.411
Specific Heat[1] (Btu/lbm-°F)	0.03	0.03	0.03	0.03
Emissivity[2]	0.28 at 75°F			

1 Edwards
2 Baumeister
3 Maximum service temperature: 600°F (based on preventing the lead from reaching its melting point of 620°F).

Table 4.2-4 Thermal Properties of Type 6061-T6 Aluminum Alloy

	Temperature (°F)[3]					
Property (units)	200	300	400	500	600	700
Conductivity[1] (Btu/hr-in-°F)	8.25	8.38	8.49	8.49	8.49	8.49
Emissivity[2]	0.22	0.22	0.22	0.22	0.22	0.22

1. "ASME Code, Section II, Part D" (The maximum temperature tabulated is 400°F. Since the conductivity increases as the temperature increases, using the value of 8.49 for higher temperatures is conservative.)

2. Recommended value for aluminum in SCOPE (Bucholz) Version 1.2 Abbreviated Input Data Guide.

3. Maximum Service Temperature: 700°F, short-term service
650°F, long-term service

Table 4.2-5 Thermal Properties of Helium

Property (units)	Temperature (°F) 200	400	600	800
Conductivity[1] (Btu/hr-in-°F)	0.00808	0.00942	0.01075	0.01150
Specific Heat[1] (Btu/lbm-°F)	1.24	1.24	1.24	1.24
Density[1] (lbm/in^3)	4.83E-6	3.70E-6	3.01E-6	2.52E-6

[1] Kreith

Table 4.2-6 Thermal Properties of Dry Air

	Temperature (°F)			
Property (units)	100	300	500	700
Conductivity[1] (Btu/hr-in-°F)	0.00128	0.00161	0.00193	0.00223
Density (lbm/ft^3)	4.11E-5	3.23E-5	2.38E-5	1.97E-5
Specific Heat[1] (Btu/lbm-°F)	0.240	0.244	0.247	0.253

[1] Kreith

Table 4.2-7 Thermal Properties of Concrete

Property (units)	Temperature Range (°F) 32 - 400
Conductivity[1] (Btu/hr-in-°F)	0.059
Specific Heat[1] (Btu/lbm-°F)	0.20
Density[2] (lbm/ft^3)	140
Emissivity[3,4]	0.90

(Emissivity = 0.93 for masonry, 0.94 for rough concrete; 0.9 is used)[3,4]

1 Fintel (Fig. 6-31, 0.71/12=0.059 Btu/hr. in.-°F)
2 ASTM-C150
3 Kreith
4 Siegel
5 Maximum service temperature: long-term 150°F; bulk/200°F local; and short-term 350°F. The local temperature allowable applies to a restricted region where the bulk temperature allowable may be exceeded.

Table 4.2-8 Thermal Properties of ASTM A 36 and ASTM A 588 Carbon Steel

Property (units)	Temperature (°F)[5]				
	100	200	400	500	700
Conductivity[1] (Btu/hr-in-°F)	1.992	2.033	2.017	1.975	1.867
Density[2] (lbm/in^3)	0.284	0.284	0.284	0.284	0.284
Specific Heat[3] (Btu/lbm-°F)	0.113	0.113	0.113	0.113	0.113
Emissivity[4]	0.80	0.80	0.80	0.80	0.80

1 ASME Code, Section II, Part D, Table TCD
2 Ross
3 Kreith
4 Baumeister
5 Maximum service temperature: 700°F

Table 4.2-9 Thermal Properties of Zircaloy and Zircaloy-4 Cladding

	Temperature (°F)			
Property (units)	392	572	752	932
Conductivity[1] (Btu/hr-in-°F)	0.69	0.73	0.80	0.87
Emissivity[1]	0.75	0.75	0.75	0.75

1 NUREG/CR-0497 (minimum value of emissivity for a cladding surface)

Table 4.2-10 Thermal Properties of Fuel (UO_2)

Property (units)	Temperature (°F) 100	440	570	793
Conductivity[1] (Btu/hr-in-°F)	0.29[1]	0.29	0.27	0.19

[1] NUREG/CR-0497 (The lower boundary of temperatures tabulated is 500°K (440°F). Since the conductivity decreases as the temperature increases, using the value of 0.29 for the 100°F entry is conservative.)

Table 4.2-11 Thermal Properties of BORAL Composite Sheet

	Temperature (°F)[3]	
Property (units)	100	500
Conductivity[1] (Btu/hr-in-°F)		
Aluminum Clad[1]	7.805	8.976
Core Matrix[1]	4.136	3.698
Emissivity[1,2]	0.15	0.15

1 AAR Advanced Structures, standard specification for BORAL composite BRJREVO-940107.

2 The emissivity of the aluminum clad of the BORAL sheet ranges from 0.10 to 0.19 based on the BORAL specification. An averaged value of 0.15 is used.

3 Maximum service temperature: 850°F

4.3 Specification of Components

There are three major components that must be maintained within their safe operating temperature ranges: the lead gamma shield and the NS-4-FR solid neutron shield in the transfer cask, and the aluminum heat transfer disk in the canister basket.

The safe operating ranges for the lead gamma shield, solid neutron shield and aluminum heat transfer disk are as follows:

Component	Safe Operating Range
Lead gamma shield	-40°F to +600°F
NS-4-FR solid neutron shield	-40°F to +300°F
Aluminum heat transfer disk	-40°F to +650°F (long term); +700°F (short term)

The safe operating range of the lead gamma shield is based on preventing the lead from reaching its melting point of 620°F (Baumeister).

The maximum operating temperature limit of the NS-4-FR solid neutron shield material to ensure sufficient neutron shielding capability is specified by the product supplier to be 300°F.

The safe operating range of the aluminum heat transfer disk is based on the integrity of the aluminum being maintained. The aluminum heat transfer disk is not a structural component to transfer load within the basket. Based on the MIL-HDBK-5F, aluminum at 700°F retains component performance. The maximum long-term and short term operating temperatures for the aluminum heat transfer disk are taken to be 650°F and 700°F, respectively.

The maximum operating temperatures for other materials are shown in Table 4.1-3.

As shown in Tables 4.4.3-1 and 4.4.3-2, the maximum temperatures for these materials in the normal (long-term) conditions of storage are well below the allowable maximum temperatures. Maximum temperatures for off-normal and accident conditions are addressed in Chapter 11.

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4.4 Thermal Evaluation for Normal Conditions of Storage

4.4.1 Thermal Models

As listed below, six finite element models are utilized for the thermal evaluation of the NAC-MPC system for normal conditions of storage. All models are generated by the ANSYS program.

1. Two-Dimensional Axisymmetric Air Flow and Concrete Cask Model
2. Three-Dimensional Canister Model
3. Two-Dimensional Fuel Model
4. Two-Dimensional Fuel Tube Model
5. Three-Dimensional Transfer Cask and Canister Model
6. Two-Dimensional Reconfigured Fuel Assembly Model

The two-dimensional axisymmetric air flow and concrete cask model includes the concrete storage cask, air in the air inlets, annulus and the air outlets, and the canister shell. It is used to perform computational fluid dynamic analyses to determine the mass flow rate, velocity and temperatures of the air flow as well as the temperature distribution of the concrete, concrete cask steel liner and the canister shell.

The three-dimensional canister model comprises the fuel assemblies, fuel tubes, stainless steel support disks, aluminum heat transfer disks, the canister shell, lids and bottom plate. The canister model is employed to evaluate the temperature distribution of the fuel cladding and components of the canister and basket. The fuel regions and the fuel tubes with BORAL plates in the three-dimensional canister model are modeled using effective conductivities.

The effective conductivity of the fuel is determined using the two-dimensional fuel model, which is a detailed two-dimensional thermal model of the fuel assembly. The model includes the fuel pellets, cladding and gas (considered to be helium) occupying the space between the fuel rods and in the gap between the fuel pellets and the fuel rod cladding.

The two-dimensional fuel tube model is used to determine the effective conductivities of the tube wall and BORAL plate.

The three-dimensional transfer cask and canister model comprises the transfer cask, the canister and the canister internals—i.e., the three-dimensional canister model with the transfer cask added. This model is used to perform transient analysis for the transfer condition when the canister is in the vacuum condition during drying.

The two-dimensional reconfigured fuel assembly model comprises the fuel rods, fuel tubes, the shell casing (the square tube with the same external dimensions as an intact fuel assembly) and the gas (helium) occupying the gap between fuel rod and tube, the space between fuel tubes and the gap between shell casing and the fuel assembly tube. This model is used to determine the temperature distribution of the reconfigured fuel assembly.

These models are described in Section 4.4.1.1 through 4.4.1.5.

4.4.1.1 Two-Dimensional Axisymmetric Air Flow and Concrete Cask Model

The storage cask consists of the fuel canister, concrete, steel liner, air gap between the fuel canister shell and steel liner, and air inlets/outlets through the concrete region. The fuel canister with a design heat load of 12.5 kW will be cooled by (1) natural/free convection of air through the lower vents, the vertical air annulus, and the upper vents; and (2) radiant heat transfer between the surfaces of the canister shell and the steel liner. The heat transferred to the liner will be rejected by air convection in the annulus and by conduction through the concrete. The heat flow through the concrete will be dissipated to the surroundings by natural convection and radiant heat transfer. The temperature in the concrete region is controlled by radiant heat transfer between the vertical annulus surfaces (canister shell outer surface and steel liner inner surface), natural convection of air in the annulus, and boundary conditions applicable to the storage cask outer surfaces—e.g., natural convection and radiant heat transfer between the outer surfaces and the environment, including consideration of incident solar energy. These heat transfer modes are combined in the air flow and concrete cask model. The entire thermal system, including mass, momentum, and energy, is analyzed using ANSYS FLOTRAN.

4.4.1.1.1 Finite Element Model for Air Flow in Storage Cask

The storage cask has four air inlets at the bottom and four air outlets at the top that extend through the concrete. Since the configuration is symmetrical, it can be simplified into a two-dimensional axisymmetric model, as shown schematically in Figure 4.4.1.1-1, by using equivalent dimensions for the air inlets and outlets, which are assumed to extend around the storage cask periphery. This model consists of the following regions: canister shell, steel liner, concrete, air inlet, transitional region, vertical annulus, and air outlet. The canister shell is included in this model in order to apply the heat flux for the design fuel heat. The canister model is described in Section 4.4.1.2.

The two-dimensional axisymmetric air flow and concrete cask finite element model is shown in Figure 4.4.1.1-2. The model has the following features. In the air region, only quadrilateral elements are used and the element sizes are nonuniform with much smaller element sizes close to the walls. In other regions to simulate conduction, a mix of quadrilateral elements and triangular elements are used.

In this model, the radiation heat transfer across the vertical air annulus is also included.

4.4.1.1.2 Loads and Boundary Conditions

In the normal storage condition, the concrete cask has the following loads and boundary conditions:

1. Heat flux from the active fuel region.

Since only the canister shell is included in this air flow model, an equivalent nonuniform heat flux from the active fuel region is applied to the inner surface of the canister shell. This heat flux corresponds to 12.5kW, which is the heat generated by the spent fuel. The distribution of the heat flux is based on the axial power distribution, as described in Section 5.2.3, for the design-basis fuel (Figure 4.4.1.1-3).

2. Solar insolance to the outer surfaces of the storage cask.

The solar insolance to the storage cask outer surface is considered in the model. The incident solar energy is applied based on 24-hour averages as shown below.

Side surface: $$\frac{1475 \text{Btu}/\text{ft}^2}{24 \text{hrs}} = 61.46 \text{Btu}/\text{hr}\cdot\text{ft}^2$$

Top surface: $$\frac{2950 \text{Btu}/\text{ft}^2}{24 \text{hrs}} = 122.92 \text{Btu}/\text{hr}\cdot\text{ft}^2$$

3. Natural convection heat transfer at the outer surfaces of the storage cask.

Natural convection heat transfer at the outer surfaces of the storage cask is evaluated using the heat transfer correlation for vertical and horizontal plates (Kreith, Incropera). This method assumes a surface temperature and then estimates Grashof (Gr) or Rayleigh (Ra) numbers to determine whether correlation for a laminar model or for a turbulence model should be used. Since Grashof or Rayleigh numbers are much higher than the critical values, correlation for a turbulence model is used as shown in the following.

Side surface (Kreith):

$$\left.\begin{aligned} Nu &= 0.13(Gr \cdot Pr)^{1/3} \\ h_c &= Nu \cdot k_f / H_{VCC} \end{aligned}\right\} \quad \text{for } Gr > 10^9$$

Top surface (Incropera):

$$\left.\begin{aligned} Nu &= 0.15 Ra^{1/3} \\ h_c &= Nu \cdot k_f / L \end{aligned}\right\} \quad \text{for } Ra > 10^7$$

Where

h_c Average natural convection heat transfer coefficient

H_{vcc} Height of the storage cask

Gr	Grashof number
k_f	Conductivity
L	Top surface characteristic length, L = area / perimeter
Nu	Average Nusselt number
Pr	Prandtl number
Ra	Rayleigh number

All material properties required in the above equations are evaluated based on the film temperature—that is, the average value of the surface temperature and ambient temperature.

4. Radiation heat transfer at the storage cask outer surfaces.

The radiation heat transfer between the outer surfaces and ambient is evaluated in the model by calculating an equivalent radiation heat transfer coefficient.

$$h_{rad} = \frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{1/\varepsilon_1 + 1/\varepsilon_2 + 1/F_{12} - 2}$$

Where:

h_{rad}	Equivalent radiation heat transfer coefficient
F_{12}	View factor
T_1 and T_2	Surface (T_1) and ambient (T_2) temperatures (°K)
ε_1 and ε_2	Surface (ε_1) and ambient (ε_2=1) emissivities
σ	Stefan-Boltzmann Constant

At the storage cask side surface, an emissivity for concrete surface of ε_1 = 0.9 is used and a calculated view factor (F_{12}) = 0.197 (Chapter 13 of Incropera) is applied. Since the center cask is surrounded by other casks, its view factor to the ambient is reduced.

At the top, an emissivity of ε_1 = 0.8 for a carbon steel surface is used, and a view factor (F_{12}) = 1 is applied.

5. Other flow and thermal boundary conditions.

At all walls bounding the air flow region, a zero velocity, vx=vy=0, is applied. At the vent inlet and outlet surfaces, a relative zero pressure, $p_{in} = p_{out} = 0$, is applied. The inlet temperature of the air is reasonably assumed to be the same as the ambient temperature. The effect of surrounding loaded casks on air inlet temperature is considered to be negligible because of the 15-foot center to center spacing of the casks (approximately 4.5 feet, clear opening). The natural air flow patterns between the casks negate potential stagnation effects.

4.4.1.1.3 Accuracy Check of the Numerical Simulation

To ensure the accuracy of the numerical simulation on the air flow in the storage cask, and to ensure reliable numerical results, the following checks and confirmations have been performed.

1. Global convergence of the iteration process for the nonlinear system.

The system controlling air flow through the cask and, therefore, the temperature field is nonlinear and is solved iteratively. The global iteration process is monitored by checking the variation of parameters with the global iteration—e.g., the maximum air temperature, the mass flow rate, and the heat carried out of the storage cask by air convection. The mass flow rate varying with the global iteration is shown in Figure 4.4.1.1-4. As shown, after 10,000 global iterations, the mass flow rate is constant, indicating that the global iteration process has converged. At the converged state, the mass flow rate at the air inlets agrees with that at the air outlets. All of the results presented are at the converged state.

2. Finite element mesh adequacy study.

Element size or number of elements used in the simulation will affect the accuracy and reliability of the numerical prediction, even though converged results can be obtained.

Two tests, using different element sizes, have been performed for the normal case. Results are shown in Table 4.4.1.1-1, together with the number and size of elements close to the vertical annulus surfaces. As shown, results for the two test cases are in agreement, with the maximum difference being less than 3.3 percent in net heat carried out of the cask by air (Q_{air}).

3. Overall energy balance and mass balance.

This step validates the overall energy balance and mass balance. The mass balance is shown in Figure 4.4.1.1-4. At the converged state, the mass flow rate at the air inlets matches the mass flow rate at the air outlets, showing that an excellent mass balance has been obtained.

The overall energy balance is checked by computing the total heat input (Q_{in}) and total heat output (Q_{out}). The total heat input includes the total heat from the fuel (Q_{fuel}) and the total solar energy (Q_{sun}) incident on the storage cask outer surfaces. The total heat output is the sum of heat carried out of the cask by air (Q_{air}) and by convection and radiation heat loss at the storage cask outer surfaces (Q_{con}). During the normal storage condition:

$$Q_{in} = Q_{fuel} + Q_{sun} = 12.5\text{kW} + 9.85\text{kW} = 22.35\text{kW}$$
$$Q_{out} = Q_{air} + Q_{con} = 12.43\text{kW} + 10.25\text{kW} = 22.68\text{kW}$$
$$Q_{out}/Q_{in} = 1.015$$

Therefore, the overall energy balance is demonstrated to be within 1.5 percent.

Figure 4.4.1.1-1 Two-Dimensional Axisymmetric Air Flow and Concrete Cask Model

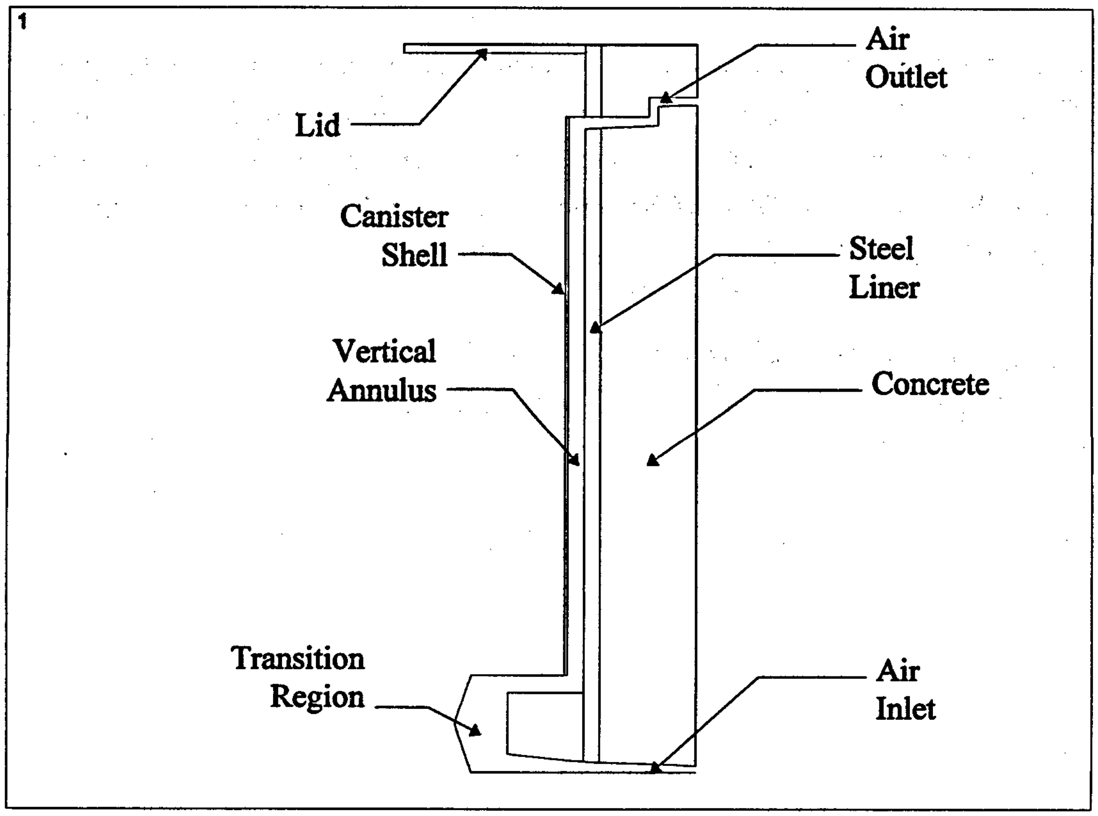


Figure 4.4.1.1-2 Two-Dimensional Axisymmetric Air Flow and Concrete Cask Finite Element Model

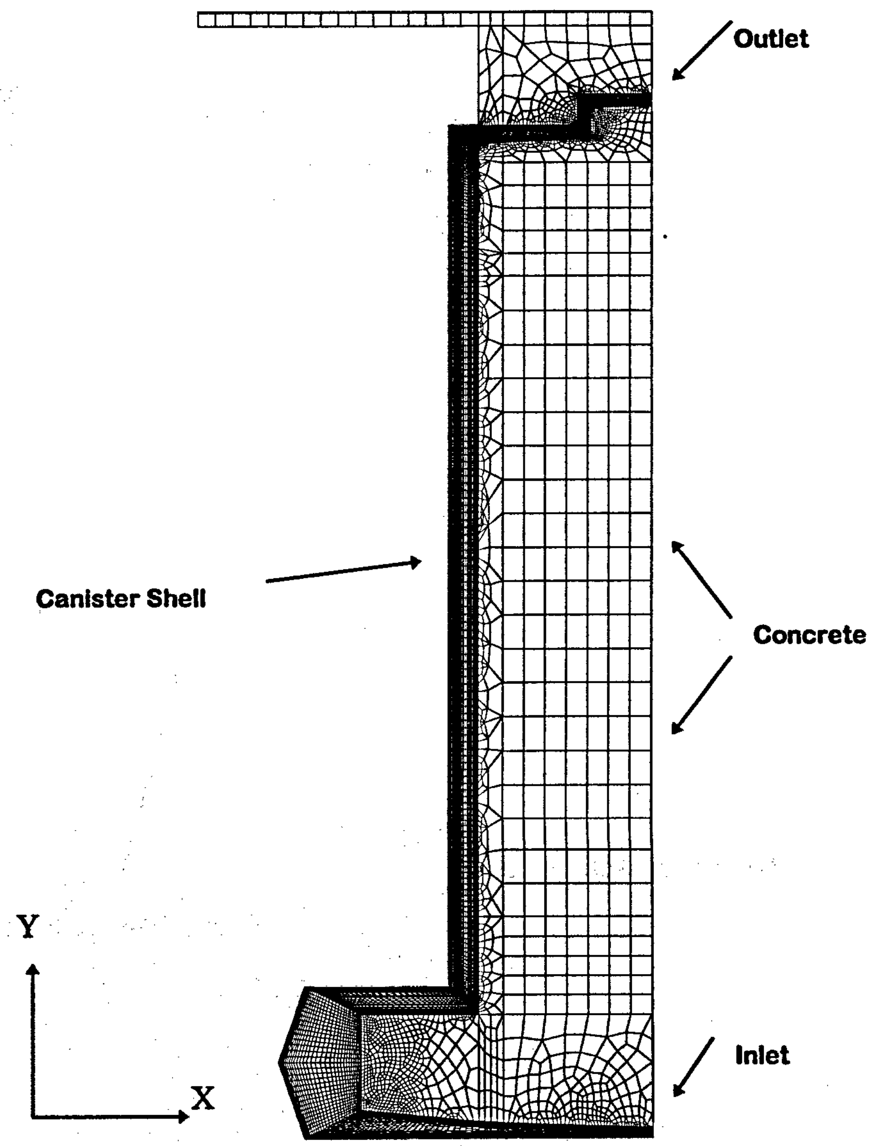


Figure 4.4.1.1-3 Axial Power Distribution for Yankee Class Fuel

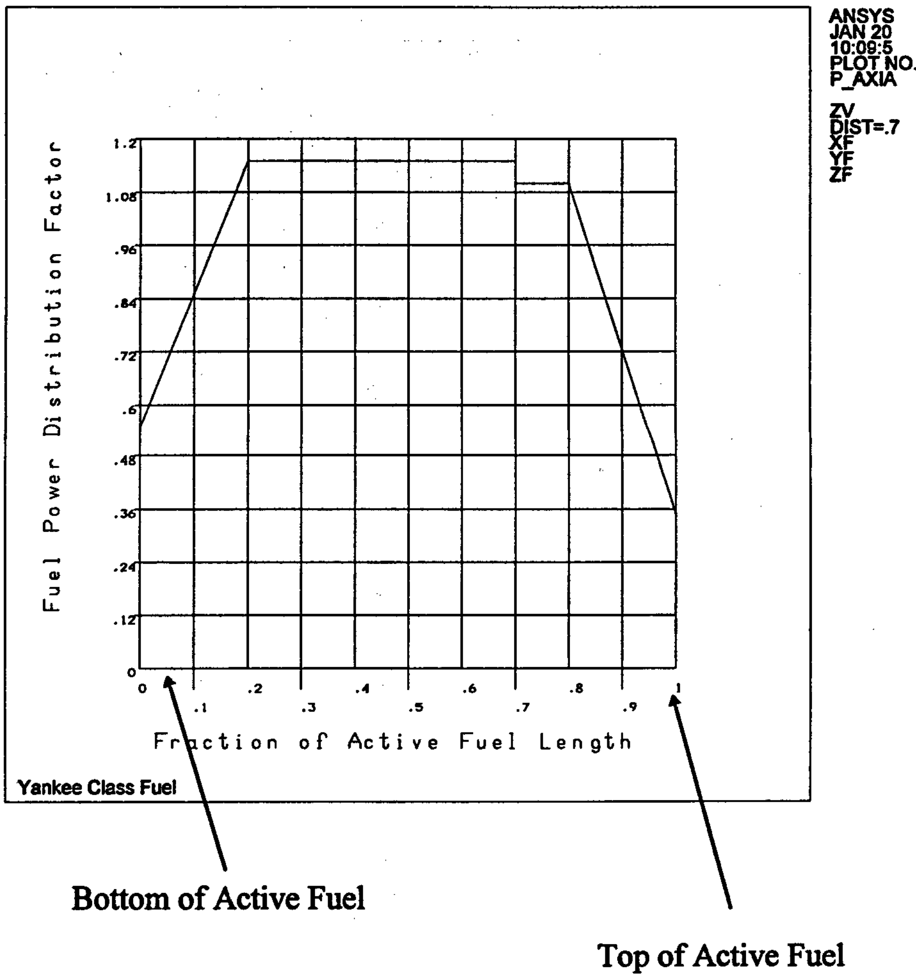


Figure 4.4.1.1-4 Convergence Process of Mass Flow Rate

Mass in: mass flow rate at the air inlets, kg/s

Mass out: mass flow rate at the air outlets, kg/s

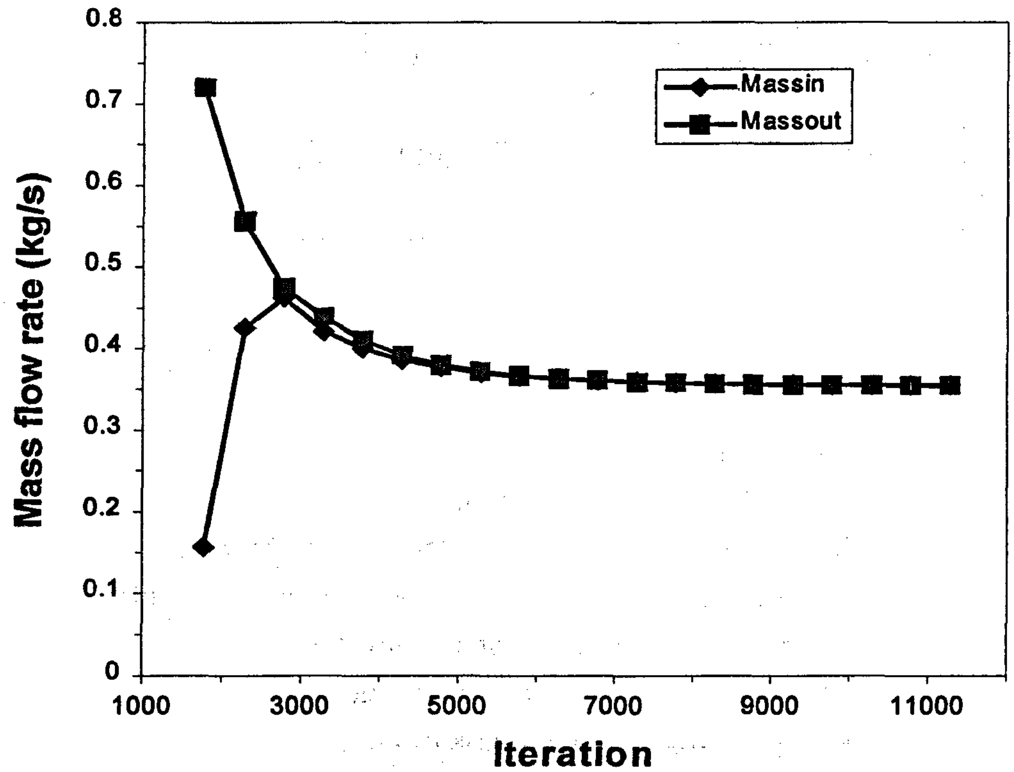


Table 4.4.1.1-1 Comparison of Numerical Results Using Different Element Sizes and Number of Elements

Test Case	Element Number	Element Size(m)	$Tmax_{air}$ (K)	$Tmax_{con}$ (K)	Mass (kg/s)	Vx_{out} (m/s)	T_{out} (K)	Q_{air} (kW)
ES1	12167	0.00184	433.25	345.33	.3582	.7780	332.84	12.84
ES2	15631	0.00136	430.61	346.89	.3543	.7673	332.45	12.43
ES1/ES2	.7784	1.353	1.0061	.9955	1.011	1.014	1.0012	1.033

Where

$Tmax_{air}$	Maximum air temperature
$Tmax_{con}$	Maximum concrete temperature
Element size	Refer to the element adjacent to the wall of the vertical gap
Mass	Average mass flow rate of air between air inlet and outlet
Vx_{out}	Average velocity component in x-direction
T_{out}	Average air temperature at the air outlet
Q_{air}	Net heat carried out of the cask by air

4.4.1.2 Three-Dimensional Canister Model

The three-dimensional canister model is shown in Figures 4.4.1.2-1 and 4.4.1.2-2. ANSYS SOLID70 three-dimensional conduction elements and LINK31 radiation elements are used to construct the model. The model includes the fuel assemblies, fuel tubes, support disks, heat transfer disks, the canister shell, lids, bottom plate and helium. Based on symmetry, only half of the canister is modeled. As shown in Figure 4.4.1.2-1, the interior of the canister contains the active fuel region. No conduction elements are defined outside of this region in the axial direction; i.e., top and bottom fittings of the fuel assemblies, fuel tubes enclosing the top and bottom fittings, the first support disk (counted from the top end), and the top and bottom weldments are not included in the model. Conduction through these components is conservatively ignored. The canister shell temperatures obtained from the two-dimensional axisymmetric air flow and concrete cask model (Section 4.4.1.1) are applied at the canister shell surface in the model as boundary conditions. The top surface of the canister lid and the bottom surface of the canister bottom plate in the model are considered to be adiabatic. In the model, the fuel assemblies are considered to be centered in the fuel tubes. The fuel tubes are centered in the slots of the support disks and heat transfer disks. The basket is centered in the canister. These assumptions are conservative since any contact between components will provide a more efficient path to reject the heat.

This model includes the following gaps:

LOCATION	GAP SIZE
1. Gap between the support disk and the canister shell	0.205 inch
2. Gap between the heat transfer disk and the canister shell	0.345 inch
3. Gap between the exterior surface of the fuel tube and the inside surface of the slots in the disks	0.079 inch
4. Gap between the BORAL sheet and tube/cladding	0.003 inch

Gas inside the canister is modeled as helium. The gap sizes are established based on nominal dimensions of the basket components and are adjusted to account for differential thermal expansion based on thermal conditions. The structural lid and the shield lid are expected to be in

full contact due to the weight of the structural lid. The thermal resistance across the contact surface is considered to be negligible and, therefore, no gap is modeled between the lids.

All material properties used in the model, except the effective properties discussed below, are shown in Tables 4.2-1 through 4.2-11.

The fuel regions (inside tubes) are modeled as homogenous regions with effective conductivities, determined by the two-dimensional fuel model as described in Section 4.4.1.3. The center slot of the basket contains no fuel and is modeled as helium. The fuel tube and the BORAL plate, including helium gaps on both sides of the BORAL sheet and the gap between the stainless steel cladding and the disks, are modeled as one-element thick with effective conductivities, established using the two-dimensional tube model described in Section 4.4.1.4.

In this model, radiation heat transfer is taken into account in the following locations:

1. From the top of the fuel region to the bottom surface of the shield lid.
2. From the bottom of the fuel region to the top surface of the canister bottom plate.
3. From the exterior surfaces of the fuel tubes (between SS and AL disks) to the inner surface of the canister shell.
4. Across all four gaps, described above.

Radiation elements (LINK31) are used to model the radiation effect for the first three locations. Radiation across gaps is accounted for by establishing effective conductivities for the gas in the gap, as shown below. Since the gaps represented in the model are small compared to the surfaces separated by the gaps, the view factor is taken to be unity.

Radiation heat transfer between two nodes i (hotter node) and j (colder node) is accounted for by the expression:

$$q_r = \sigma \varepsilon_{eff} A F \left(T_i^4 - T_j^4\right)$$

where

σ = the Stefan-Boltzman constant
= 1.19×10^{-11} Btu/hr-in^2-°R^4
ε_{eff} = effective graybody emissivity
A = surface area
F = the gray body shape factor for the surfaces
T_i = temperature of the i th node
T_j = temperature of the j th node

The total heat transfer can be expressed as the sum of the radiation and the conduction processes.

$$Q_t = q_r + q_k$$

where q_r is specified above for the radiation heat transfer and q_k, which is the heat transfer by conduction is expressed as:

$$q_k = \frac{KA}{g}(T_i - T_j)$$

where

T_i = temperature of the i th node
T_j = temperature of the j th node
g = gap distance (between the two surfaces defined by node i and node j)
K = conductivity of the gas in the gap
A = area of gap surface

By combining the two expressions (for q_k and q_r) and factoring out the term $A(T_i - T_j)/g$,

$$Q_t = [g\sigma\varepsilon_{eff}F(T_i^2 + T_j^2)(T_i+T_j) + K][A(T_i - T_j)/g]$$

or

$$Q_t = K_{eff}A(T_i - T_j)/g$$

where

$$K_{eff} = g\sigma\varepsilon_{eff}F(T_i^2 + T_j^2)(T_i+T_j) + K$$

The material conductivity used in the analysis for the elements comprising the gap includes the heat transfer by both conduction and radiation.

Effective emissivities are used for all radiation calculations, based on the formula below (Kreith).

$\varepsilon_{eff} = 1/(1/\varepsilon_1 + 1/\varepsilon_2 - 1)$ where ε_1 and ε_2 are the emissivities of two parallel plates

Radiation between the exterior surfaces of the fuel tubes and the radiation between the stainless steel support disk and the aluminum disk are conservatively ignored in this model.

Volumetric heat generation (Btu/hr-in^3) is applied to the active fuel region based on a total heat load of 12.5 kW, active fuel length of 91 inches and an axial power distribution as shown in Figure 4.4.1.1-3.

Figure 4.4.1.2-1 Three-Dimensional Canister Model

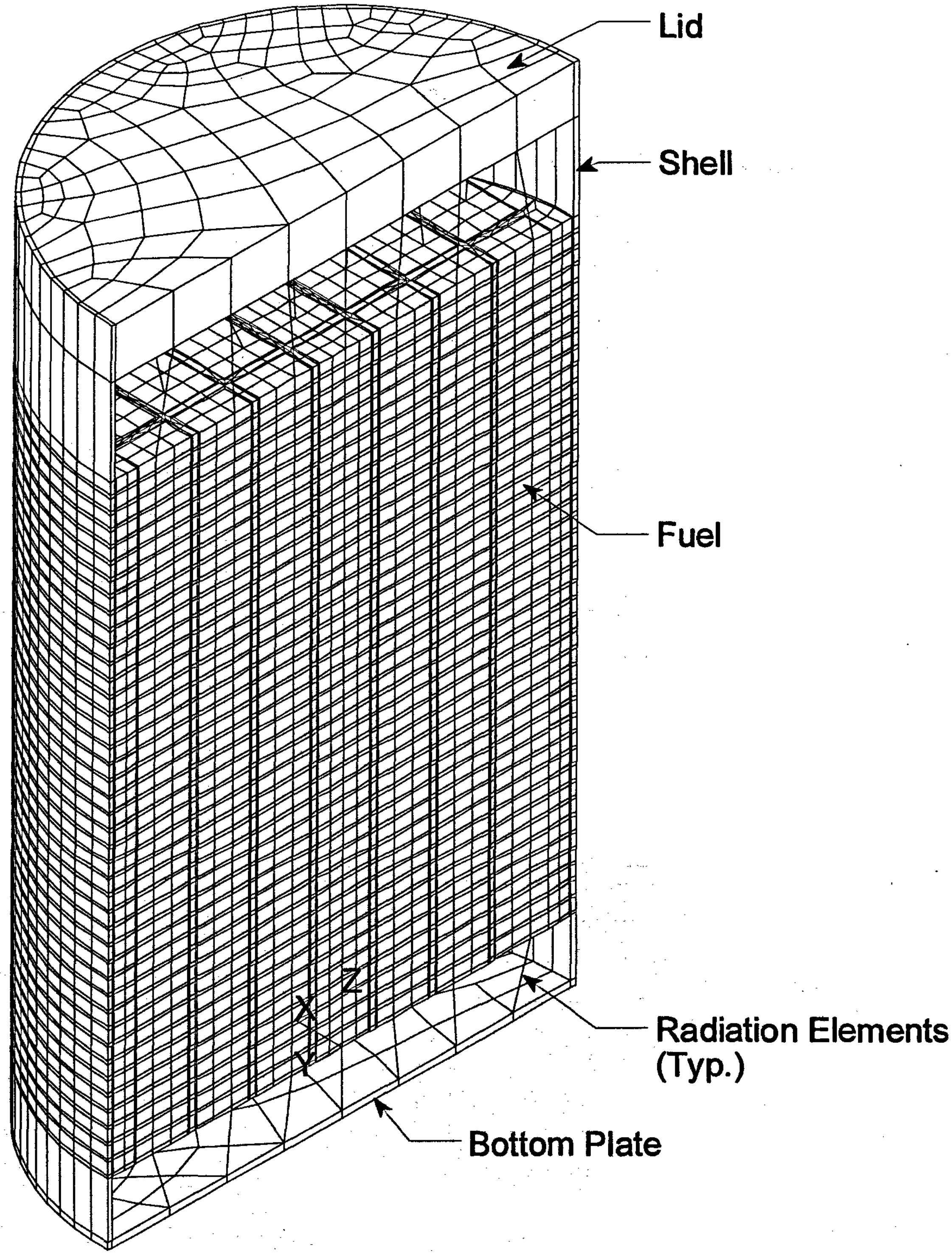
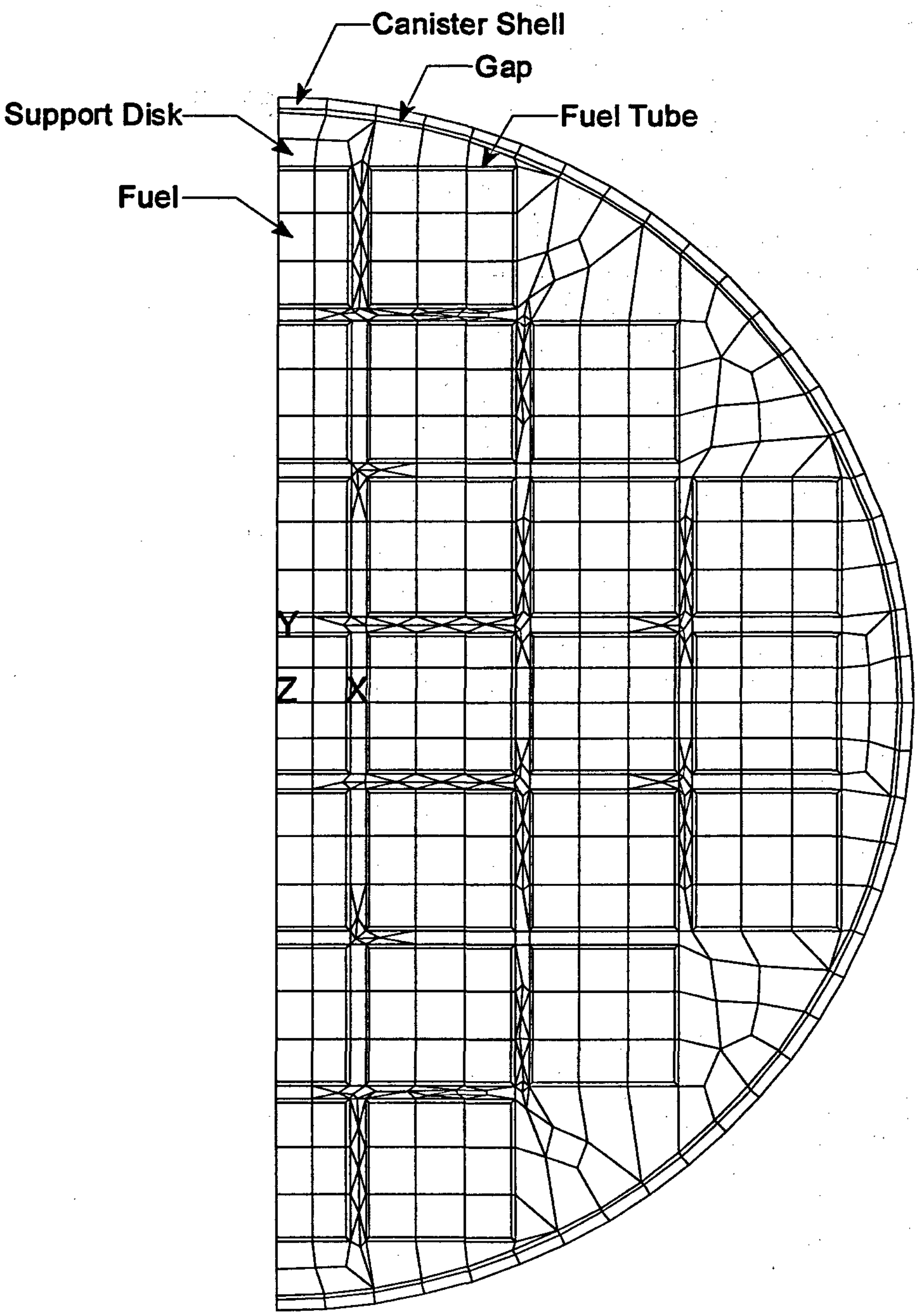


Figure 4.4.1.2-2 Three-Dimensional Canister Model - Cross-Section



4.4.1.3 Two-Dimensional Fuel Model

The effective conductivity of the fuel is determined by a two-dimensional finite element model of the fuel assembly. The model includes the fuel pellets, cladding, gas between fuel rods and gas (considered to be helium) occupying the gap between the fuel pellets and cladding. The configuration of the design basis fuel (CE Type A) is used in the model. Note that the fuel cladding material for this fuel is zircaloy, which is less conductive than stainless steel. Therefore, the fuel model bounds the fuel with zircaloy cladding, as well as the fuel with stainless steel cladding. Modes of heat transfer modeled include conduction and radiation between individual fuel rods for the steady-state condition. The model is shown in Figure 4.4.1.3-1.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used in the model, which includes a total of 240 fuel rods. Each fuel rod consists of the pellet, zircaloy cladding, and a gap between the pellet and cladding. The gas in the gap between the pellet and cladding, as well as the gas between fuel rods, is considered to be helium. Radiation elements are defined between fuel rods and from the fuel rods to the boundary of the model (inside surface of the fuel tube). Radiation effects at the gap between the pellets and the cladding are conservatively ignored. Effective emissivities are determined using the formula shown in Section 4.4.1.2.

The effective conductivity for the fuel is determined using the equation (SANDIA) to determine the maximum temperature of a square cross-section of an isotropic homogeneous fuel with a uniform volumetric heat generation. At the boundary of the square cross-section, the temperature is constrained to be uniform. The expression for the maximum temperature is given by:

$$T_c = T_e + 0.29468\ (Q\ a^2 / K_{eff})$$

where T_c = the temperature at the center of the fuel (°F)
T_e = the temperature applied to the exterior of the fuel (°F)
Q = volumetric heat generation rate (Btu/hr-in^3)
a = half length of the square cross-section of the fuel (inch)
K_{eff} = effective thermal conductivity for the isotropic homogeneous fuel material (Btu/hr-in-°F)

Volumetric heat generation (Btu/hr-in^3) based on the design heat load of 12.5 kW is applied to the pellets. The effective conductivity is determined based on the heat generated and the temperature difference from the center of the model to the edge of the model. The temperature-dependent effective properties, as shown below, are established using different boundary temperatures. The effective conductivity in the axial direction of the fuel assembly is calculated based on the material area ratio.

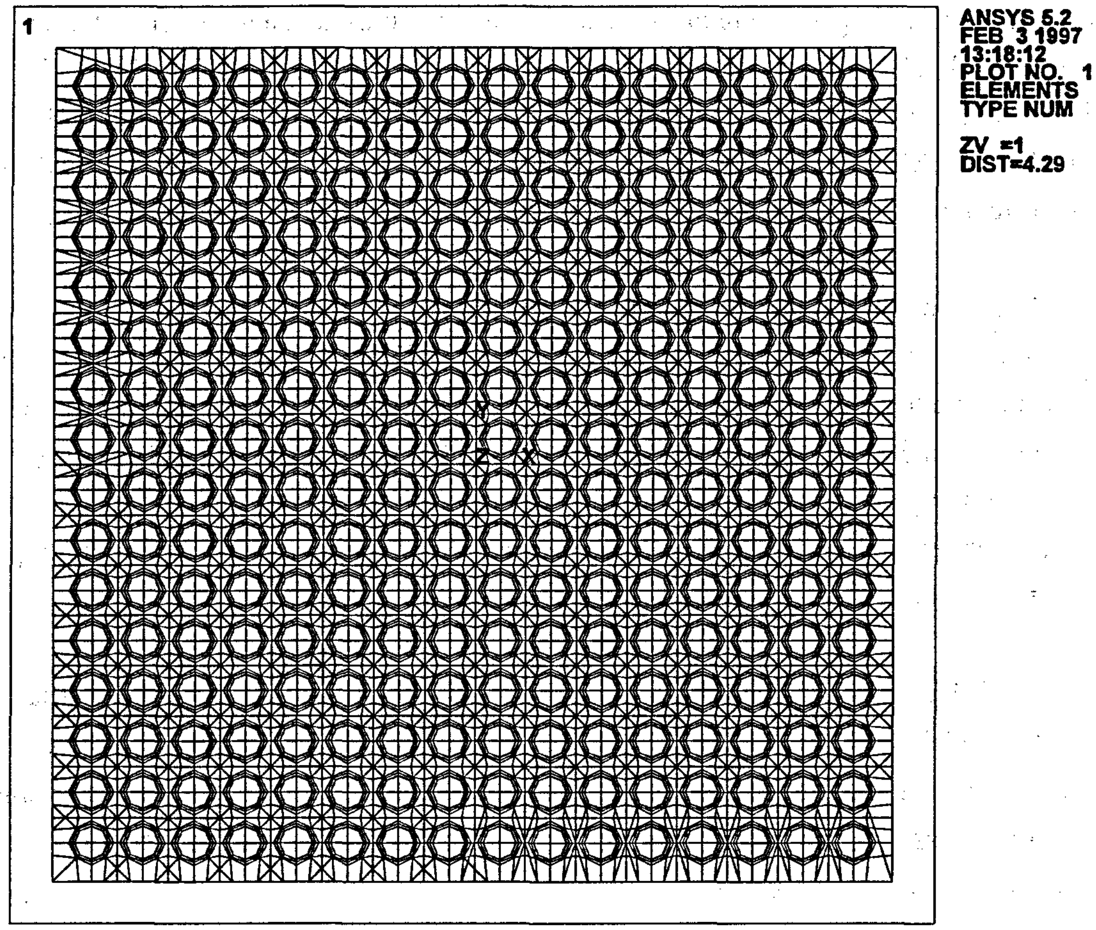
Conductivity (Btu/hr-in-°F)

Temperature (°F)	kxx	kyy	kzz
128	0.0167	0.0167	0.163
322	0.0204	0.0204	0.152
518	0.0262	0.0262	0.141
714	0.0330	0.0330	0.138
911	0.0405	0.0405	0.140

Note:

1. x and y axes are in-plane of the model, z is in the canister axial direction.
2. The temperature associated with each row is the average temperature of the fuel assembly.

Figure 4.4.1.3-1 Two-Dimensional Fuel Model



4.4.1.4 Two-Dimensional Fuel Tube Model

The purpose of the two-dimensional fuel tube model is to determine the effective conductivity of the fuel tube and BORAL plate, which is used in the three-dimensional canister model. As shown in Figure 4.4.1.4-1, this model includes the fuel tube, the BORAL plate (including the core matrix sandwiched by aluminum claddings), helium gaps on both sides of the BORAL plate, and the helium gap between the stainless steel cladding on the outside of the BORAL plate and the support disk or heat transfer disk.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the model. The model consists of eight layers of conduction elements and six radiation elements that are defined at the helium gaps (two for each gap). The thickness of the model (x-direction) is the distance measured from the inside face of the fuel tube to the inside face of the slot in the support disk (assuming the fuel tube is centered in the hole in the disk). The tolerance of the BORAL plate thickness, 0.003 inch, is used as the gap size for both sides of the BORAL plate. The height of the model is defined as equal to the width of the model.

Heat flux is applied at the left side of the model (fuel tube), and the temperature at the right boundary of the model is constrained. The heat flux is determined based on the design heat load of 12.5 kW. The maximum temperature of the model (at the left boundary) and the temperature difference (ΔT) across the model are calculated by ANSYS. The effective conductivity is determined using the following formula:

$$q = k\,(A/L)\,\Delta T$$

or

$$k = q\,L/(A\,\Delta T)$$

where

q = heat rate (Btu/hr)
A = area (in^2)
L = length of model (in)
ΔT = temperature difference across the model (°F)
k = effective conductivity (Btu/hr-in-°F)

The temperature-dependent conductivity (k) is determined by varying the temperature constraints at one boundary of the model and resolving for the heat rate (q) and temperature difference. The effective conductivity for the parallel path (the Y direction in Figure 4.4.1.4-1) is calculated by

$$Kyy = \frac{\sum K_i t_i}{T}$$

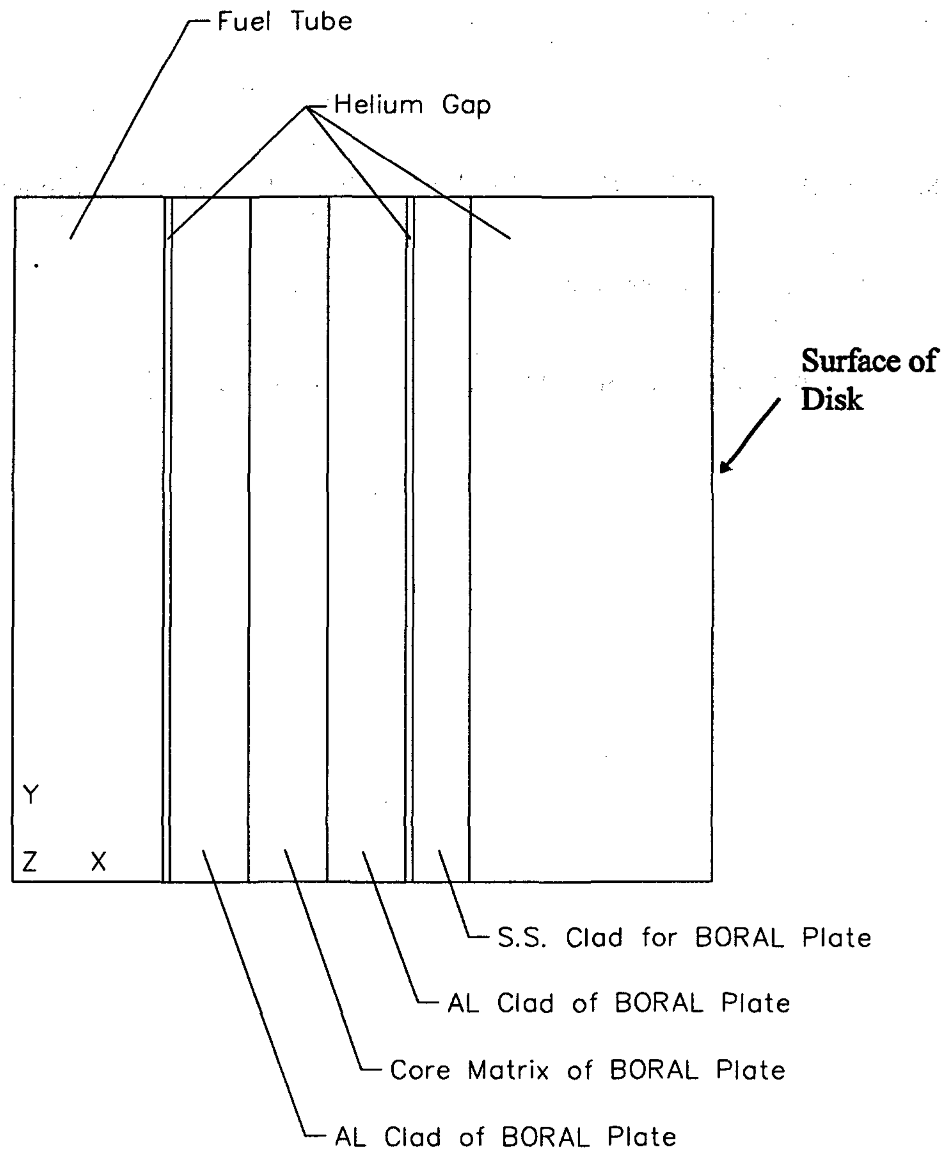
Where

K_i = thermal conductivity of each layer (fuel tube, helium aluminum clad)

t_i = thickness of each layer

T = total thickness of fuel tube, gaps (in Figure 4.4.1.4-1)

Figure 4.4.1.4-1 Two-Dimensional Fuel Tube Model



4.4.1.5 Three-Dimensional Transfer Cask and Canister Model

The three-dimensional transfer cask and canister model comprises the transfer cask, the canister and the canister internals. This model is one half (90°) of the three-dimensional canister model (Section 4.4.1.2) with the transfer cask added. The region below the active fuel is modeled with solid elements. The radiation from the bottom of the fuel to the top of the canister bottom plate is considered using the method described in Section 4.4.1.2. The trunnions and the retaining ring at the top of the transfer cask are not included in the model. This is conservative since it reduces the surface area for radiation and convection. The model is used to calculate the transient temperature distribution for the fuel cladding and the components of the transfer cask, canister and basket for the transfer condition when the canister is back-filled with helium. The model is shown in Figure 4.4.1.5-1. ANSYS SOLID70 elements and LINK31 elements are used to construct the model. Convection and radiation heat transfer are considered at the surfaces of the transfer cask and on the top of the canister lid. The bottom of the transfer cask is conservatively considered to be adiabatic. An ambient temperature of 75°F is assumed and no solar insolance is considered, since the transfer operation occurs inside a building. The canister is considered to be centered in the cavity of the transfer cask. In addition to the gaps inside the canister as described in Section 4.4.1.2, the following two gaps are considered in the model:

	LOCATION	GAP SIZE
1.	Gap between transfer cask inner shell and lead	0.063 inch
2.	Gap between the canister outer surface and the transfer cask inner shell	0.43 inch

These two gaps are considered to be filled with air. The 0.063-inch gap size between the transfer cask inner shell and the lead is used based on the dimensional tolerances of the transfer cask design. The gap size of 0.43 inch is based on the nominal dimensions of canister shell and the transfer cask. Radiation heat transfer across the gaps is considered using the same method described in Section 4.4.1.2. Radiation at the transfer cask outer surface and canister lid top surface is accounted for by the expression:

$$q_r = \sigma \varepsilon_{eff} A F \left(T_i^4 - T_j^4\right)$$

where

σ = the Stefan-Boltzman constant
= 1.19×10^{-11} Btu/hr-in^2-°R^4
ε_{eff} = emissivity
A = surface area
F = the gray body shape factor for the surfaces
T_i = temperature of the hotter node
T_j = temperature of the colder node

Radiation heat transfer from the surface can be incorporated in the model by modifying the convection coefficient as shown below:

$$Q_t = q_r + q_c$$

where q_r is specified above for the radiation heat transfer and q_c, which is the heat transfer by convection, is expressed as

$$q_c = h_c A(T_i - T_j)$$

where

h_c = film coefficient (Btu/hr-in^2)

The q_r can be rewritten as

$$q_r = \sigma \varepsilon_{eff} AF(T_i^2 + T_j^2)(T_i + T_j)(T_i - T_j)$$

By combining both expressions

$$Q_t = (\sigma \varepsilon_{eff} F(T_i^2 + T_j^2)(T_i + T_j) + h_c)A(T_i - T_j)$$

or

$$Q_t = h_{eff} A(T_i - T_j)$$

where

$$h_{eff} = \sigma \varepsilon_{eff} F(T_i^2 + T_j^2)(T_i + T_j) + h_c$$

The convection coefficient, h_{eff} used for the cask surface now includes the radiation heat transfer. The form factor (F) is taken to be unity.

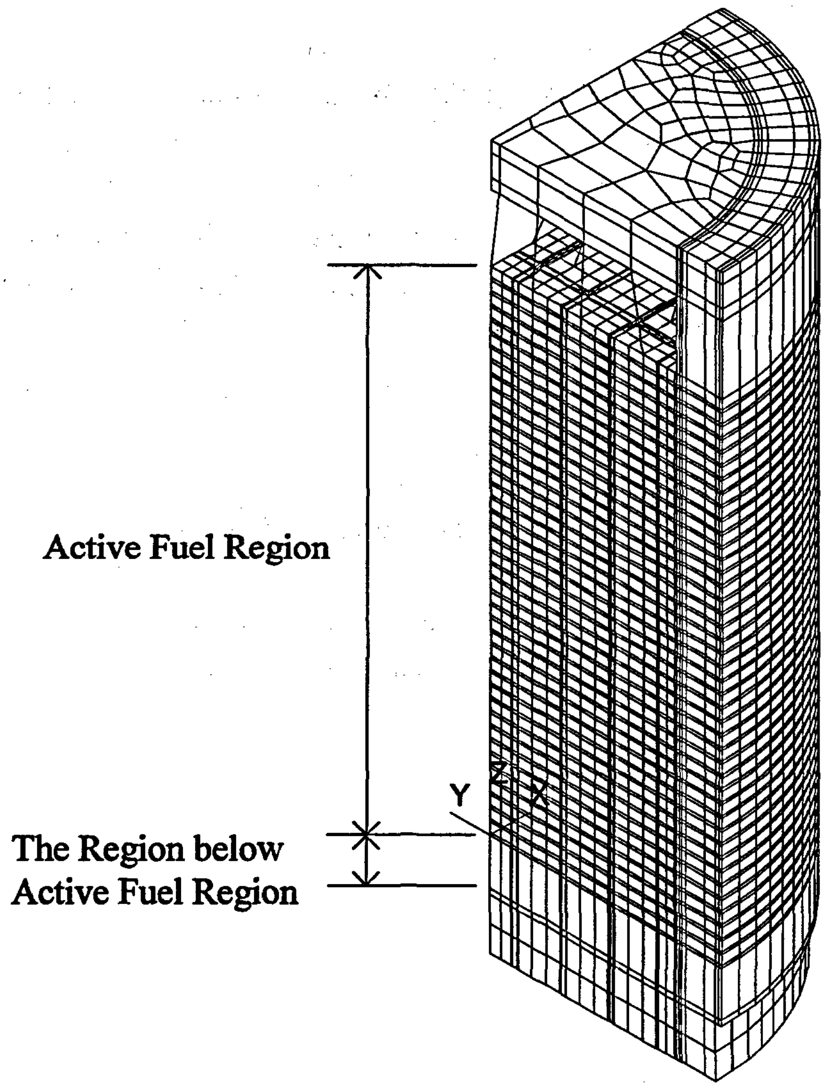
The convection heat transfer coefficient is determined by the following expression, which is established by empirical correlation for vertical plate and cylinders and horizontal plates (Kreith):

$$h_c = 0.0015\ \Delta T^{1/3}\ (\text{Btu/hr-in}^2\text{-}^\circ\text{F})$$

where ΔT is the temperature difference between the cask surface and ambient

Volumetric heat generation (Btu/hr-in^3) is applied to the active fuel region based on a total heat load of 12.5 kW, active fuel length of 91 inches and an axial power distribution, as shown in Figure 4.4.1.1-3.

Figure 4.4.1.5-1 Three-Dimensional Transfer Cask and Canister Model



4.4.1.6 Two-Dimensional Reconfigured Fuel Assembly Model

The two-dimensional reconfigured fuel assembly model is generated to calculate the temperature distribution of the hottest cross-section (1 inch long in the cask axial direction) of the Reconfigured Fuel Assembly (RFA). Because of symmetry, the model considers one-fourth of a cross-section of the RFA. The model is shown in Figure 4.4.1.6-1. ANSYS 'PLANE55' conduction elements and "LINK31" radiation elements are used in the model. The model includes a total of 16 fuel rods, 16 fuel tubes, the shell casing (the square tube with the same external dimensions as an intact fuel assembly) and the cover gas (considered to be Helium). Each fuel rod is located inside a stainless steel fuel tube. The fuel rod, which consists of the zircaloy clad, the fuel pellet (UO_2) and a small gap between the clad and fuel pellet, is modeled as a solid rod with the thermal conductivity of the UO_2. This is conservative since the conductivity of UO_2 is less than that of the zircaloy and the main interest of the fuel rod is the cladding temperature. The gas between the fuel rod and the fuel tube, the gas between fuel tubes and the gas outside of the shell casing are considered to be helium.

As shown in Figure 4.4.1.6-1, radiation elements are defined between tubes and from tubes to the inner surface of the shell casing. Form factor of 1 is used for the radiation elements. Effective emissivity is computed using the following formula (Kreith) based on corresponding material emissivities:

$$\varepsilon_{eff} = 1/(1/\varepsilon_1 + 1/\varepsilon_2 - 1)$$

where ϵ_1 and ϵ_2 are the emissivities of two parallel plates

Radiation between the fuel rod and the fuel tube is conservatively ignored. Radiation between the shell casing and the inner surface of the fuel assembly tube is accounted for by establishing effective conductivities for the gas in the gap using the method described in Section 4.4.1.2

Volumetric heat generation (Btu/hr-in^3) based on the design heat load of 0.0016 kW/pin is applied to the fuel rod elements. An active fuel length of 91 inches and a peaking factor of 1.15 are used.

Heat generation rate $= Q / V$

$= 0.6595$ Btu/hr-in^3

where,

Q = heat rate per pin (unit height)

$= (0.0016)\,(3413)\,(1.15)\,/(91) = 0.069$ Btu/hr

V = volume of pin (unit height)

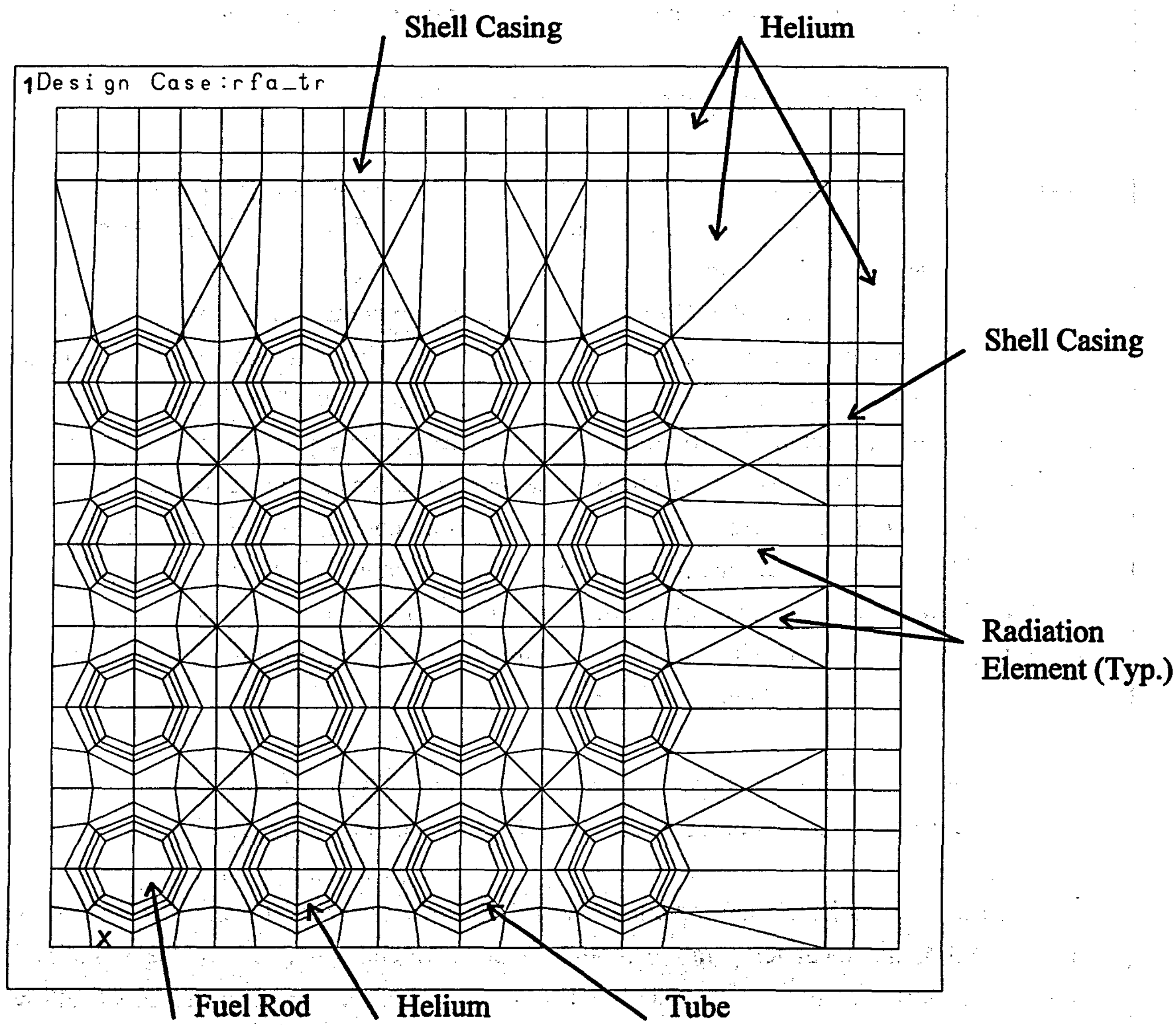
$= \pi\, 0.365^2 /4 = 0.1046$ inch^3

Boundaries of the model at planes of symmetry (at X=0 and at Y=0) are considered to be adiabatic. The temperature at the right and top boundaries (at X=3.9 inch and at Y=3.9 inch) of the model is constrained to be uniform based on the maximum temperatures of the fuel tube as shown below. These temperatures envelope the calculated maximum tube temperatures for the design basis Yankee Class fuel assembly and are conservative since the heat load for the RFA (0.102 kW) is less than one-third of the heat load for the design basis fuel assembly (0.347 kW).

Design Condition	Maximum Fuel Tube Temperature (°F)
Normal	540
Off-Normal and Accident	580
Transfer	715

1. The Fuel Tube is shown in Drawing 455-881.

Figure 4.4.1.6-1 Two-Dimensional Reconfigured Fuel Assembly Model



4.4.2 Test Model

The NAC-MPC system is conservatively designed by analysis so that testing is not required.

4.4.3 Maximum Temperatures for Normal Conditions

Figure 4.4.3-1 shows the temperature distribution of the concrete storage cask and the canister for the normal, long-term storage condition. The air flow field and air temperatures in the annulus between the canister and the storage cask liner for the normal condition of storage are shown Figures 4.4.3-2 and 4.4.3-3, respectively. The temperature distribution in the concrete portion of the storage cask is shown in Figure 4.4.3-4. The transient history of maximum temperatures of the fuel region in the canister for the transfer conditions (canister containing water for 20 hours, vacuum for 10 hours and helium for 36 hours) is shown in Figure 4.4.3-5. Table 4.4.3-1 shows the maximum component temperatures for the normal condition of storage. The maximum component temperatures for the transfer conditions, transient condition with helium inside the canister and the transient condition of vacuum are shown in Tables 4.4.3-2 and 4.4.3-3, respectively. The maximum component temperatures for the reconfigured fuel assembly are shown in Table 4.4.3-4. Temperature distributions for the off-normal and accident conditions are presented in Sections 11.1 and 11.2.

As shown in Figure 4.4.3-3, a high-temperature gradient exists near the wall of the canister and at the liner of the concrete storage cask. The air in the center of the annulus exhibits a much lower temperature gradient, indicating cooler air. The higher temperature at the storage cask steel liner surface indicates that radiation heat transfer occurs across the annulus. As shown in Figure 4.4.3-4, the local temperature in the concrete, directly affected by the radiation heat transfer across the annulus, can reach 165°F (347°K), which is less than the 200°F allowable temperature. The bulk temperature in the concrete, as determined by averaging the temperatures at the mid-radius of the concrete region, is less than the allowable value of 150°F.

For the transient transfer condition, the maximum temperature of the water is 205°F at the end of 20 hours based on an initial water temperature of 100°F.

Figure 4.4.3-1 Temperature Distribution (°F) for Normal Storage

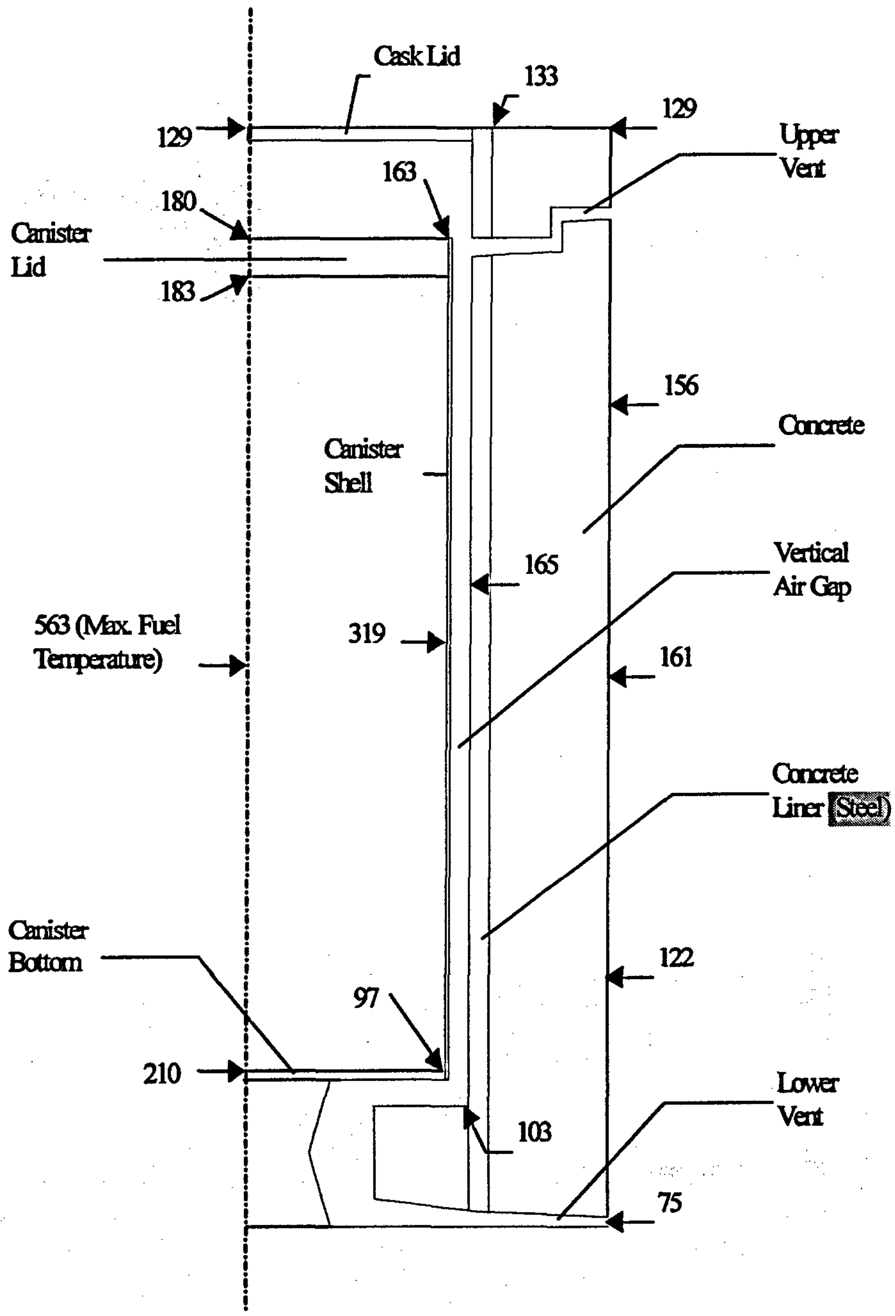


Figure 4.4.3-2 Air Flow Pattern in the Storage Cask in Normal Storage

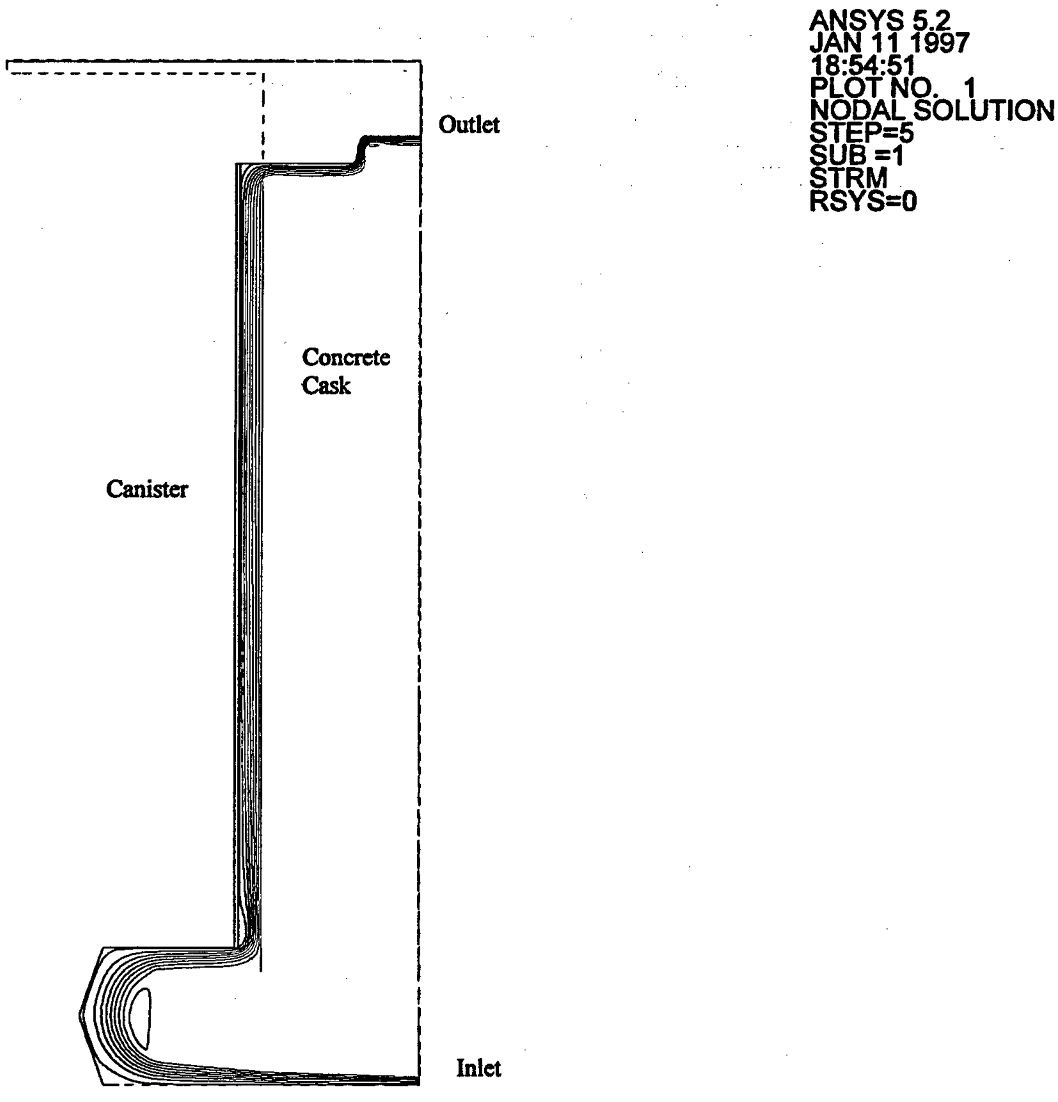
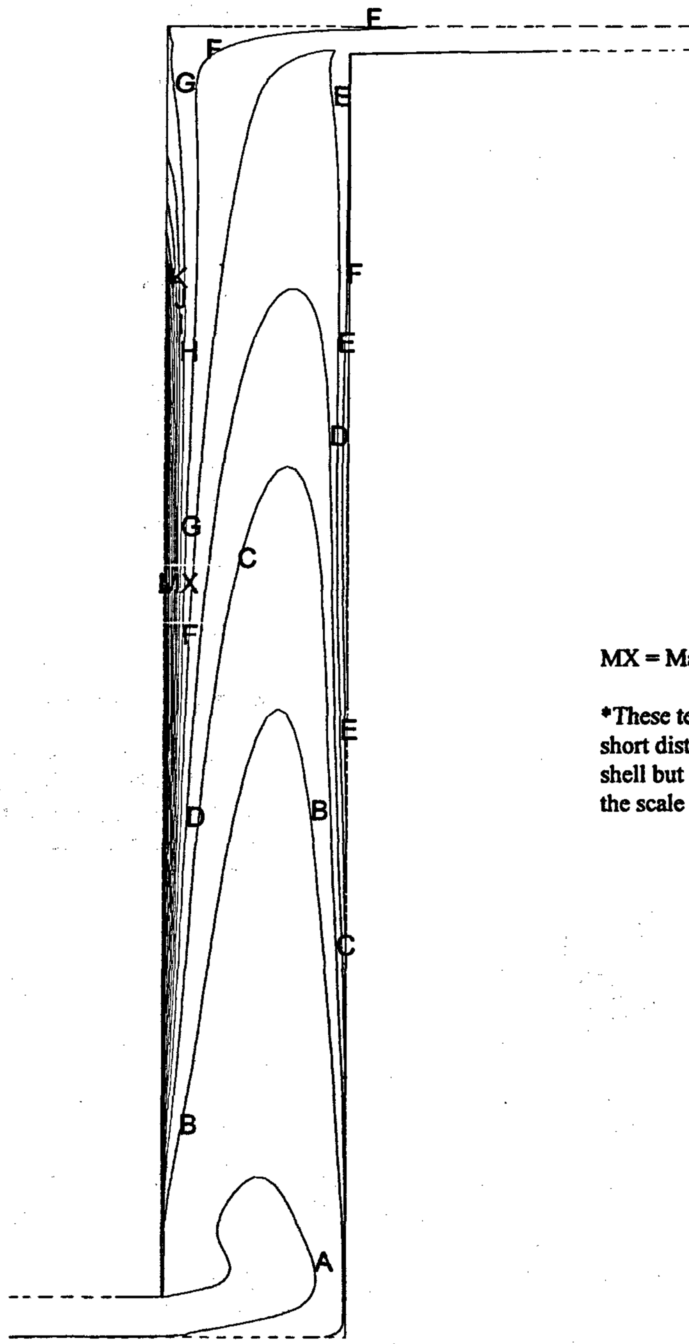


Figure 4.4.3-3 Air Temperature Field in the Storage Cask During the Normal Storage Condition

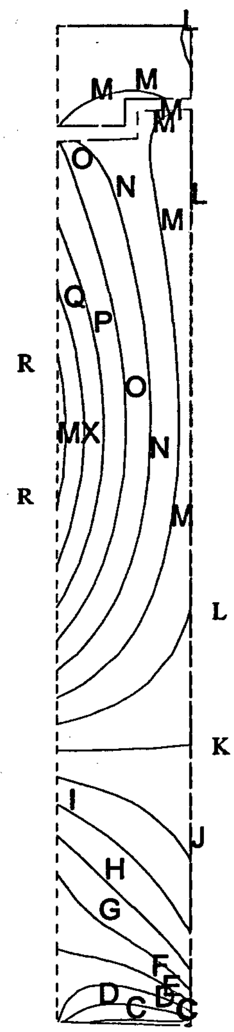


°F	
MX=	315
A=	79
B=	93
C=	106
D=	120
E=	133
F=	147
G=	160
H=	174
I=	187
J=	201
K=	214
L=	228
*M=	241
*N=	255
*O=	268
*P=	282
*Q=	295
*R=	309

MX = Maximum temperature

*These temperatures occur over short distances along the canister shell but are not shown due to the scale of the figure.

Figure 4.4.3-4 Concrete Temperature Field During the Normal Storage Condition

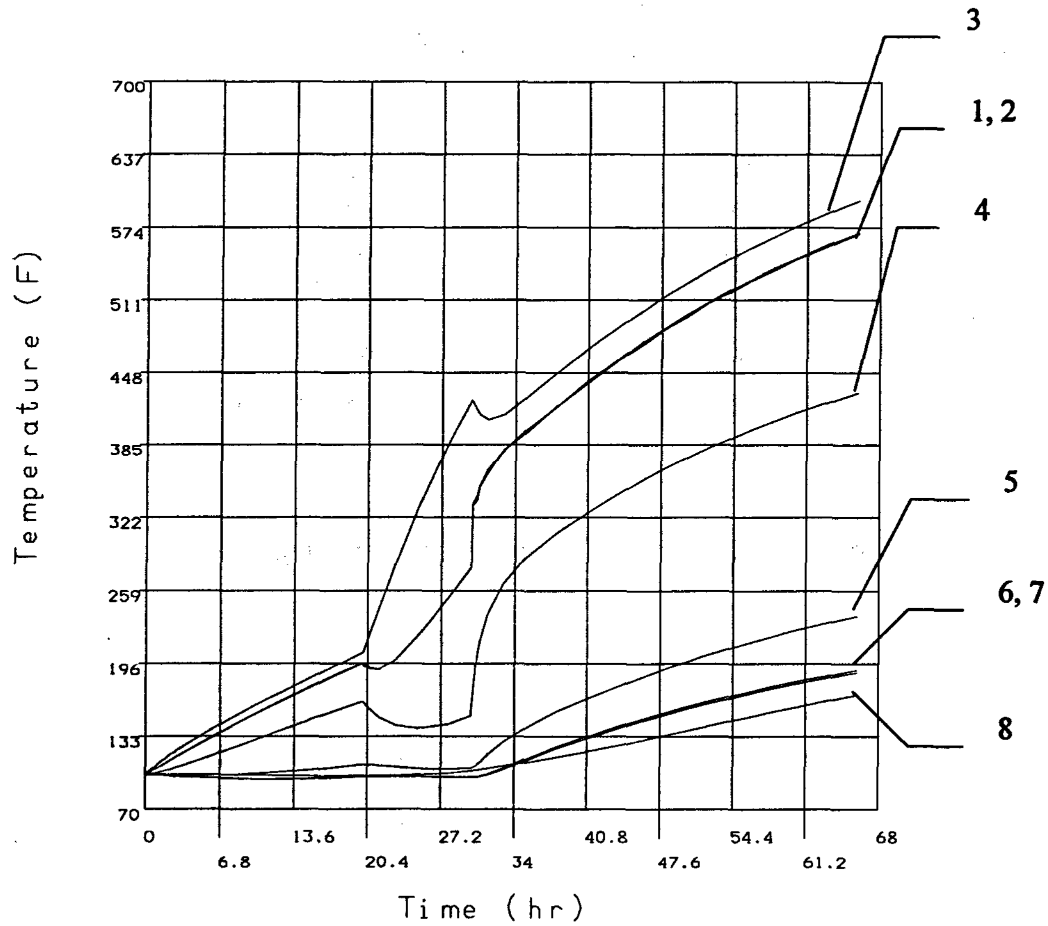


°F
MX= 165
*A= 77
*B= 82
C= 87
D= 92
E= 97
F= 102
G= 107
H= 112
I= 117
J= 122
K= 127
L= 132
M= 137
N= 142
O= 147
P= 152
Q= 157
R= 162

MX = Maximum temperature

*These temperatures occur in the lower edge of the concrete above the inlet vent. They are not shown due to the scale of the figure.

Figure 4.4.3-5 History of Maximum Component Temperatures for Transfer Conditions



1. Temperature of Support Disks
2. Temperature of Aluminum Disks
3. Temperature of the Fuel
4. Temperature of the Canister
5. Temperature of the Inner Shell
6. Temperature of the Lead
7. Temperature of the Neutron Shield
8. Temperature of Transfer Cask Doors

Table 4.4.3-1 Maximum Component Temperatures for the Normal Condition of Storage

Component	Maximum Temperature (°F)	Allowable Temperature (°F)
Fuel Cladding	563	644
Aluminum Disk	527	650
Support Disk	529	650
Canister	319	800
Concrete Liner (steel)	165	700
Concrete	165 (local)	200 (local)
	133 (bulk*)	150 (bulk)

* The average temperature of the concrete region is used as the bulk concrete temperature.

Table 4.4.3-2 Maximum Component Temperatures for the Helium Transfer Condition

Component	Maximum Temperature (°F)[1]	Allowable Temperature (°F)
Fuel	597	1058
Lead	191	600
Neutron Shield	188	300
Aluminum Disk	569	700
Support Disk	570	800
Canister	430	800
Transfer Cask Shells	237	700

1. Maximum temperatures calculated for the transient condition that considers the canister inside of the transfer cask containing water for 20 hours, a vacuum for 10 hours, and helium for 36 hours.

Table 4.4.3-3 Maximum Component Temperatures for the Vacuum Transfer Condition

Component	Maximum Temperature (°F)[1]	Allowable Temperature (°F)
Fuel	424	1058
Lead	98	600
Neutron Shield	98	300
Aluminum Disk	278	700
Support Disk	279	800
Canister	151	800
Transfer Cask Shells	105	700

1. Maximum temperatures calculated for the transient condition that considers the canister inside of the transfer cask containing water for 20 hours and a vacuum for 10 hours.

Table 4.4.3-4 Maximum Component Temperatures for the Reconfigured Fuel Assembly

Design Condition	Maximum Temperatures (°F)			
	PWR Fuel Tube[1,2]	Shell Casing[3,4]	Reconfigured Fuel Assembly Tube[5,6]	Fuel Rod Cladding[7]
Normal	540	543	563	563
Off-Normal and Accident Conditions	580	583	602	602
Transfer	715	718	734	734

1. Fuel Tube as shown in Drawing 455-881.
2. Bounding fuel tube temperatures as described in Section 4.4.1.6.
3. Reconfigured Fuel Assembly Shell Casing as shown in Figure 4.4.1.6-1.
4. Material allowable temperature: 800°F.
5. Reconfigured Fuel Assembly (Fuel) Tube as shown in Figure 4.4.1.6-1.
6. Material allowable temperature: 800°F.
7. Fuel cladding allowable temperatures:
   Normal conditions: 644°F
   Off-normal, Accident and Transfer conditions: 1058°F

4.4.4 Minimum Temperatures

Section 11.1 provides the temperature distribution for the off-normal severe cold environmental conditions of -40°F. At this extreme condition, the components are above their minimum material limits.

4.4.5 Maximum Internal Pressure for Normal Conditions

The NAC-MPC canister is backfilled with helium to atmospheric pressure (0.0 psig) and closed by welding. Normal condition pressure comprises the pressure due to the heating of the backfilled helium, plus the pressure due to the postulated failure of 3 percent of the stored fuel rods with the subsequent release of 30 percent of the fission gas and all of the rod charge gas to the canister cavity, at temperature, from those failed rods. All of the gases except the fission gases are assumed to be helium. The total pressure for each volume is found by calculating the molar quantity of each gas and summing those directly. The calculated average temperature of the helium gas is 442°F based on the thermal analysis results using the three-dimensional canister model described in Section 4.4.1.2. The pressure is calculated using the ideal gas law and applying a conservative average temperature of 450°F. The gas constant, R, is 0.0821 (atm x liters)/(Mole °K) (Lamarsh). The design basis fuel assembly for the internal pressure calculation is the CE Type A assembly. This assembly has the highest rod backfill pressure (315 psig) and received the highest burnup (36,000 MWd/MTU).

The number of moles of the backfill gases is calculated using the Ideal Gas Law, PV = NRT. Backfill gas for the canister is assumed to be initially at 1 atmosphere absolute. The quantity of fission gas is derived from the SAS2H generated isotopics of the CE Type A fuel assembly. The release of fission gas is as assumed for directly loaded fuel. For normal operating conditions, 3 percent of the fuel rods are assumed to fail, releasing 30 percent of their total fission gas and all of the backfill helium.

The fuel rod plenum volume is:

$$V_1 = \pi r^2 L - \frac{M_{Spring}}{r}$$

$$V_1 = \pi\left\{\left(\frac{0.317\text{ inches}}{2}\right)^2 \times 1.942\text{ inches}\right\} - \frac{\left(3.3\text{ g} \times 2.2046 \times 10^{-3}\ \frac{\text{lb}}{\text{g}}\right)}{0.288\ \frac{\text{lb}}{\text{inch}^3}} = 0.1280\text{ inches}^3$$

The pellet clad gap volume is:

$$V_2 = \pi L\left(r^2_{\text{Clad ID}} - r^2_{\text{Pellet OD}}\right)$$

$$V_2 = \pi \times (91\text{ inches}) \times \left(\frac{(0.317\text{ inches})^2}{4} - \frac{(0.3105\text{ inches})^2}{4}\right) = 0.2915\text{ inches}^3$$

The fuel rod lower plenum volume is:

$$V_3 = \pi \times r^2_{\text{Clad ID}} \times L$$

$$V_3 = \pi \times \frac{(0.317\text{ inches})^2}{4} \times 2.458\text{ inches} = 0.1940\text{ inches}^3$$

The total fuel rod backfill volume is:

$$V_{\text{Rod Back-Fill}} = V_1 + V_2 + V_3$$

$$V_{\text{Rod Back-Fill}} = 0.1280\text{ inches}^3 + 0.2915\text{ inches}^3 + 0.1940\text{ inches}^3 = 0.6135\text{ inches}^3$$

For the loaded canister, the total backfill gas volume is:

$$V = \text{Total Back-Fill } 0.6135\text{ inches}^3 \times 231\ \frac{\text{Rods}}{\text{Assembly}} \times 36\ \frac{\text{Assemblies}}{\text{Cask}} \times \left(2.54\ \frac{\text{cm}}{\text{inch}}\right)^3 \times \frac{0.001\ \ell}{\text{cm}^3}$$
$$= 83.605\ \frac{\ell}{\text{Cask}}$$

From the rod backfill volume and pressure, the quantity of rod backfill gas is calculated using the ideal gas law:

$$N = \frac{Pv}{RT}$$

$$N = \frac{\left\{(315 \text{ psig} + 14.7) \times \dfrac{1 \text{ atm}}{14.7 \text{ psia}}\right\} \times 83.605 \dfrac{\ell}{\text{Cask}}}{0.0821 \dfrac{\text{atm } \ell}{\text{Mole K}} \times 293 \text{ K}} = 77.95 \frac{\text{Moles of Rod Fill Gas}}{\text{Cask}}$$

The number of moles of fission gas per assembly is:

Isotope	Atomic Weight (gram/mole)	Mass (gram)	Number of Moles
KR	83	10.9	0.131
KR	84	29.9	0.356
KR	85	3.54	0.042
KR	86	48.4	0.563
I	127	11	0.087
I	129	47.2	0.366
XE	130	1.78	0.014
XE	131	112	0.855
XE	132	285	2.159
XE	134	395	2.948
XE	136	577	4.243
Total	--	--	11.76

There is a maximum of 36 assemblies per cask. Therefore the number of moles of fission gas per cask is 36 times that of the single assembly.

$$N = 36 \frac{\text{Assemblies}}{\text{Cask}} \times 11.76 \frac{\text{Moles}}{\text{Assembly}} = 423.44 \frac{\text{Moles of Fission Gas}}{\text{Cask}}$$

The canister is backfilled to 1.5 atmosphere with helium at room temperature for leak testing, after which the pressure is reduced to 1 atmosphere. During leak testing the temperature of the helium may rise above the 150°F assumed in the pressure evaluation.

$$V_{\text{Free Gas Volume}}^{\text{TSC}} = V_{\text{Canister}} - \left(\frac{\left(M_{\text{TSC Shield Lid}} + M_{\text{TSC Structural Lid}}\right)}{\rho_{\text{Steel}}} + V_{\text{Basket}}^{\text{TSC}} + V_{\text{Fuel}} \right)$$

$$V_{\text{Canister}} = \pi \frac{d^2}{4}\left(L_{\text{Canister}} - L_{\text{TSC Bottom Plate}}\right) = \pi \times \frac{(69.39 \text{ inches})^2}{4} \times (122.50 \text{ inches} - 1.0 \text{ inch})$$

$$V_{\text{Canister}} = 459{,}472.93 \text{ inches}^3$$

$$V_{\text{Basket}}^{\text{TSC}} = \frac{\left(M_{\text{Basket}}^{\text{TSC}} - \left(M_{\text{BORAL}} + M_{\text{Aluminum}} + M_{\text{Support Disks}}\right)\right)}{\rho_{\text{Steel}}} + \frac{M_{\text{BORAL}}}{\rho_{\text{BORAL}}} + \frac{M_{\text{Aluminum}}}{\rho_{\text{Aluminum}}} + \frac{M_{\text{Support Disk}}}{\rho_{\text{17-4-PH}}}$$

$$V_{\text{Basket}}^{\text{TSC}} = \frac{(9{,}530 \text{ lb} - (694.81 \text{ lb} + 810 \text{ lb} + 3{,}720 \text{ lb}))}{0.288 \frac{\text{lb}}{\text{in}^3}} + \frac{694.81 \text{ lb}}{0.095 \frac{\text{lb}}{\text{in}^3}} + \frac{810 \text{ lb}}{0.098 \frac{\text{lb}}{\text{in}^3}} + \frac{3{,}720 \text{ lb}}{0.282 \frac{\text{lb}}{\text{in}^3}}$$

$$V_{\text{Basket}}^{\text{TSC}} = 43{,}719.16 \text{ inches}^3$$

$$V_{\text{Free Gas Volume}}^{\text{TSC}} = 459{,}472.93 - \left(\frac{(5{,}390 \text{ lb} + 3{,}230 \text{ lb})}{0.288 \frac{\text{lb}}{\text{in}^3}} + 43{,}719.16 \text{ inches}^3 + 88{,}171.78 \text{ inches}^3 \right)$$

$$V_{\text{Free Gas Volume}}^{\text{TSC}} = 297{,}651.43 \frac{\text{inches}^3}{\text{Cask}}$$

$$V_{\text{Free Gas Volume}}^{\text{TSC}} = 297{,}651.43 \frac{\text{inches}^3}{\text{Cask}} \times \frac{1 \ \ell}{61.02 \text{ inches}^3} = 4{,}877.93 \frac{\ell}{\text{Cask}}$$

$$N = \frac{1 \text{ atm} \times 4{,}877.93 \frac{\ell}{\text{Cask}}}{0.0821 \frac{\text{atm } \ell}{\text{Mole K}} \times 339 \text{ K}} = 175.26 \frac{\text{Moles of TSC Backfill Gas}}{\text{Cask}}$$

The maximum normal operating pressure (MNOP) in the canister is calculated using the ideal gas law where:

$$N = N_{\text{TSC Back-Fill}} + 0.03\left(N_{\text{Rod Back-Fill}}\right) + 0.3(0.03)\left(N_{\text{Fission Gas}}\right)$$

$$N = 175.26\,\frac{\text{Moles}}{\text{Cask}} + 0.03\left(77.95\,\frac{\text{Moles}}{\text{Cask}}\right) + 0.3(0.03)\left(423.44\,\frac{\text{Moles}}{\text{Cask}}\right)$$

$$N = 181.41\,\frac{\text{Moles}}{\text{Cask}}$$

Therefore, the maximum normal operating condition canister internal pressure is:

$$P = \frac{\left(181.41\,\frac{\text{Moles}}{\text{Cask}}\right)\times\left(0.0821\,\frac{\text{atm}\,\ell}{\text{mole K}}\right)\times 505.37\text{ K}}{\left(4{,}877.93\,\frac{\ell}{\text{Cask}}\right)} = 1.54\text{ atm} \approx 22.6\text{ psia} \approx 7.9\text{ psig}$$

4.4.6 Maximum Thermal Stresses for Normal Conditions

The canister and concrete storage cask thermal stresses are evaluated in Section 3.4.4.

4.4.7 Evaluation of Cask Performance for Normal Conditions of Storage

As shown in the preceding sections, the NAC-MPC system operates within the thermal design limits. Therefore, no degradation due to temperature effects on material or components is expected over the lifetime of the cask.

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5.0 SHIELDING EVALUATION

5.1 Discussion and Results

The regulation governing spent fuel storage, 10 CFR 72, does not establish specific cask dose rate limits. However, 10 CFR 72.104 and 10 CFR 72.106 specify that for an array of casks in an Independent Spent Fuel Storage Installation (ISFSI), the annual dose to an individual outside the controlled area boundary must not exceed 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other organ during normal operations. In the case of a design basis accident, the dose to an individual outside the area boundary must not exceed 5 rem to the whole body or any organ. The ISFSI must be at least 100 meters from the owner controlled area boundary. In addition, the occupational dose limits and radiation dose limits for individual members of the public in 10 CFR Part 20 (Subparts C and D) must be met. Chapter 10, Section 10.3 demonstrates NAC-MPC compliance with the requirements of 10 CFR 72 with regard to annual and occupational doses at the owner controlled area boundary. This chapter presents the shielding evaluations of the NAC-MPC storage system. Dose rate profiles are calculated as a function of distance from the side, top and bottom of the NAC-MPC storage and transfer casks. Shielded source terms from the NAC-MPC storage cask are calculated to establish owner controlled area boundary dose estimates due to the presence of the ISFSI.

The NAC-MPC storage system can safely transfer and store up to 36 Combustion Engineering (CE) Yankee Class fuel assemblies with a maximum of 36,000 MWD/MTU burnup and a minimum of 8 years cooling. CE, United Nuclear (UN) and Westinghouse Yankee Class spent fuel assemblies having a maximum burnup of 32,000 MWD/MTU with 7.0, 7.1 and 21.0 years cooling, respectively, may also be stored. The NAC-MPC storage system is comprised of a transportable storage canister, a transfer cask, and a vertical concrete storage cask. License drawings for these items are provided in Section 1.5. The transfer cask containing the canister and the basket is loaded under water in the spent fuel pool. Once filled with fuel, the shield lid is placed on top of the canister and transfer cask is removed from the pool. After draining about 12 inches of water (approximately 50 gallons) from the cavity, the shield lid is welded in place, and the canister is drained and dried. Finally, the structural lid is welded in place. The transfer cask is then used to transfer the canister to the storage cask where it is stored dry until transport. Shielding evaluations are performed for the transfer cask with both a wet and dry canister cavity as would occur during the welding of the shield lid and during the welding of the structural lid, respectively. Shielding evaluations are performed for the storage cask with the cavity dry.

A canister may contain one or more reconfigured fuel assemblies. The reconfigured fuel assembly is designed to confine Yankee Class spent fuel rods, or portions thereof, which have been classified as failed. Each assembly can accommodate up to a total of 64 fuel pins, which is significantly less than other Yankee Class fuel assemblies. A depiction of the assembly is provided in Figure 1.2-5. Because the source term (neutron and gamma) is directly proportional to fuel mass, for a given burnup and enrichment, the reconfigured assembly source term is bounded by that of a design basis fuel assembly. Consequently, a separate shielding analysis is not required for the reconfigured fuel assembly.

The transfer cask has a multiwall radial shield comprised of 0.75 inches of carbon steel, 3.5 inches of lead, 2 inches of solid borated polymer (NS-4-FR), and 1.25 inches of carbon steel. An additional 0.625 inch of stainless steel shielding is provided, radially, by the canister shell. Gamma shielding is provided primarily by the steel and lead layers, and neutron shielding is provided primarily by the NS-4-FR. The transfer cask bottom shield design is a solid section of 9.50 inches of carbon steel. The top shielding is provided by the stainless steel canister shield and structural lids which are 5 inches and 3 inches thick, respectively. In addition, 5 inches of carbon steel is used as temporary shielding during welding, draining, drying and helium backfill operations. This temporary shielding is removed prior to storage.

The storage cask radial shield design is comprised of a 3.5-inch thick carbon steel inner liner surrounded by 21 inches of concrete. Gamma shielding is provided by both the carbon steel and concrete, and neutron shielding is provided primarily by the concrete. As in the transfer cask, an additional 0.625 inch thickness of stainless steel radial gamma shielding is provided by the canister shell. The storage cask top shielding design is comprised of 8 inches of stainless steel from the canister lids, a shield plug containing a 1 inch thickness of NS-4-FR and 4.125 inches of carbon steel, and a 1.5 inch thick carbon steel lid. Since the bottom of the storage cask sits on a concrete pad, the storage cask bottom shielding is comprised of 1 inch of stainless steel from the canister bottom plate, 2 inches of carbon steel (pedestal plate) and 1 inch of carbon steel cask base plate. The base plate and pedestal base are structural components that position the canister above the air inlets. The cask base plate supports the storage cask during lifting, and forms the cooling air inlet channels at the cask bottom.

If the canister overpack is used, additional shielding is provided by the inner and outer lids, and by the overpack shell (0.5-inches thick) and the bottom plate (1.38-inches). The lids provide an additional 5-inches of shielding axially above the overpack. The overpack bottom, shell and

outer lid are stainless steel. This additional shielding ensures that the dose rates calculated for the concrete cask containing a canister with design basis fuel bound the dose rates that result if the concrete cask contains an overpack holding a canister with design basis fuel.

Shielding evaluations of the NAC-MPC transfer and storage casks are performed with SCALE 4.3 for the PC (ORNL). In particular, the SCALE shielding analysis sequence SAS2H (Herman) is used to generate source terms for the design basis fuel, using the 27 group ENDF/B-IV (Jordan) library, 27GROUPNDF4. SAS1 (Knight) is used to perform one-dimensional radial and axial shielding analysis, and a modified version of SAS4 (Tang) is used to perform three-dimensional shielding analysis. The 27 group neutron, 18 group gamma, coupled cross section library (27N-18COUPLE) based on ENDF/B-IV is used in all shielding evaluations. Source terms include fuel neutron, fuel gamma, and activated hardware gamma. Dose rate evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms.

Dose rate profiles are shown for the storage and transfer casks in Section 5.4.3. Maximum dose rates for the storage cask under normal and accident conditions are shown in Table 5.1-1 for design basis fuel. These dose rates are based on three-dimensional Monte Carlo and one-dimensional discrete ordinates calculations. Monte Carlo error (1σ) is indicated in parenthesis. In normal conditions with design basis fuel, the storage cask maximum side dose rate is 47.3 (0.4%) mrem/hr at the bottom endfitting elevation and 54.0 (4.9%) mrem/hr on the top lid surface just above the heat transfer annulus. Since the storage cask is vertical during normal storage operation, the bottom is inaccessible. The dose rates at the inlet and outlet vents are 99.0 (5.4%) mrem/hr and 23.8 mrem/hr (5.0%) due to radiation streaming. Under accident conditions involving a projectile impact and a loss of 6 inches of concrete, the surface dose rate increases to 314 mrem/hr with design basis fuel. There are no design basis accidents that result in a tip-over of the NAC-MPC storage cask.

Maximum dose rates for the transfer cask with design basis fuel and with a wet and dry canister cavity are shown in Table 5.1-2. The maximum dose rates with design basis fuel and the canister cavity wet during shield lid welding operations are 210.2 (0.8%), 188.7 (1.1%) and 77.2 (0.7%) mrem/hr on the side, top, and bottom, respectively. The maximum dose rates with design basis fuel and the canister cavity dry during structural lid welding operations are 413.4 (1.5%), 358.9 (2.6%) and 398.0 (3.9%) mrem/hr on the side, top, and bottom, respectively. These values include the addition of 5 inches of carbon steel operational shielding installed on the shield lid during its closure and on the structural lid during its handling and closure. In normal operations during welding of the canister lids, the bottom of the transfer cask is generally inaccessible.

Table 5.1-1 Summary of NAC-MPC Storage Cask Maximum Dose Rates with Design Basis Fuel

Condition	Source	Cask Surface (mrem/hr)			1 Meter From Surface (mrem/hr)		
		Side	Top	Bottom[1]	Side	Top	Bottom[1]
Normal	neutron	0.3	42.5	32.0	0.3	11.4	2.3
	gamma	47.0	11.5	67.0	21.5	4.0	2.8
	Total	47.3 (0.4%)	54.0 (4.9%)	99.0 (5.4%)	21.8 (1.3%)	15.4 (2.5%)	6.1 (6.0%)
Postulated Accident[2]	neutron	4.0	na	na	1.5	na	na
	gamma	310.0	na	na	137.5	na	na
	Total	314.0	na	na	139.0	na	na

Table 5.1-2 Summary of NAC-MPC Transfer Cask Maximum Dose Rates with Design Basis Fuel

Condition	Source	Cask Surface (mrem/hr)			1 Meter From Surface (mrem/hr)		
		Side	Top	Bottom	Side	Top	Bottom
Normal Wet[3]	neutron	0.0	1.2	0.2	0.7	0.3	0.0
	gamma	210.2	187.5	77.0	39.8	388.8	19.0
	Total	210.2 (0.8%)	188.7 (1.1%)	77.2 (0.7%)	40.5 (0.7%)	389.1 (5.1%)	19.0 (2.1%)
Normal Dry[4]	neutron	77.5	116.6	276.2	44.8	13.5	33.4
	gamma	335.9	242.3	121.8	58.6	26.1	33.3
	Total	413.4 (1.5%)	358.9 (2.6%)	398.0 (3.9%)	103.4 (0.6%)	39.6 (4.5%)	66.7 (3.6 %)

[1] Bottom surface is inaccessible. Dose rates adjacent to bottom inlet indicated.
[2] Projectile impact, 6 inches loss of concrete.
[3] 5 inches of carbon steel temporary shielding, shield lid in position.
[4] 5 inches of carbon steel temporary shielding, shield lid and structural lid in position.

5.2 Source Specification

The NAC-MPC storage system can safely transfer and store Yankee Class fuel from four vendors in two fuel rod configurations. These are: Combustion Engineering (CE) 16 x 16 Type A and Type B, Exxon 16 x 16 Type A and Type B, United Nuclear (UN) 16 x 16 Type A and Type B, and Westinghouse (WE) 18 x 18 stainless steel clad Type A and Type B. The geometry of the Type A and Type B fuel assemblies allows a cruciform control rod to be inserted between assemblies during reactor operation. The cross-section of a typical Yankee Class fuel assembly is shown in Figure 5.2-1.

The NAC-MPC accommodates up to 36 CE Yankee Class fuel assemblies with a maximum of 36,000 MWD/MTU burnup and with a minimum of 8 years cool time. CE fuel with this burnup and cool time is defined as the design basis fuel. CE, UN and Westinghouse Yankee Class fuel assemblies with a maximum burnup of 32,000 MWD/MTU at minimum cool times of 7.0, 7.1 and 21.0 years, respectively, may also be loaded in the NAC-MPC. For shielding evaluation purposes the Exxon assembly type is identical to the CE fuel. The physical parameters of the Yankee Class fuel assemblies are presented in Table 5.2-1.

The SAS2H code sequence (Herman) is used to generate source terms. This code sequence is part of the SCALE 4.3 code package for the PC (ORNL). SAS2H includes an XSDRNPM (Greene) neutronics model of the fuel assembly and ORIGEN-S (Herman) fuel depletion/source terms calculations. The 27 energy group ENDF/B-IV neutron cross section library, 27GROUPNDF4, is used in the source terms calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware. The hardware activation is calculated by light element transmutation using the incore neutron flux spectrum produced by the SAS2H neutronics model. The hardware is assumed to be Type 304 stainless steel with 1.2 g/kg of ^{59}Co impurity. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios based on empirical data (Luskic).

An evaluation of the Yankee Class fuel types established the Combustion Engineering (CE) 16x16 Type A fuel assembly (Table 5.2-2) at 36,000 MWD/MTU burnup and 8 years cool time as the Yankee Class design basis fuel assembly for the shielding evaluations. A minimum fuel enrichment of 3.7 wt % ^{235}U is assumed to maximize the fuel neutron source. Reactor operating conditions assumed for the analysis are shown in Table 5.2-3.

The NAC-MPC design basis fuel source terms are shown Table 5.2-4. Source strengths are defined for five source regions: active fuel, upper end fitting, upper plenum, lower end fitting and lower plenum. The fuel assembly length, active fuel region length and fuel assembly hardware elevations are shown for the design basis fuel assembly in Figure 5.2-2.

5.2.1 Gamma Source

The design basis fuel and hardware gamma source spectra are shown in Table 5.2-5. The fuel gamma source contains contributions from both fission products and actinides. The spectra are presented in the 18 group structure consistent with the SCALE 4.3 27N-18COUPLE cross section library. The hardware gamma spectra contains contributions primarily from ^{60}Co due to the activation of Type 304 stainless steel with 1.2 g/kg ^{59}Co impurity and with some minor contributions from ^{59}Ni and ^{58}Fe. The magnitude of this spectra is based on the irradiation of 1 kg of stainless steel in the incore flux spectrum produced by the SAS2H neutronics calculation.

The activated fuel assembly hardware source terms are found by multiplying the source strength from 1 kilogram by the number of kilograms of steel or inconel material in the plenum, upper end fitting and lower end fitting regions, and by multiplying by a regional flux ratio. The regional flux ratio accounts for the effects of both magnitude and spectrum variation on hardware activation. These ratios are based on empirical data (Luskic). A flux ratio of 0.2 is applied to hardware regions directly adjacent to the active core region, i.e. upper and lower plenum. A flux ratio of 0.1 is applied to hardware regions once removed from the active core region, i.e. upper and lower end fitting region.

5.2.2 Neutron Source

The design basis fuel neutron spectrum is shown in Table 5.2-6. The neutron source results from actinide spontaneous fission and from (α,n) reactions with the oxygen in UO_2. The isotopes ^{242}Cm and ^{244}Cm characteristically produce all but a few percent of the spontaneous fission neutrons and (α,n) source in light water reactor fuel. The next largest contribution is from (α,n) reactions from ^{238}Pu. The neutron spectra from spontaneous fission is based on fission spectrum measurements of ^{235}U and ^{252}Cf. Neutron spectra from (α,n) reactions is based on Po-α-O source measurements. These spectra are included in the ORIGEN-S nuclear data libraries of the

SCALE 4.3 code package. The spectra are automatically collapsed from the energy group structure of the data library into that of the SCALE 27 group neutron cross section library (Herman).

5.2.3 Source Axial Profile

An enveloping burnup shape for three-dimensional shielding and thermal evaluations is created based on core depletion calculations for the Yankee Class fuel. The normalized burnup profile, averaged over the range from 30,000 to 36,000 MWD/MTU, and the corresponding enveloping shape, is shown in Figure 5.2-3. A burnup peak of 1.15 is found to envelope the design basis fuel axial burnup distribution. The corresponding gamma and neutron source distribution is shown in Figure 5.2-4. The gamma source distribution follows the burnup shape directly and has a 1.15 peaking factor. However, the neutron source distribution peaks to a higher level. Based on SAS2H calculations of the neutron source magnitude as a function of burnup, a 4.2 power dependence of the neutron source on burnup, i.e. neutron source ~ $B^{4.2}$ is exhibited. This yields a 1.80 peaking factor for neutrons.

Figure 5.2-1 Yankee Class Combustion Engineering Design Basis Fuel Assembly Array

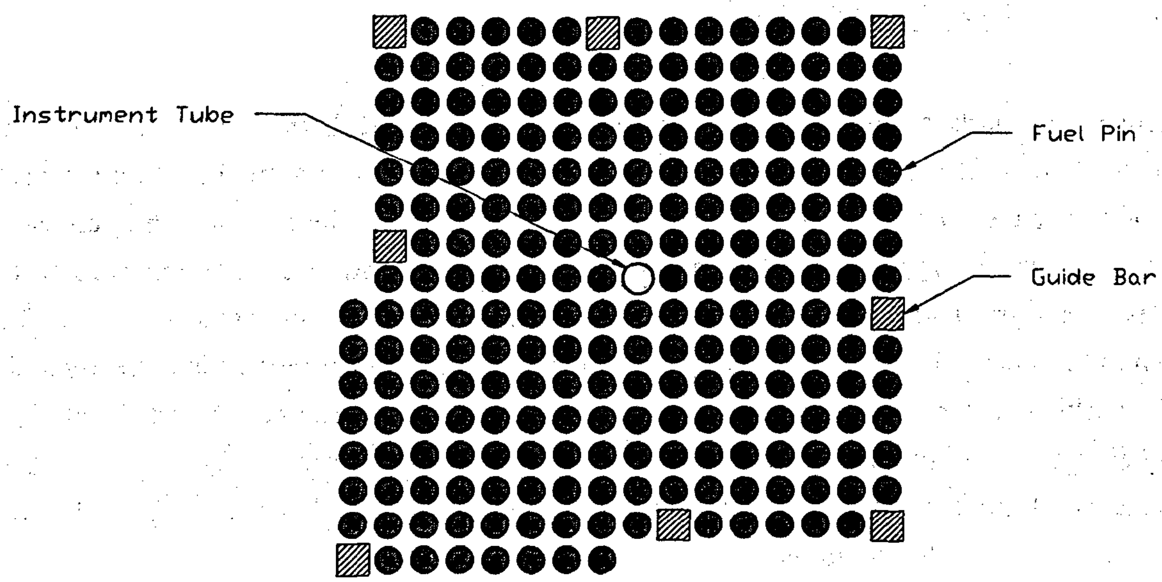
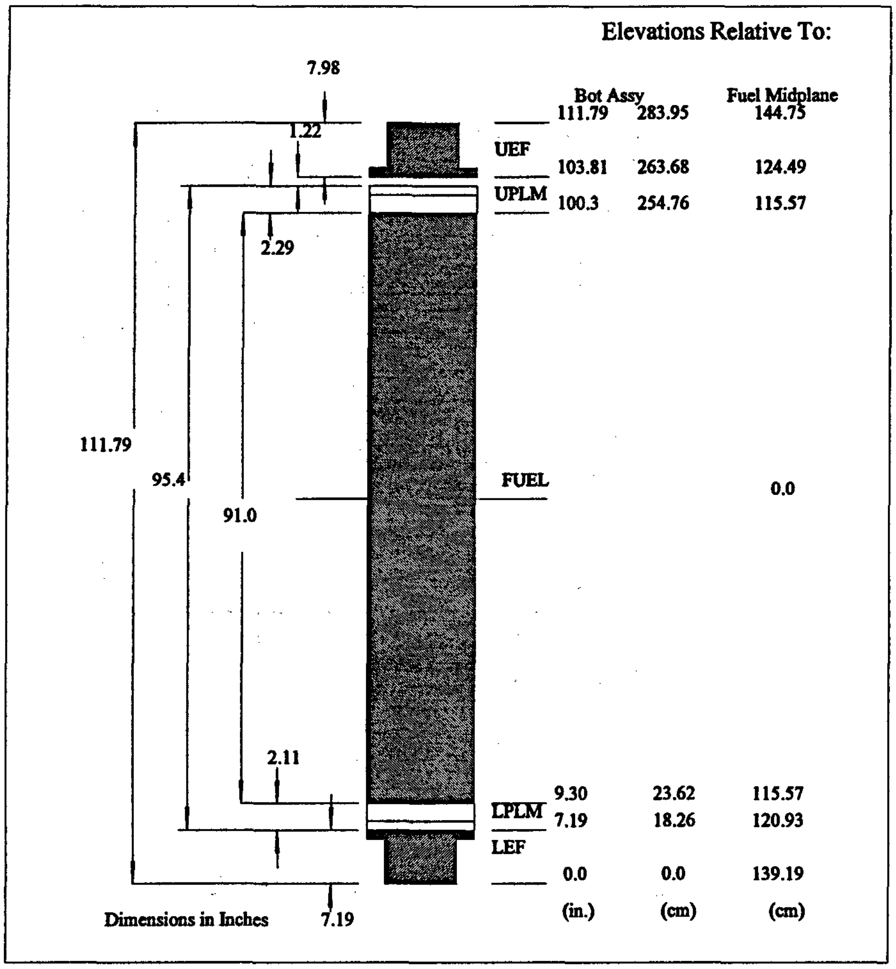
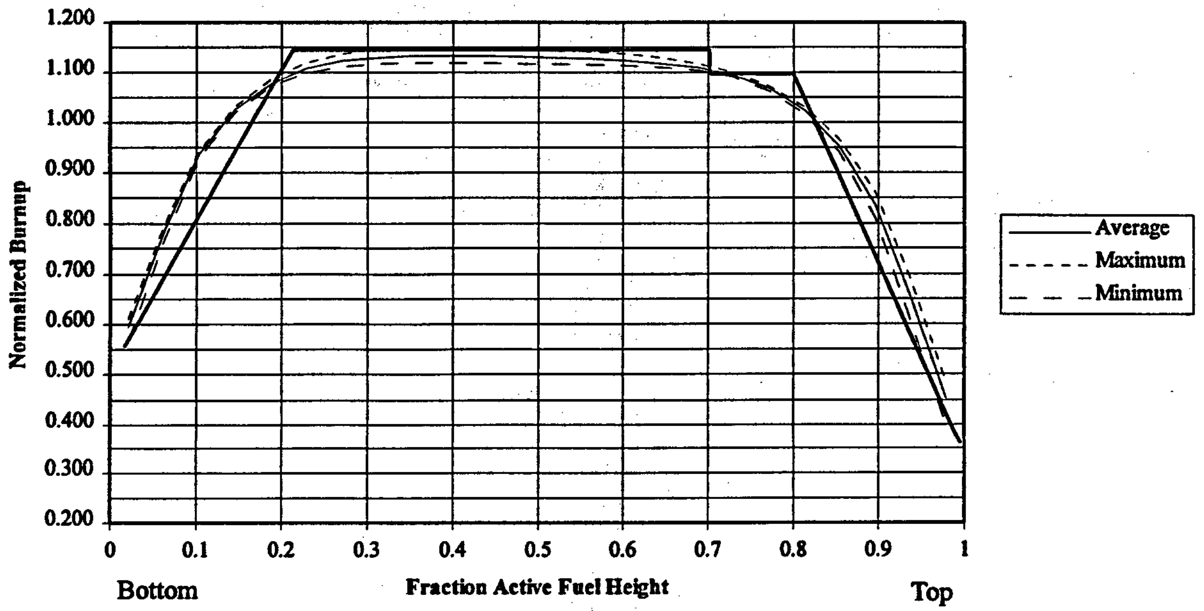


Figure 5.2-2 Yankee Class Combustion Engineering Design Basis Fuel Assembly Source Regions and Elevations



SOURCE	REGION
FUEL	Active fuel
UPLM	Upper Plenum
UEF	Upper End Fitting
LPLM	Lower Plenum
LEF	Lower End Fitting

Figure 5.2-3 NAC-MPC Design Basis Fuel Burnup Profile



Condition: 30,000 - 36,000 MWD/MTU

Figure 5.2-4 NAC-MPC Design Basis Neutron and Gamma Source Axial Profiles

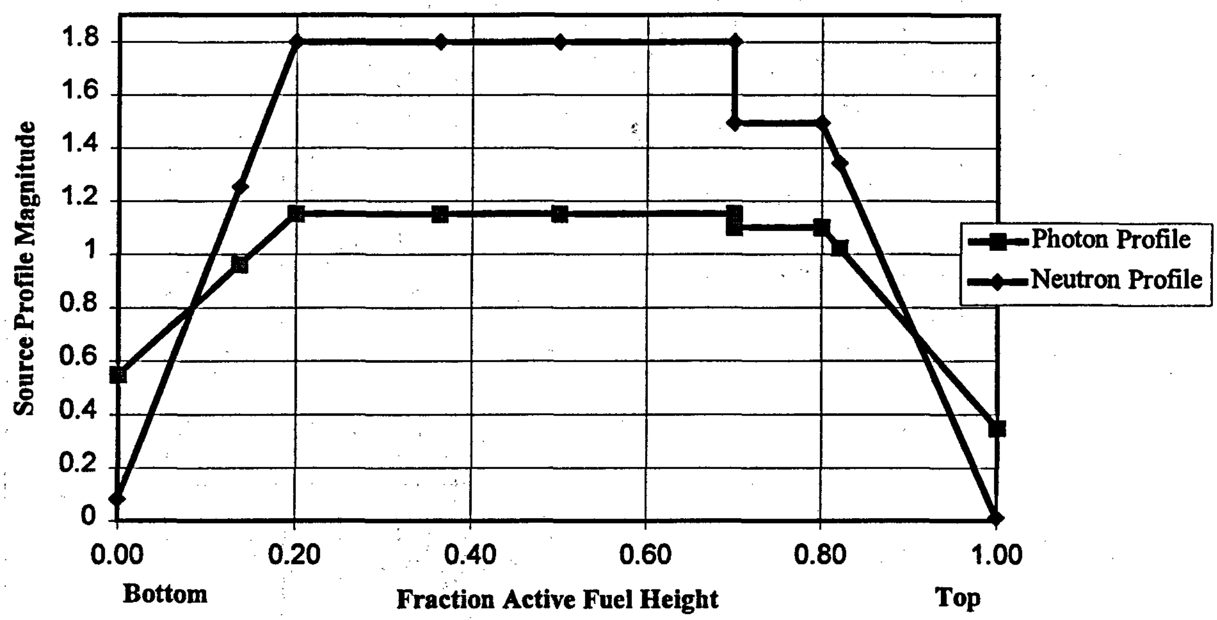


Table 5.2-1 Yankee Class Fuel Assembly Physical Parameters

Parameter	CE Type A	CE Type B	Exxon Type A	Exxon Type B	Exxon Type A	Exxon Type B	Westinghouse Type A	Westinghouse Type B	United Nuclear Type A	United Nuclear Type B
Assembly Configuration	-	-	-	-	-	-	-	-	-	-
Assembly Array	16x16	16x16	16x16	16x16	16x16	16x16	18x18	18x18	16x16	16x16
Max. Enrichment (wt % U^{235})	3.90	3.90	4.00	4.00	3.70	3.70	4.94	4.94	4.00	4.00
Max. MTU	0.2394	0.2384	0.2394	0.2384	0.2394	0.2384	0.2869	0.2860	0.2456	0.2446
Fuel Rod Configuration	-	-	-	-	-	-	-	-	-	-
Fuel Rod Pitch (cm)	1.1989	1.1989	1.1989	1.1989	1.1989	1.1989	1.0719	1.0719	1.1887	1.1887
Active Fuel Length (cm)	231.1400	231.1400	231.1400	231.1400	231.1400	231.1400	233.9975	233.9975	231.1400	231.1400
Rod OD (cm)	0.9271	0.9271	0.9271	0.9271	0.9271	0.9271	0.8636	0.8636	0.9271	0.9271
Clad ID (cm)	0.8052	0.8052	0.8052	0.8052	0.8052	0.8052	0.7569	0.7569	0.8052	0.8052
Pellet OD (cm)	0.7887	0.7887	0.7887	0.7887	0.7887	0.7887	0.7468	0.7468	0.7887	0.7887
Diametral Gap (cm)	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0102	0.0102	0.0165	0.0165
Rods per Assembly	231	230	231	230	231	230	305	304	237	236
Fuel Material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Clad Material	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	SS 348	SS 348	Zircaloy	Zircaloy
Displacement Rod Configuration	-	-	-	-	-	-	-	-	-	-
Displacement Rod Material	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Zircaloy - 4	Zircaloy - 4
Displacement Rod Diameter (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.9271	0.9271
Number Per Assembly	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	2
Guide Bar Configuration	-	-	-	-	-	-	-	-	-	-
Guide Bar Material	Zircaloy - 4	Zircaloy - 4	SS 304L	SS 304L	Zircaloy	Zircaloy	N/A	N/A	N/A	N/A
Guide Bar Width (cm)	1.0973	1.0973	1.0566	1.0566	1.0566	1.0566	N/A	N/A	N/A	N/A
Guide Bar Shape (cm)	Square	Square	Square	Square	Square	Square	N/A	N/A	N/A	N/A
Number Per Assembly	8	8	8	8	8	8	N/A	N/A	N/A	N/A
Instrument Tube Configuration	-	-	-	-	-	-	-	-	-	-
Instrument Tube ID (cm)	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9995	0.9995	0.9995	0.9995
Instrument Tube OD (cm)	1.1481	1.1481	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884
Number Per Assembly	1	1	1	1	1	1	1	1	1	1
Instrument Tube Material	Zircaloy - 4	Zircaloy - 4	SS 304	SS 304	Zircaloy	Zircaloy	SS 304	SS 304	SS 304	SS 304

Table 5.2-2 Yankee Class Design Basis Fuel Characteristics for Shielding Evaluations

Parameter	CE Type A
Assembly Configuration	
Assembly Length (inches)	111.79
Assembly Array	16x16
Maximum Enrichment (w/o U^{235})	3.70
UO_2 Fuel Mass (kg) @ 95 TD	271.6
Fuel Rod Configuration	
Fuel Rod Pitch (inches)	0.472
Overall Rod Length (inches)	95.4
Active Fuel Length (inches)	91
Rod OD (inches)	0.365
Clad ID (inches)	0.317
Pellet OD (inches)	0.3105
Diametral Gap (inches)	0.0065
Rods per Assembly	231
Clad Material	Zircaloy
Guide Bar Configuration	
Guide Bar Material	Zircaloy - 4
Guide Bar Width (inches)	0.432
Guide Bar Length (inches)	96.52
Guide Bar Shape	Square
Number Per Assembly	8
Instrument Tube Configuration	
Instrument Tube ID (inches)	0.3925
Instrument Tube OD (inches)	0.452
Instrument Tube Length (inches)	97.35
Number Per Assembly	1
Instrument Tube Material	Zircaloy - 4
Hardware Configuration	
Top Nozzle Material	SS 304
Bottom Nozzle Material	SS 304
Upper Plenum Spring Material	SS 302[1]
Top Nozzle Length (inches)	7.98
Bottom Nozzle Length (inches)	7.19
Upper Plenum Length (inches)	1.942
Top Nozzle Mass (kg)	5.5
Bottom Nozzle Mass (kg)	5.18
Upper Plenum Spring Mass (kg)	0.762
Upper Plenum Grid Mass (kg)	0.590
Lower Plenum Material	Steel and Inconel[1,2]
Lower Plenum Mass (kg)	1.73[2]
Incore Grid Spacers	Zircaloy -4

Notes: 1. For simplicity, all inconel and steel are modelled as stainless steel 304
2. Includes inconel grid and lower plenum spacer

Table 5.2-3 Yankee Class Design Basis Fuel Reactor Operating Conditions

Assembly Power, MW	8.486
$Temperature_{fuel}$, °K	797
$Temperature_{clad}$, °K	600
$Temperature_{mod}$ °K	551
$Density_{mod}$, g/cc	0.766
Boron, ppm	800
Fuel Burnup, MWD/MTU	36,000
Burnup Cycle, days	2 Cycles of 496.22 days
Down Time, days	60

Table 5.2-4 NAC-MPC Design Basis Fuel Source Terms

Decay Heat, kW	12.5
Active Fuel, photons/sec	6.423+16
Active Fuel, neutrons/sec	2.415+9
Upper End fitting, photons/sec	8.330+13
Upper Plenum, photons/sec	2.309+13
Lower End fitting, photons/sec	7.876+13
Lower Plenum, photons/sec	5.242+13

Condition: 36 Combustion Engineering Yankee Class Fuel Assemblies, 8 Years Cooled, and 36,000 MWD/MTU Burnup.

Table 5.2-5 NAC-MPC Design Basis Fuel Gamma Source Spectra

Group	Gamma Source Spectra[1] Fuel Photons/sec	Fuel Hardware Photons/sec-kg
1	3.7701E+04	0.0000E+00
2	1.7759E+05	0.0000E+00
3	9.0547E+05	0.0000E+00
4	2.2566E+06	0.0000E+00
5	6.2676E+08	1.0141E-15
6	5.1211E+09	3.3511E+04
7	1.0789E+11	2.1611E+07
8	9.9933E+10	9.5163E-03
9	4.8070E+12	9.1066E+11
10	3.4718E+13	3.2247E+12
11	6.3503E+13	4.3841E+09
12	8.2333E+14	3.8100E+06
13	1.1897E+14	1.0971E+07
14	1.7831E+13	1.7359E+08
15	2.8386E+13	1.3230E+08
16	1.0201E+14	2.6645E+09
17	1.3136E+14	1.1044E+10
18	4.5899E+14	5.5673E+10
Total	1.7842E+15	4.2095E+12

1. 36,000 MWD/MTU and 8 years cool time.

Table 5.2-6 NAC-MPC Design Basis Fuel Neutron Source Spectra

Group	Neutrons/sec[1]
1	1.2290E+06
2	1.4080E+07
3	1.5760E+07
4	8.7930E+06
5	1.1840E+07
6	1.2870E+07
7	2.5190E+06
8	0.0000E+00
9	0.0000E+00
10	0.0000E+00
11	0.0000E+00
12	0.0000E+00
13	0.0000E+00
14	0.0000E+00
15	0.0000E+00
16	0.0000E+00
17	0.0000E+00
18	0.0000E+00
19	0.0000E+00
20	0.0000E+00
21	0.0000E+00
22	0.0000E+00
23	0.0000E+00
24	0.0000E+00
25	0.0000E+00
26	0.0000E+00
27	0.0000E+00
TOTAL	6.7090E+07

1. 36,000 MWD/MTU and 8 year cool time.

5.3 Model Specification

Both one-dimensional SAS1 and three-dimensional SAS4 models are used in the shielding evaluations of the NAC-MPC storage system. The SAS1 radial and axial models are used to estimate the peak and average dose rates on the sides, top and bottom of the storage and transfer casks. The one-dimensional models represent the casks as either semi-infinite cylinders or slabs. The method of solution uses the XSDRNPM (Greene) discrete ordinates code and the XSDOSE (Buckholz) flux at a point estimation code. Bucklings are applied to the SAS1 models to account for transverse leakage. One-dimensional analysis also serves as a cross check to the more complex three-dimensional model results.

The SAS4 three-dimensional shielding models are used to estimate the dose profiles at the surfaces of the cask and at streaming paths such as the storage cask inlets and outlets, or the canister vent and drain ports. The method of solution is adjoint discrete ordinates and Monte Carlo (Tang) using the XSDRNPM and MORSE codes, respectively. Since SAS4 requires model symmetry at the fuel midplane, two models are created for each cask, a top and a bottom model. Radial biasing is performed to estimate dose rates on the sides of the cask, and axial biasing is performed to estimate dose rates on the top and bottom surfaces of the cask. Modifications are made to SAS4 to tally dose rates all along the radial, top and bottom surfaces of the cask as well as any cylindrical surface surrounding the cask. Thus, detailed dose rate profiles are determined that explicitly show peaks due to the fuel burnup profile, activated hardware gamma emission and streaming paths.

In both SAS1 and SAS4 models, the fuel and hardware source regions are homogenized within the volumes defined by the periphery of the basket tubes and by the elevations of the basket heat transfer zone, the active fuel, the plenum and the end fittings (Table 5.3-1). Within these volumes, the material masses of the fuel assembly and basket are homogenized (Table 5.3-2). The design basis fuel assembly and the NAC-MPC basket materials are obtained from Table 5.2-2 and from drawings 455-881, 455-891, 455-892, 455-893, 455-894 and 455-895 (Section 1.5). The SCALE 4.3 standard composition library (Landers) default compositions and isotopic distributions are used except for BORAL, NS-4-FR and concrete (Section 5.3.2). The resultant material zones and nuclide densities are summarized in Table 5.3-3. In all models, the cask and canister shield thicknesses are explicitly represented.

Both the SAS1 and SAS4 models utilize fuel midplane symmetry. Thus, all shielding models are developed with respect to the fuel midplane as the origin. This symmetry is required in the SAS4 models due to the automated biasing techniques employed and because the dose rate tallies from the symmetric halves are averaged together for computational efficiency.

5.3.1 Description of Radial and Axial Shielding Configurations

The NAC-MPC storage cask has an interior cavity with a radius of 39.5 inches (100.33 cm). Radial shielding consists of a 3.5-inch (8.89 cm) carbon steel shell surrounded by 21 inches (53.34 cm) of concrete. Gamma shielding is provided by both the carbon steel and concrete, and neutron shielding is provided primarily by the concrete. An additional 0.625 inch (1.59 cm) of stainless steel is provided by the canister shell for radial gamma shielding. The storage cask top shielding comprises 8 inches (20.32 cm) of stainless steel from the canister lids, 4.125 inches (10.48 cm) of carbon steel from the shield plug which encloses 1 inch (2.54 cm) of NS-4-FR and finally, 1.5 inches (3.81 cm) of carbon steel from the storage cask lid. The bottom of the storage cask rests on the concrete pad and is inaccessible. In the case of the storage cask inlets, some shielding is provided by the storage cask structural components. These are 2 inches (5.08 cm) of carbon steel from the pedestal plate, 1 inch (2.54 cm) of carbon steel from the cask base plate and 1 inch (2.54 cm) of stainless steel from the canister bottom plate.

The NAC-MPC transfer cask has an inside radius of 35.75 inches (90.81 cm) and has a multiwall radial shield design consisting of 0.75 inch (1.91 cm) of carbon steel, 3.5 inches (8.89 cm) of lead, 2 inches (5.08 cm) of a solid borated polymer (NS-4-FR), and 1.25 inches (3.18 cm) of carbon steel. Gamma shielding is provided by the steel and lead layers, and neutron shielding is provided primarily by the NS-4-FR. An additional 0.625 inch (1.59 cm) of stainless steel gamma shielding is provided by the canister shell. The transfer cask bottom shield design comprises carbon steel doors 9.50 inches (24.13 cm) thick. The top shielding of the transfer cask is provided by the 5-inch (12.70 cm) stainless steel shield lid and the 3-inch (7.62 cm) stainless steel structural lid. In addition, a 5-inch (12.70 cm) carbon steel temporary shield is used during welding, draining, drying and transfer operations. This temporary shielding is removed prior to storage.

5.3.1.1 One-Dimensional Radial and Axial Shielding Models

Since the fuel assembly and basket features are not explicitly modeled in one-dimensional analysis, the fuel/basket interior is modeled as a set of homogenized material volumes based on equivalent cylindrical volumes. These volumes are defined by the areas created by: the central basket hole; the periphery of the basket tubes and the edge of the steel support disks; and by the elevations created by the basket heat transfer zone, the active fuel, the fuel assembly plenums and the fuel assembly end fittings.

The NAC-MPC fuel basket is divided into three radial regions: a central hole (void), fuel/basket region, and a basket/disk region. These regions have equivalent radii of 4.66, 30.63 and 34.51 inches (11.83, 77.80, and 87.66 cm), respectively. Axially, the basket is divided into seven regions: the top, middle and bottom fuel/basket regions; the upper and lower plenum/basket regions; and the upper and lower end fittings/basket regions. For the top models, the top fuel, top plenum and top end fitting regions have elevations with respect to the fuel midplane of 45.50, 49.01, and 56.99 inches (115.57, 124.49 and 144.75 cm), respectively. For the bottom models, the bottom fuel, bottom plenum and bottom end fitting regions have elevations with respect to the fuel midplane of 45.50, 47.61, and 54.80 inches (115.57, 120.93 and 139.19 cm), respectively

In each of these regions, the relevant fuel assembly material and any basket material present are homogenized. Basket materials include the steel support disks, aluminum heat transfer disks, top and bottom weldments, fuel tubes, BORAL sheets, and BORAL cover sheets. Fuel assembly materials include: UO_2, cladding, grids, plenum springs and spacers, and end-fittings. The resultant material and nuclide densities are described in Section 5.3.2.

The one-dimensional radial models of the storage cask and the transfer cask are based on the cylindrical representation of the fuel/basket source regions (previously described) surrounded by the explicit canister and cask radial shield dimensions. An axial buckling equal to the active fuel height of 91 inches (231.14 cm) is assumed for all radial models.

The one-dimensional top and bottom axial models of the storage and transfer casks are based on a slab representation of the fuel/basket axial regions covered by the explicitly modeled canister and storage cask axial shield regions. As previously stated, the one-dimensional axial model elevations are specified from the active fuel centerline, which SAS1 automatically establishes as

the reflecting boundary. Two models are utilized for each cask: one from the active fuel centerline to the top of the cask; and one from the active fuel centerline to the base plate of the cask. Two transverse bucklings equal to the fuel/basket zone equivalent diameter of 61.26 inches (155.6 cm) are assumed for both axial models.

5.3.1.2 Three-Dimensional Top and Bottom Shielding Models

SAS4 three-dimensional shielding analysis allows detailed modeling of the fuel assemblies, basket and cask shield configuration including streaming paths. Some fuel assembly and basket detail is homogenized to simplify model input and improve computational efficiency. Thus, the three-dimensional models maintain the equivalent fuel/basket source volumes developed for the one-dimensional models, but explicitly model the radial and axial extent of the source regions and the cask body details. As in the SAS1 models, the fuel and hardware source regions are homogenized within the volumes defined by the periphery of the basket tubes and by the elevations of the basket heat transfer zone, the active fuel, the plenum and the end fittings. Cask body details include the true axial extent of the cask shields as described by the drawings in Section 1.5 as well as radiation streaming paths such as the storage cask inlets and outlets and the canister vent and drain ports.

SAS4 requires cask model symmetry at the fuel midplane due to the nature of the automated biasing techniques employed, and because dose rate tallies from the symmetric halves of the model are averaged together for computational efficiency. Thus, two models are created for each cask, a top and a bottom model. As in the SAS1 models, all three-dimensional shielding models are developed with respect to the fuel midplane as the origin.

The geometry of SAS4 is based on MARS (West) combinatorial geometry embedded in the MORSE code (Emmett). In this geometry, bodies such as cylinders and rectangular parallelepipeds are used to describe the extent of zones of material. Zones are volumes of constant material (cross sections) and are defined by logical operations on geometric bodies.

SAS4 employs an automated biasing technique for the MORSE Monte Carlo calculations based on either a radial or an axial XSDRNPM adjoint calculation. In the case of radial biasing, the adjoint calculation is performed for the radial shields and corresponding fuel/basket regions. In the case of axial biasing, the adjoint calculation is performed for the top or bottom shields and corresponding axial fuel/basket regions. Radial biasing is employed to improve the Monte Carlo

computational efficiency and dose rate statistics on the sides of the cask. Axial biasing is employed to improve Monte Carlo computational efficiency and dose rate statistics on the top or bottom surfaces of the cask. The dose rate profiles resulting from both radial and axial biasing calculations yield a complete dose profile of the entire cask with design basis fuel.

MORSE Monte Carlo calculations are performed for each type of source in each source region. In the case of the NAC-MPC basket and design basis fuel assembly configuration, this leads to eight source terms: middle fuel neutron, gamma and n-gamma; top or bottom fuel neutron, gamma and n-gamma; activated plenum hardware gamma and activated end fitting gamma. Twenty to thirty million histories (gamma and neutron combined) are tracked to yield a dose rate surface profile for each surface.

5.3.1.2.1 NAC-MPC Storage Cask Three-Dimensional Models

The three-dimensional top model of the NAC-MPC storage cask containing 36 design basis Yankee Class fuel assemblies is based on the homogenized cylindrical representation of the basket, and the following top features of the storage cask:

- Heat transfer annulus
- Carbon steel shell with four cutouts for outlet vents
- Concrete shield with four cutouts for outlet vents
- Four outlet vents including carbon steel lining
- Carbon steel shield plug
- Shield plug neutron shield
- Carbon steel top lid

Details in the elevations and radii used in creating the three-dimensional top model are taken directly from the drawings in Section 1.5. Elevations associated with the storage cask three-dimensional features are established with respect to the active fuel midplane of the Yankee Class fuel assembly (Figure 5.2-2) for the combinatorial model. The three-dimensional storage cask top model is shown in Figure 5.3-1. The MARS geometry required 71 bodies (23 right circular cylinders and 48 rectangular parallelepipeds) to define 39 model zones with combinatorial logic.

The three-dimensional bottom model of the NAC-MPC storage cask [redacted] is based on the homogenized cylindrical representation of the fuel/basket and the following bottom features of the storage cask:

- Heat transfer annulus
- Carbon steel shell with four cutouts for inlet vents
- Concrete shield with four cutouts for inlet vents
- Four inlet vents with carbon steel linings
- Carbon steel bottom base plate
- Carbon steel support stand with four cutouts for air flow
- Carbon steel shield ring
- Carbon steel storage cask bottom
- Concrete pad below base plate

The three-dimensional storage cask bottom model is shown in Figure 5.3-2. The MARS geometry requires 55 bodies (30 right circular cylinders and 25 rectangular parallelepipeds) to define 50 model zones with combinatorial logic.

5.3.1.2.2 NAC-MPC Transfer Cask Three-Dimensional Models

Several different three-dimensional models of the top portion of the transfer cask are used in the shielding evaluations. These include wet and dry cavity conditions as well as the corresponding shield lid and structural lid placement. The top configuration of the transfer cask is evaluated in detail for the welding, draining and drying operations. As with the storage cask models, top models of the NAC-MPC transfer cask containing 36 design basis Yankee fuel assemblies are based on a homogenized representation of the basket, but the rectangular periphery of the basket source region is modeled in order to more accurately estimate vent and drain port dose rates.

The basket disks outside the fuel/basket region are explicitly modeled to more accurately account for basket streaming. The following features of the transfer cask are considered:

- Vent and drain port openings in the shield lid
- Upper weldment shield ring
- Edge tapering and port cutouts in the temporary shielding
- Two lifting trunnions cut through the radial shield to the inner shell
- Lead and neutron shielding overlap at the top as shown on the transfer cask drawings

Details of the elevations and radii used in creating the three-dimensional top model are taken directly from the drawings in Section 1.5. As with the other three-dimensional models, elevations associated with the transfer cask three-dimensional features are established with respect to the active fuel midplane of the Yankee Class fuel assembly for the combinatorial geometry model. The three-dimensional transfer cask top model including shield and structural lid installation is shown in Figure 5.3-3. The MARS geometry required 108 bodies (94 right circular cylinders and 14 rectangular parallelepipeds) to define 68 model zones.

The three-dimensional bottom model of the NAC-MPC transfer cask is based on the same homogenized representation of the fuel/basket as the top model. As with the top model of the transfer cask, the evaluations include both wet and dry canister cavity. The following bottom features of the transfer cask are considered:

- Termination of the radial shields at the bottom doors
- 9.5 inches of carbon steel shielding representing the bottom doors

The transfer cask bottom model is shown in Figure 5.3-4. The MARS geometry required 69 bodies (56 right circular cylinders and 13 rectangular parallelepipeds) to define 59 model zones with combinatorial logic.

5.3.2 Shield Regional Densities

The SCALE 4.3 standard composition library (Landers) default compositions and isotopic distributions are used unless otherwise indicated. The composition densities before homogenization are:

Material	Density (g/cc)	
UO_2 at 95% TD	- 10.412	
Zircaloy	- 6.56	
H_2O	- 0.9982	
Stainless Steel 304	- 7.92	
Lead	- 11.344	
Aluminum	- 2.702	
BORAL (core)	- 2.623	(non-standard)
NS-4-FR	- 1.629	(non-standard)
Concrete	- 2.243	(based on 140 lb/ft^3 design spec. minimum)
Carbon Steel	- 7.821	

Reinforcing steel is conservatively ignored in the concrete density. Basket and fuel assembly regional volumes are shown in Table 5.3-1 and the regional masses are shown in Table 5.3-2. The resultant regional homogenized densities for the design basis CE fuel assembly and shield densities are provided in Table 5.3-3.

Figure 5.3-1 NAC-MPC Storage Cask Three-Dimensional Top Model

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 5.3-2 NAC-MPC Storage Cask Three-Dimensional Bottom Model

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 5.3-3 NAC-MPC Transfer Cask Three-Dimensional Top Model Including Shield and Structural Lid

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 5.3-4 NAC-MPC Transfer Cask Three-Dimensional Bottom Model

FIGURE WITHHELD UNDER 10 CFR 2.390

Table 5.3-1 Fuel/Basket Regional Volumes (cm^3)

Axial Zone[1]	Fuel/Basket Region	Basket/Disk Region
LEF	3.3927E+05	9.3029E+04
LPLM	9.9562E+04	2.7301E+04
$FUEL_{bot}$	5.8652E+05	1.6083E+05
$FUEL_{mid}$	2.9368E+06	8.0530E+05
$FUEL_{top}$	7.7054E+05	2.1129E+05
UPLM	1.6562E+05	4.5415E+04
UEF	3.7654E+05	1.0325E+05

1. See Figure 5.2-2 for zone locations.

Table 5.3-2 Fuel/Basket Regional Masses (kg)

	Fuel/Basket Region						Basket/Disk Region	
	Fuel Assembly Contribution			Basket Contribution				
Axial Zone[1]	UO_2	Zirc	SS304	SS304	Al	B_4C	SS304	Al
LEF	-	0.00	186.48	141.37	-	-	51.24	-
LPLM	-	61.01	62.28	42.55	-	-	51.24	-
$FUEL_{bot}$	1335.47	359.43	0.00	173.01	36.46	5.90	102.47	-
$FUEL_{mid}$	6687.02	1884.71	0.00	1004.41	320.40	29.55	768.52	235.15
$FUEL_{top}$	1754.48	472.20	0.00	237.61	47.89	7.75	153.70	-
UPLM	-	94.69	27.43	52.41	-	-	51.24	-
UEF	-	0.0000	198.00	56.15	-	-	51.24	-

1. See Figure 5.2-2 for zone locations.

Table 5.3-3 Regional Homogenized Densities and Shield Densities

Zone/Material	Density (g/cc)	Nuclides	Density (atom/b-cm)
Middle Fuel Zone			
UO_2	2.2769	^{234}U	2.793E-07
		^{235}U	3.656E-05
		^{238}U	5.041E-03
		O	1.016E-02
Zircaloy	0.6417	Zr	4.236E-03
SS304	0.3420	Cr	7.526E-04
		Mn	7.498E-05
		Fe	2.563E-03
		Ni	3.334E-04
Aluminum	0.1091	Al	2.435E-03
B_4C	0.0101	^{10}B	8.764E-05
		^{11}B	3.528E-04
		C	1.101E-04
H_2O Wet Transfer Cask	0.6000	H	4.010E-02
		O	3.021E-02
Middle Basket/Disk Zone			
SS304	0.9543	Cr	2.100E-03
		Mn	2.092E-04
		Fe	7.152E-03
		Ni	9.303E-04
Aluminum	0.2920	Al	6.517E-03
H_2O Wet Transfer Cask	0.7700	H	5.151E-02
		O	2.575E-02
Steel Shielding			
SS304	7.9200	Cr	1.743E-02
		Mn	1.736E-03
		Fe	5.9336-02
		Ni	7.721E-03
Carbon Steel Shielding			
Carbon Steel	7.8212	Fe	8.350E-02
		C	3.925E-03
Concrete Shielding			
Concrete	2.2430	Fe	3.386E-04
		H	1.340E-02
		Al	1.702E-03
		Ca	1.483E-03
		O	4.494E-02
		Na	1.704E-03
		N	1.621E-02

Table 5.3-3 Regional Homogenized Densities and Shield Densities (Continued)

Material/Zone	Density (g/cc)	Nuclides	Density (atom/b-cm)
Top Fuel/Basket Zone			
UO_2	2.2769	^{234}U	2.793E-07
		^{235}U	3.656E-05
		^{238}U	5.041E-03
		O	1.016E-02
Zircaloy	0.6128	Zr	4.046E-03
SS304	0.3084	Cr	6.787E-04
		Mn	6.761E-05
		Fe	2.311E-03
		Ni	3.006E-04
Aluminum	0.0622	Al	1.388E-03
B_4C	0.0101	^{10}B	8.764E-05
		^{11}B	3.528E-04
		C	1.101E-04
H_2O Transfer Cask Wet	0.6303	H	4.214E-02
		O	3.123E-02
Top Plenum Zone			
Zircaloy	0.5718	Zr	3.775E-03
SS304	0.4821	Cr	1.485E-03
		Mn	1.057E-04
		Fe	3.613E-03
		Ni	4.700E-04
H_2O Transfer Cask Wet	0.7019	H	4.695E-02
		O	2.348E-02
Top End Fitting Zone			
SS304	0.6749	Cr	1.743E-02
		Mn	1.480E-04
		Fe	5.058E-03
		Ni	6.579E-04
H_2O Transfer Cask Wet	0.9132	H	6.108E-02
		O	3.054E-02
Neutron Shield			
NS-4-FR	1.6291	^{10}B	8.553E-05
		^{11}B	3.422E-04
		Al	7.763E-03
		H	5.854E-02
		O	2.609E-02
		N	1.394E-03
		C	2.264E-02

Table 5.3-3 Regional Homogenized Densities and Shield Densities (Continued)

Material/Zone	Density (g/cc)	Nuclides	Density (atom/b-cm)
Bottom Fuel/Basket Zone			
UO_2	2.2769	^{234}U	2.793E-07
		^{235}U	3.656E-05
		^{238}U	5.041E-03
		O	1.016E-02
Zircaloy	0.6128	Zr	4.046E-03
SS304	0.2350	Cr	6.492E-04
		Mn	6.467E-05
		Fe	2.211E-03
		Ni	2.876E-04
Aluminum	0.0622	Al	1.388E-03
B_4C	0.0101	^{10}B	8.764E-05
		^{11}B	3.528E-04
		C	1.101E-04
H_2O Transfer Cask Wet	0.6322	H	4.228E-02
		O	3.130E-02
Bottom Plenum Zone			
Zircaloy	0.6128	Zr	4.046E-03
SS304	1.0529	Cr	2.317E-03
		Mn	2.308E-03
		Fe	7.891E-03
		Ni	1.026E-03
H_2O Transfer Cask Wet	0.5447	H	3.644E-02
		O	1.822E-02
Bottom End fitting Zone			
SS304	0.9664	Cr	2.127E-03
		Mn	2.119E-04
		Fe	7.243E-03
		Ni	9.421E-04
H_2O Transfer Cask Wet	0.8764	H	5.862E-02
		O	2.931E-02

5.4 Shielding Evaluation

This section evaluates the shielding design of NAC-MPC transfer and storage casks. The calculational methods are described. Shielding calculations are performed with design basis Yankee Class fuel source terms at 36,000 MWD/MTU and 8 years cooling time. Dose rate profiles are reported as a function of distance from the sides, top, and bottom of the NAC-MPC storage and transfer casks. Storage cask shielded source terms (neutron and gamma fluxes at the cask surface) are provided for ISFSI controlled area boundary dose evaluations.

5.4.1 Calculational Methods

Shielding evaluations of the transfer and storage casks are performed with SCALE 4.3 for the PC. In particular, SCALE shielding analysis sequence SAS2H is used to generate source terms for the design basis fuel. SAS1 is used to perform one-dimensional radial and axial shielding analysis, and a modified version of SAS4 is used to perform three-dimensional shielding analysis. The coupled 27 group neutron, 18 group gamma ENDF/B-IV (27N-18COUPLE) cross section library is used in all shielding evaluations. Source terms include fuel neutron, fuel gamma, and gamma contributions from activated hardware. Dose rate evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms. The SCALE shielding analysis sequences and cross section libraries recently have been benchmarked to measurements of light water reactor fuel source terms, shielding material dose rate attenuation, and spent fuel storage and transport cask dose rates (Broadhead).

The SAS2H code sequence is used to generate source terms for the Yankee Class design basis fuel. SAS2H includes an XSDRNPM neutronics model of the fuel assembly and ORIGEN-S fuel depletion/source terms calculations. The 27 energy group ENDF/B-IV neutron cross section library, 27GROUPNDF4, is used in the source terms calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware. The hardware activation is calculated by ORIGEN-S using the incore neutron flux spectrum produced by the SAS2H neutronics model. The hardware is assumed to be Type 304 stainless steel with 1.2 g/kg ^{59}Co impurity. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios based on empirical data (Luskic).

Both the one-dimensional SAS1 and the three-dimensional SAS4 shielding models are used in the evaluations of the NAC-MPC storage system. The SAS1 radial and axial models are used to estimate the peak and average dose rates on the sides, top, and bottom of the storage and transfer casks. The models represent the cask as either semi-infinite cylinders or slabs. The method of solution is XSDRNPM discrete ordinates. Bucklings are applied to the one-dimensional models to account for transverse leakage. One-dimensional analysis also serves as a cross check of the three-dimensional model results and is employed to establish the minimum cool time for the loading of 32,000 MWD/MTU burnup assemblies.

The SAS4 shielding models are used to estimate the dose profiles along the surfaces of the transfer and storage casks and to estimate doses in and around streaming paths such as the storage cask inlets and outlets, and the canister vent and drain ports. The SAS4 models represent the cask body and any streaming paths with combinatorial logic. The method of solution is adjoint discrete ordinates and Monte Carlo using the XSDRNPM and MORSE codes, respectively. Since SAS4 requires model symmetry at the fuel midplane, two models are created for each cask, a top and a bottom model. Radial biasing is performed to estimate dose rate on the sides of the cask, and axial biasing is performed to estimate dose rates on the top and bottom surfaces of the cask. Modifications are made to SAS4 to determine dose rates all along the radial, top and bottom surfaces of the cask as well as any cylindrical surface surrounding the cask. Thus, detailed dose profiles are determined that explicitly show peaks due to the fuel burnup profile, activated hardware gamma emission and any streaming paths.

In both the SAS1 and SAS4 models, the fuel and hardware source regions are homogenized within the volumes described by the periphery of the basket tubes, and defined by the fuel assembly active fuel, plenum, and end fitting elevations. Within these volumes, the material masses of the fuel assembly and basket are preserved.

5.4.2 Flux-to-Dose Rate Conversion Factors

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are used in all NAC-MPC shielding evaluations. These factors are default for SCALE 4.3. Tables 5.4-1 and 5.4-2 show the group flux-to-dose rate factors associated with the coupled 27 group neutron and 18 group gamma cross section library used in the shielding evaluations.

5.4.3 Dose Rates

This section provides detailed dose rate profiles for the NAC-MPC storage and transfer cask based on the source terms presented in Section 5.2. Design basis fuel source terms include contributions from fuel neutron, fuel gamma and activated hardware gamma. The fuel assembly activated hardware gamma source terms include: steel and inconel in the upper and lower fuel assembly end fittings, and upper and lower fuel rod plenum hardware. Peaking factors of 1.15 and 1.80 are applied to the one-dimensional radial fuel gamma and neutron dose rates, respectively. The three-dimensional model dose rates include the axial profiles for neutron and gamma source distributions shown in Figure 5.2-4.

5.4.3.1 One-Dimensional Storage Cask Dose Rates

One-dimensional radial dose rates with design basis fuel were found to be in good agreement with the three-dimensional models at the radial midplane. However, the peaks in the radial dose rates due to activated endfittings cannot be captured by one-dimensional analysis. One-dimensional dose rates at the top of the storage cask are significantly lower than those calculated using three-dimensional analysis. This is primarily due to the neutron component of the dose rates and the transverse bucklings applied in the one-dimensional axial model as well as streaming effects caused by the heat transfer annulus and top vents. Except for the neutron component of the top axial model and obvious limitations in geometry, one-dimensional analysis is found to supports the results of the more complicated three-dimensional models. Except for the storage cask loss of concrete accident radial dose rates shown in Table 5.4-3, the dose rate results from three-dimensional analysis are reported.

One-dimensional radial surface dose rates are also used to determine the minimum cool times, based on the design basis fuel values, for CE, UN, and WE fuel types with a maximum burnup of 32,000 MWD/MTU. The calculated minimum cool times for CE, UN, and WE fuel at 32,000 MWD/MTU, are 7.0, 7.1 and 21.0 years, respectively.

5.4.3.2 Three-Dimensional Storage Cask Dose Rates

The NAC-MPC storage cask three-dimensional model dose rates are presented in Figures 5.4-1 through 5.4-7. Approximately 50 million particle histories (neutron and gamma) are tracked to yield the dose rate profiles presented in theses figures. The average standard deviation for the

side total dose rate shown in Figures 5.4-1 and 5.4-2 is less than ± 2%, and the average standard deviation for the top total dose rate shown in Figures 5.4-6 and 5.4-7 is less than ± 5%. The average standard deviation for the inlet and outlet vent total dose rates shown in Figures 5.4-3, 5.4-4 and 5.4-5 is less than ± 5%, and the standard deviation for the peak dose rates at the vent opening are less than ± 10%.

The vertical profile along the radial surface of the storage cask, as well as at distances of 30.48 cm (1 foot), 1 meter, and 2 meters from it, are plotted in Figure 5.4-1 as a function of elevation. Each datum represents the circumferentially average dose rate at the corresponding distance and elevations. The negative elevations are the dose rates from the bottom model computations, while the positive elevations are the dose rates from the top model computations. The discontinuity observed at zero elevation (midplane of the fuel) is a modeling artifact due to the decoupling of the upper and lower portions of the cask. In the vertical dose profile, peaking is observed at the upper and lower end fitting locations as well as at the locations of the lower intake and upper outlet vents. The average and maximum side surface dose rate for the storage cask are 37 (0.3%) and 47.3 (0.4%) mrem/hr, respectively.

The radial surface dose profile is further described by source component in Figure 5.4-2. The source components in both models contribute to the radial doses largely as one would expect, i.e. at the elevations where they are located. Since these doses are circumferential averages, the detailed circumferential dose rate profile at the top vent elevation and the bottom vent inlet are shown radially in Figure 5.4-3 and Figure 5.4-4, respectively. The dose rates shown in Figures 5.4-3 and 5.4-4 were computed using a variance-weighted average of the dose rates in the four symmetric quadrants at the vent elevation. A maximum dose rate of 24 mrem/hr (5%) is calculated at the surface of the outlet vent and a maximum dose rate of 99 (5.4%) mrem/hr was calculated at the entrance of the inlet vent.

In Figure 5.4-5, the circumferential dose rate profile at the support ring cutout elevation is shown on the storage surface and at distances of 30.48 cm (1 foot), 1 meter, and 2 meters from the surface. The peak in the circumferential dose rate is not at the location of the cutout, but above the inlet vent location. Note that these peak dose rates are higher at 1 foot from the storage cask than they are on the surface of the storage cask. This is due to photon scattering off the storage cask concrete base through the inlet vent opening and up to the cutout elevation.

The dose rate profiles on the top surface of the storage cask and at distances of 1 foot and 1 meter above the lid are shown in Figure 5.4-6. The dose rates are plotted radially out from the centerline of the storage cask. Two dose rate peaks are observed on the storage cask top surface: one in the vicinity of 90 - 100 cm which corresponds to the location of the heat transfer annular gap and another at approximately 130 cm. The dose rate profile on the top surface of the storage cask is shown by source component in Figure 5.4-7 and indicates that the peak dose rate above the annular gap is caused by neutrons streaming up the gap. The component profile also indicates that the second peak is created by gammas from the end fitting, top fuel, and top plenum source regions. This peak occurs at approximately the same radial location as the vertical leg in the upper outlet vent. Thus, it is a result of a decrease in effective shield thickness caused by the void in the concrete due to the outlet vents. The average dose rate over the top of the storage cask is computed to be 25.1 mrem/hr (1.2%), while the peak dose on top of the storage cask is 54 mrem/hr (4.9%).

5.4.3.3 One-Dimensional Transfer Cask Dose Rates

One-dimensional radial dose rates with design basis fuel are in good agreement with the three-dimensional models at the radial midplane. As with the storage cask one-dimensional radial model, the peaks in the radial dose rates due to activated endfittings cannot be captured by one-dimensional analysis. One-dimensional top dose rates at the top and bottom of the transfer cask were significantly lower than three-dimensional analysis. This was primarily due to the neutron component of the dose rates and the transverse bucklings applied in the one-dimensional axial model as well as streaming effects around the temporary shielding. Except for the neutron component of the top axial model, one-dimensional analysis supports the results of the more complicated three-dimensional models.

5.4.3.4 Three-Dimensional Transfer Cask Dose Rates

The transfer cask three-dimensional model dose rates are presented in Figures 5.4-8 through 5.4-15. Approximately 100 million particle histories (neutron and gamma) are tracked to yield the dose rate profiles presented in theses figures. The average standard deviation for the side total dose rates shown in Figures 5.4-8 through 5.4-11 is less than ± 2%, and the average standard deviation for the top total dose rates shown in Figures 5.4-12 through 5.4-15 is less than ± 2%.

The transfer cask side dose rate profiles with a wet cavity are shown in Figure 5.4-8 as a function of distance and in Figure 5.4-9 as a function of source component. In this condition, the majority of the dose rate is from fuel gamma and activated end fitting gamma. It is assumed in the model that the water level in the canister is lowered for welding operations, thus, the top end fitting is uncovered and causes a large peak in dose rate at the top of the transfer cask due to the gamma source from the activated top end fitting. In this condition, the peak and average dose rates on the side of the transfer cask are 210.2 (0.8%) and 79.5 (0.3%) mrem/hr, respectively, and the peak and average dose rates at 1 meter are 40.5 (0.7%) and 26.4 (0.2 %) mrem/hr, respectively.

The transfer cask side dose rate profiles with a dry cavity are shown in Figure 5.4-10 as a function of distance and in Figure 5.4-11 as a function of source component. In this condition, the majority of the dose rate is from fuel neutron and gamma source, but significant peaks are shown from the activated end fittings. The peak and average dose rates on the side of the transfer cask are 413.4 (1.5%) and 226.3 (0.2%) mrem/hr, respectively, and the peak and average dose rates at 1 meter are 103.4 (0.6%) and 72.2 (0.2 %) mrem/hr, respectively.

The transfer cask peak and average dose rate on the temporary shield surface are 188.7 (1.1%) and 172.0 (0.3%) mrem/hr, respectively. In this condition, the majority of the dose rate is from the activated top end fitting. The peak and average dose rate at 1 meter are 389.1 (5.1%) and 263.7 (1.5%) mrem/hr, respectively.

In the final configuration, the canister cavity is dry, the shield lid and structural lid are in place, and 5" of temporary steel shielding is installed. In this condition, the transfer cask top dose rate are shown in Figure 5.4-12 as a function of distance and in Figure 5.4-13 as a function of component. The majority of the dose rate is from the fuel neutron. The dose rate peaks at the lid edge due to gamma streaming around the tapered edge of the temporary shield. The peak and average dose rates on the top of the transfer cask are 358.9 (2.6%) and 224.6 (0.9%) mrem/hr, respectively, and the peak and average dose rates at 1 meter are 39.6 (4.5%) and 34.2 (1.3 %) mrem/hr, respectively

The transfer cask bottom dose rate profiles with the cavity wet and dry are shown in Figures 5.4-14 and 5.4-15, respectively. In the wet cavity situation, the peak and average dose rates on the bottom of the transfer cask are 77.2 (0.7%) and 55.9 (0.2 %) mrem/hr, respectively, and the peak

and average dose rates at 1 meter are 19.0 (2.1%) and 12.2 (0.3 %) mrem/hr, respectively. In the dry cavity situation, the peak and average dose rates on the bottom of the transfer cask are 398.0 (3.9%) and 194.7 (0.3 %) mrem/hr, respectively, and the peak and average dose rates at 1 meter are 66.7 (3.6%) and 28.2 (0.4 %) mrem/hr, respectively.

5.4.4 Storage Cask Shielded Source Terms

The storage cask shielded source terms are provided in this section for use in the ISFSI controlled area boundary dose evaluations. These shielded source terms are the neutron and gamma fluxes at the surface of the NAC-MPC storage cask due to the neutron and gamma sources specified in Section 5.2. The cask surface fluxes are obtained from one-dimensional SAS1 radial and axial shielding evaluations. These fluxes are in the 27 group neutron and 18 group gamma energy group structure consistent with the SCALE 4.3 27N-28COUPLE cross section library. The group wise fluxes are listed in Tables 5.4-11 through 5.4-13 for the side and the top of the storage cask. At the bottom of each column is the total source strength for use in SKYSHINE-III. This source strength, in the case of the radial component, is based on the surface area of the side storage cask at the active fuel region, and, in the case of the top axial component, is based on the surface area of the top lid. The total source strengths and spectra are used in the SKYSHINE-III direct and air-scatter dose evaluations presented in Chapter 10 for an array of NAC-MPC storage casks at an ISFSI.

Figure 5.4-1 Storage Cask Radial Dose Rate Profile

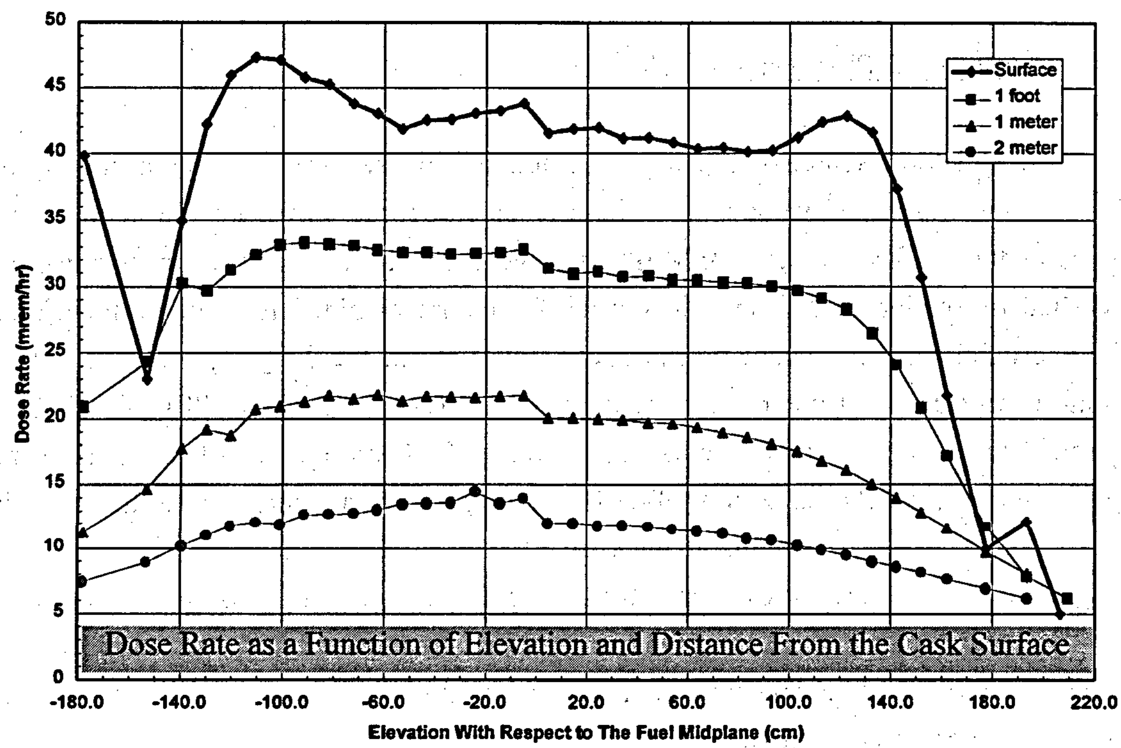


Figure 5.4-2 Storage Cask Three-Dimensional Model Surface Dose Rate Profile

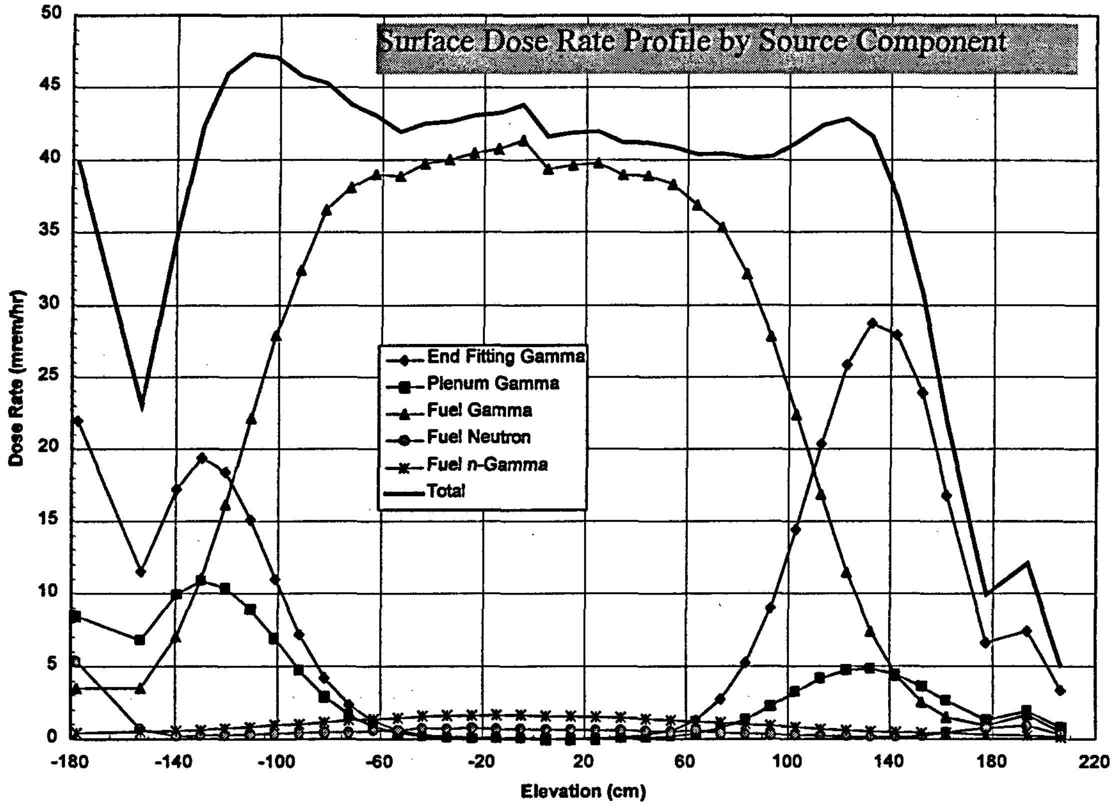


Figure 5.4-3 Storage Cask Top Outlet Vent Dose Rate Profile

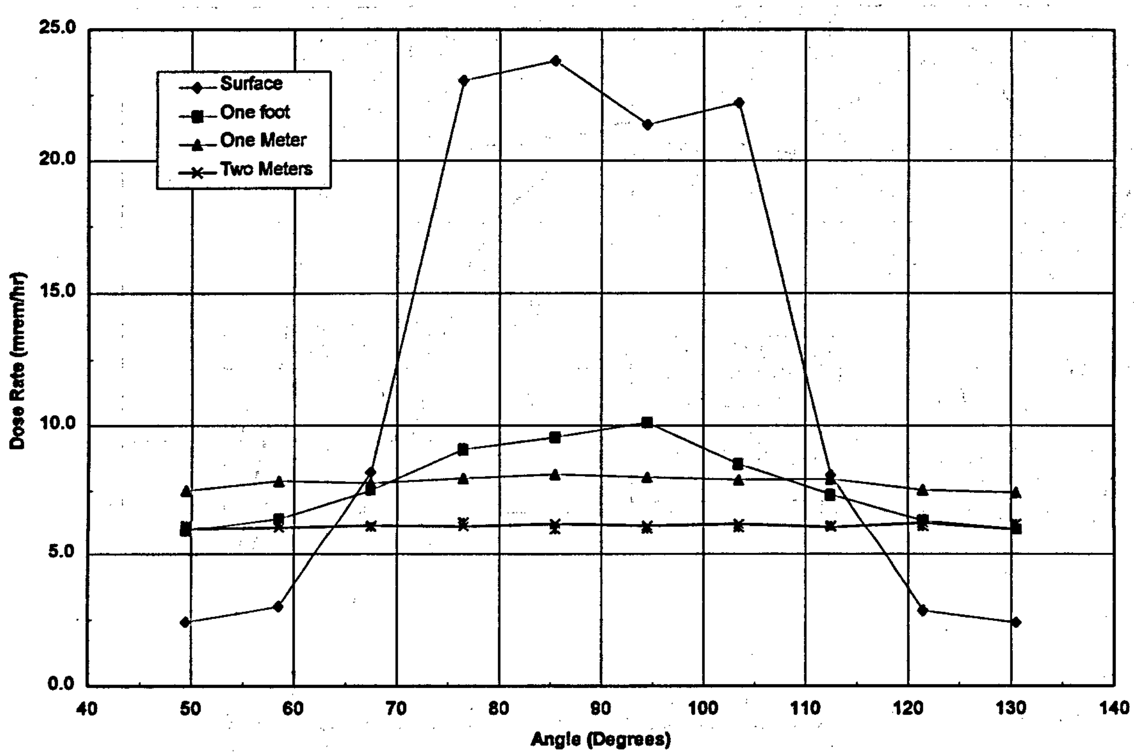


Figure 5.4-4 Storage Cask Bottom Inlet Vent Dose Rate Profile

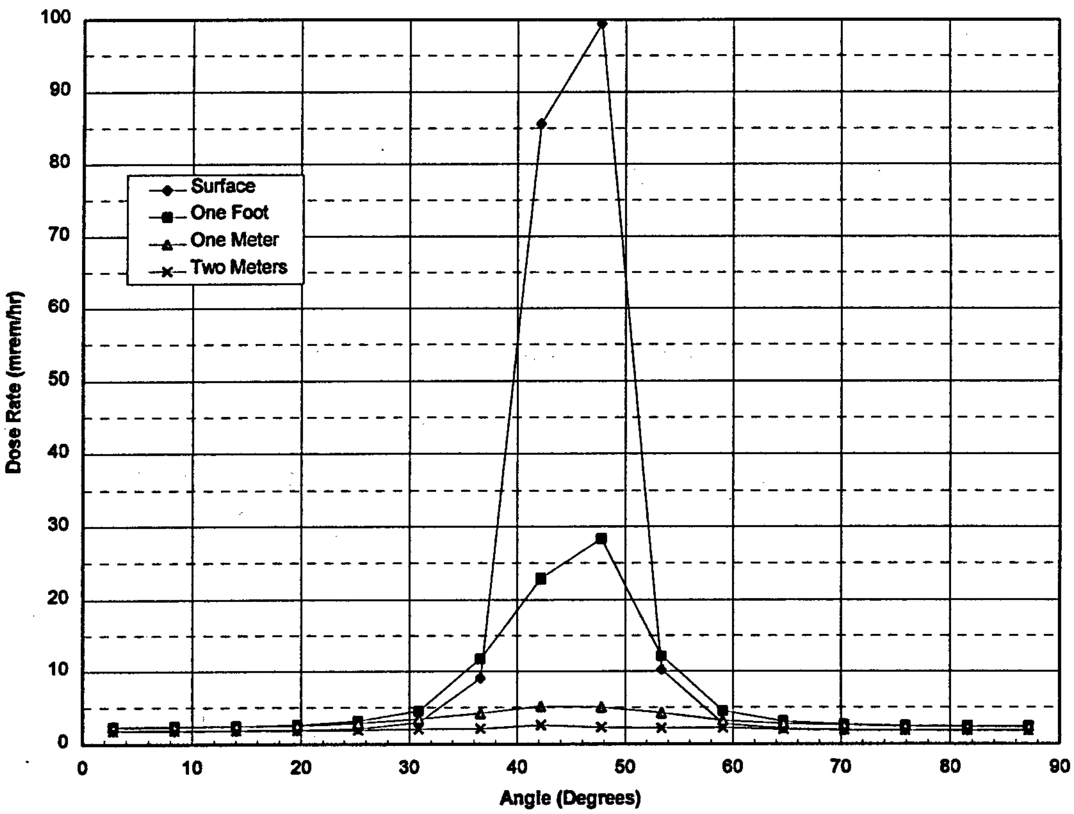


Figure 5.4-5 Storage Cask Dose Rate Profile at Stand Cutout Elevation

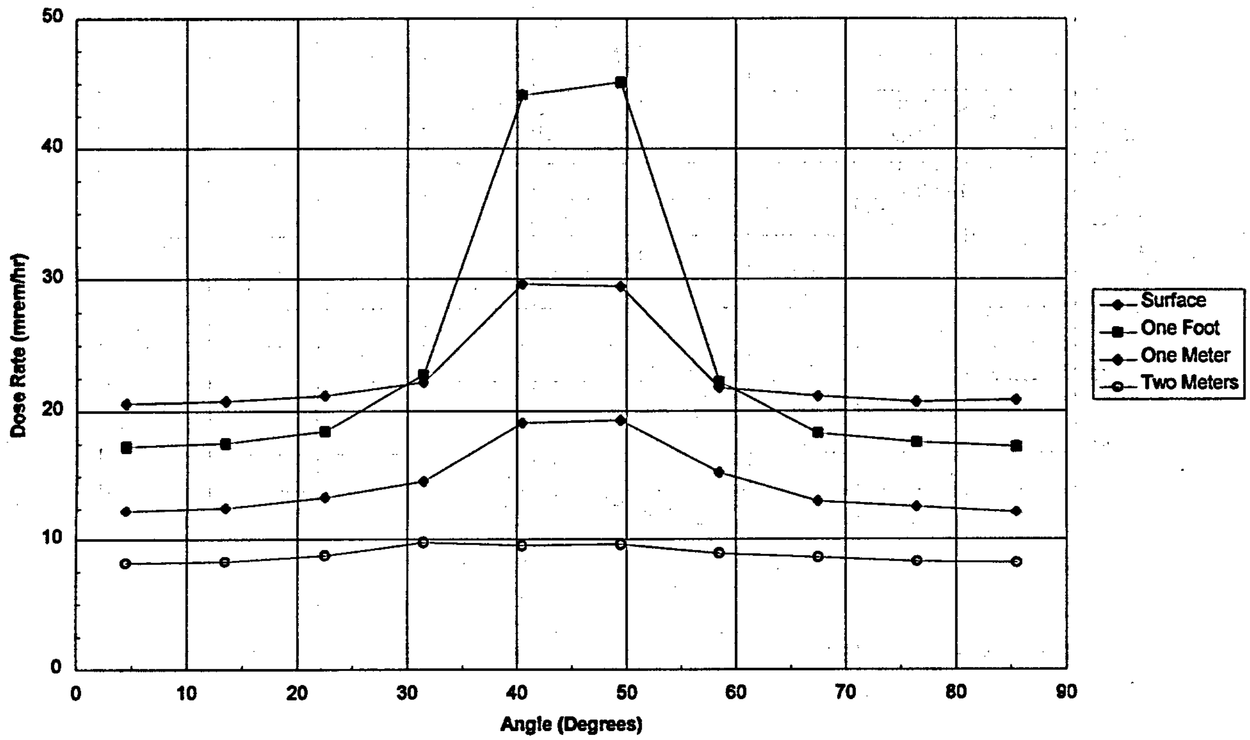


Figure 5.4-6 Storage Cask Top Dose Rate Profile as a Function of Radius from the Centerline and Distance from Surface

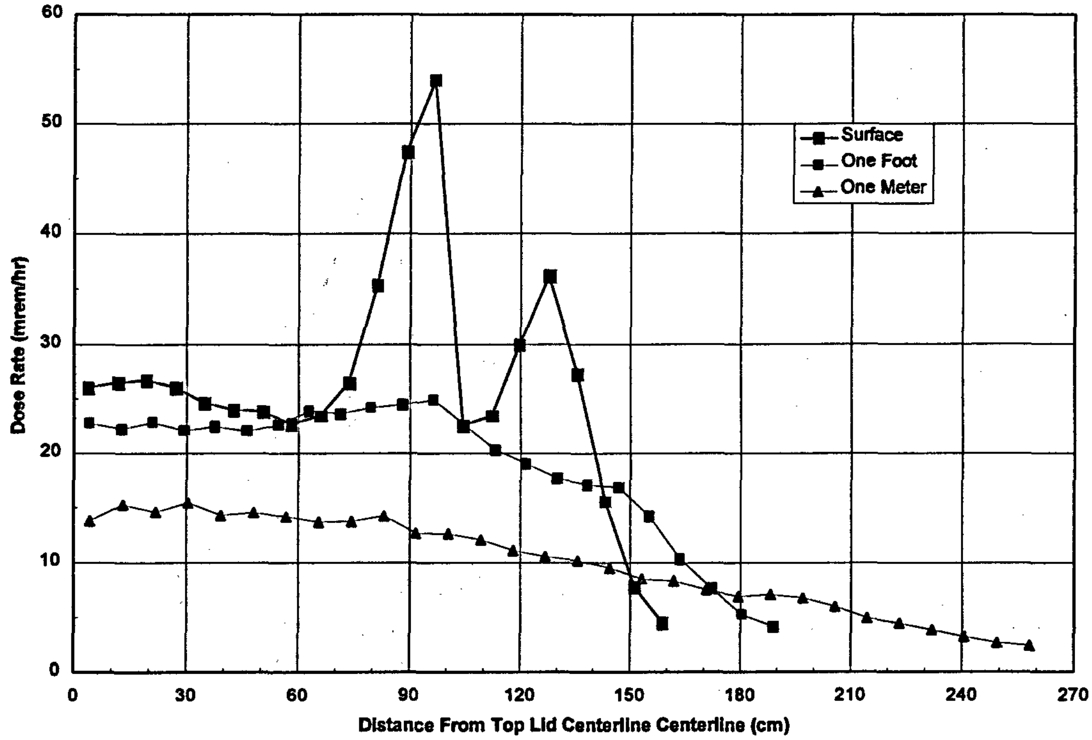


Figure 5.4-7 Storage Cask Top Surface Dose Rate Profile by Source Component

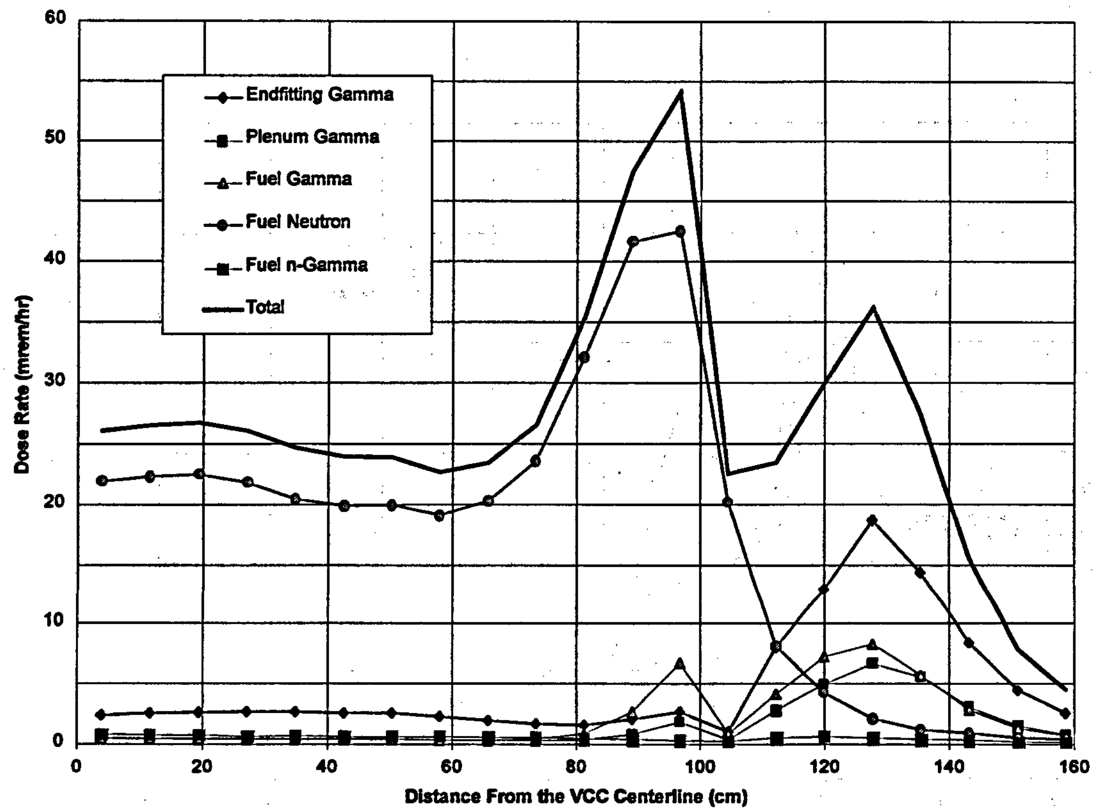


Figure 5.4-8 Transfer Cask Side Dose Rate Profile as a Function of Elevation and Distance, Wet Cavity

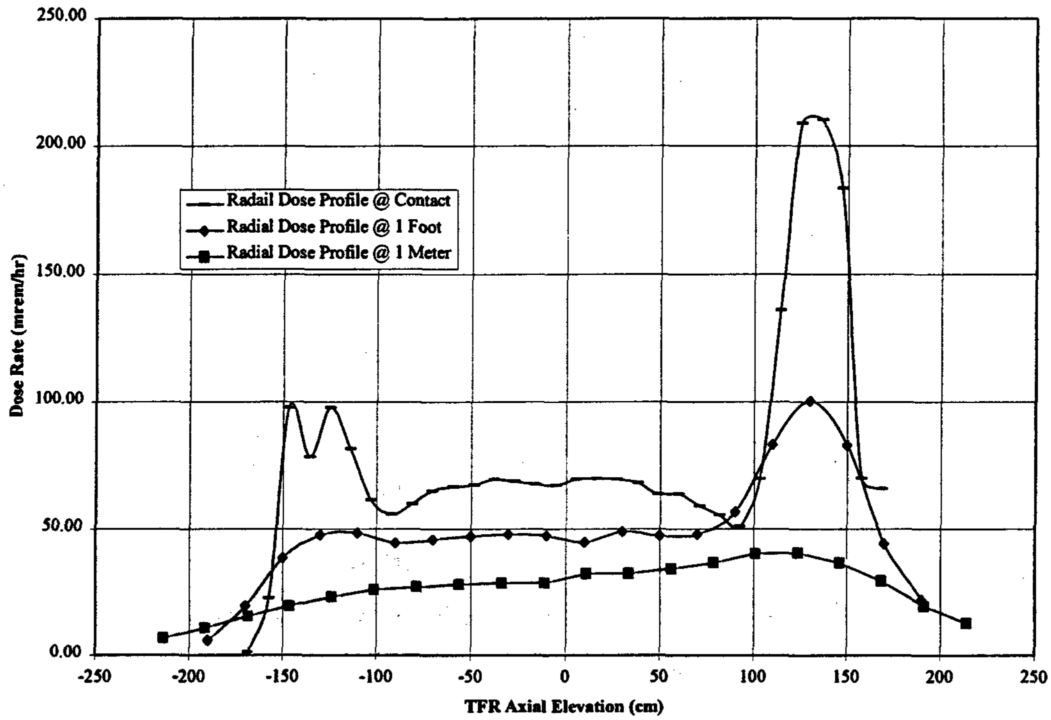
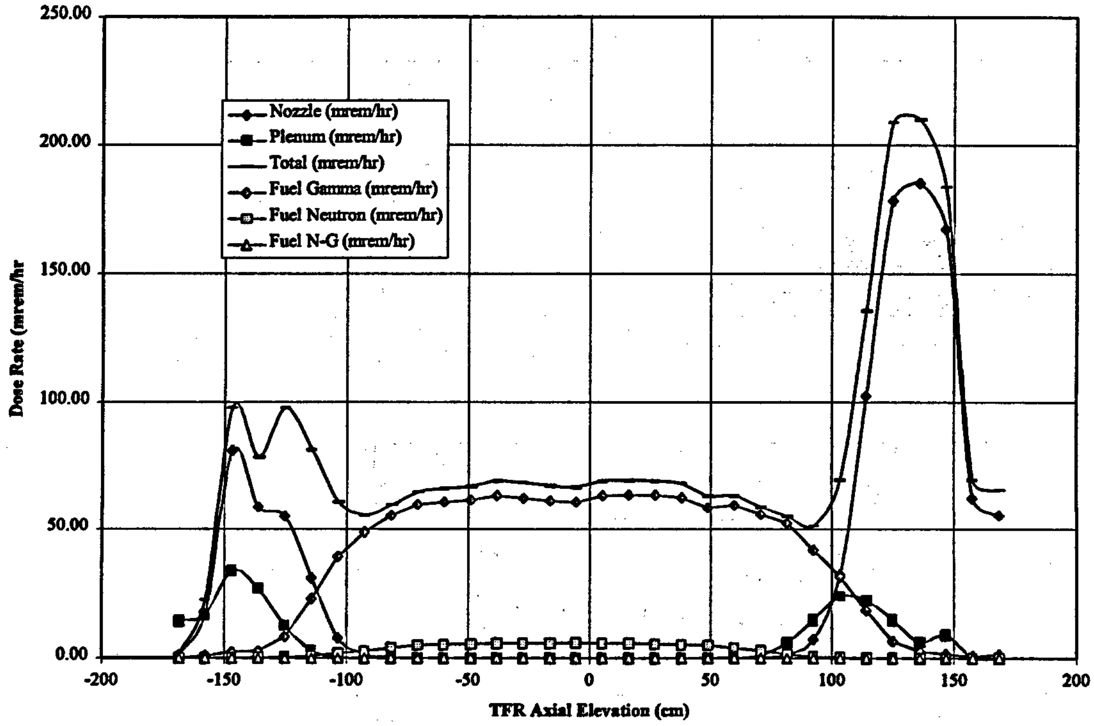


Figure 5.4-9 Transfer Cask Side Dose Rate Profile by Source Component, Wet Cavity



Note: Peak in nozzle dose at 135 cm is due to draining 50 gallons of water which uncovers the nozzle.

Figure 5.4-10 Transfer Cask Side Dose Rate Profile as a Function of Elevation and Distance, Dry Cavity

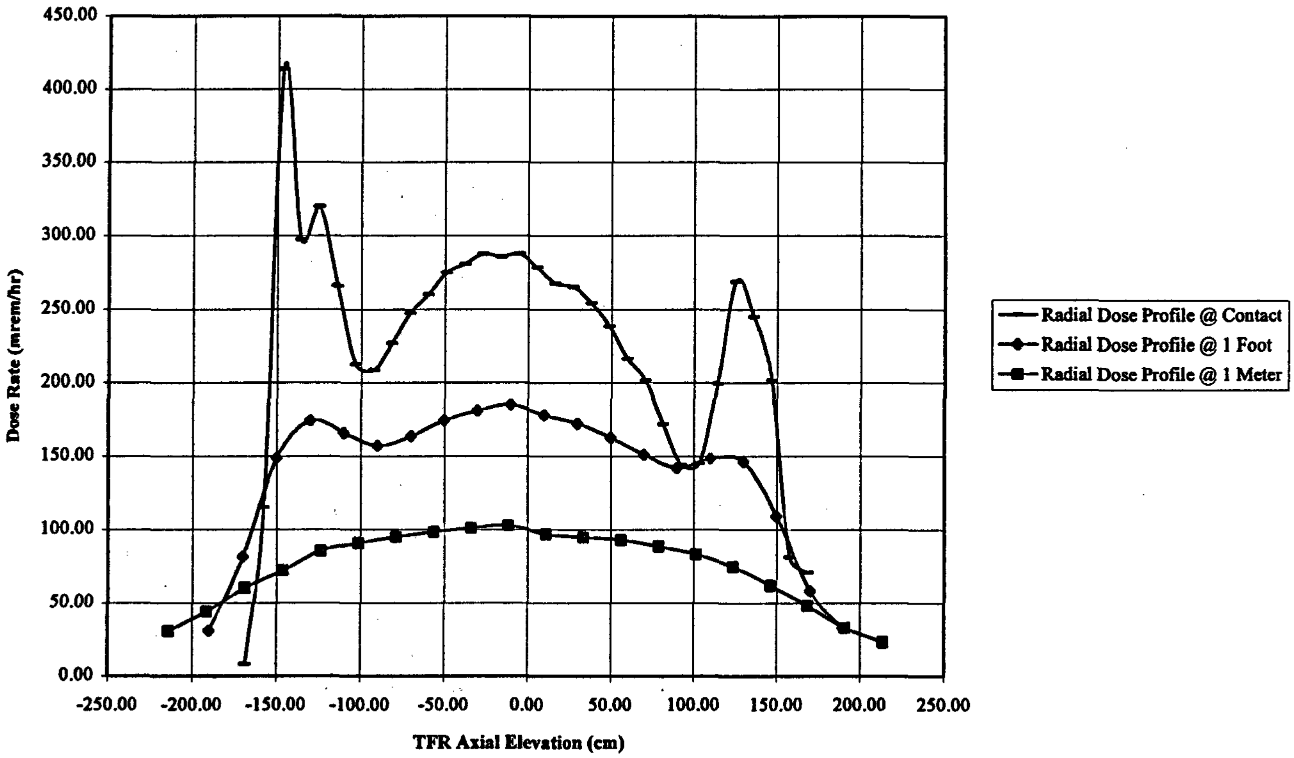


Figure 5.4-11 Transfer Cask Side Dose Rate Profile by Source Component, Dry Cavity

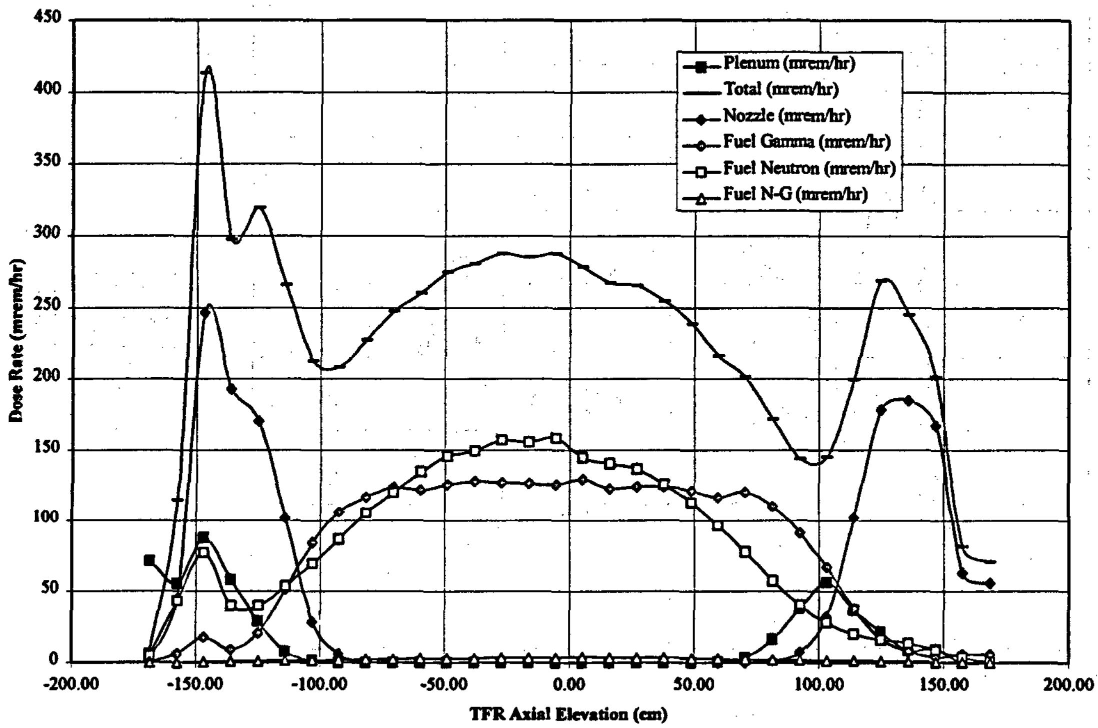


Figure 5.4-12 Transfer Cask Top Surface Dose Rate as a Function of Radius and Distance from Surface, Shield Lid, Structural Lid, and Temporary Shield On, Dry Cavity

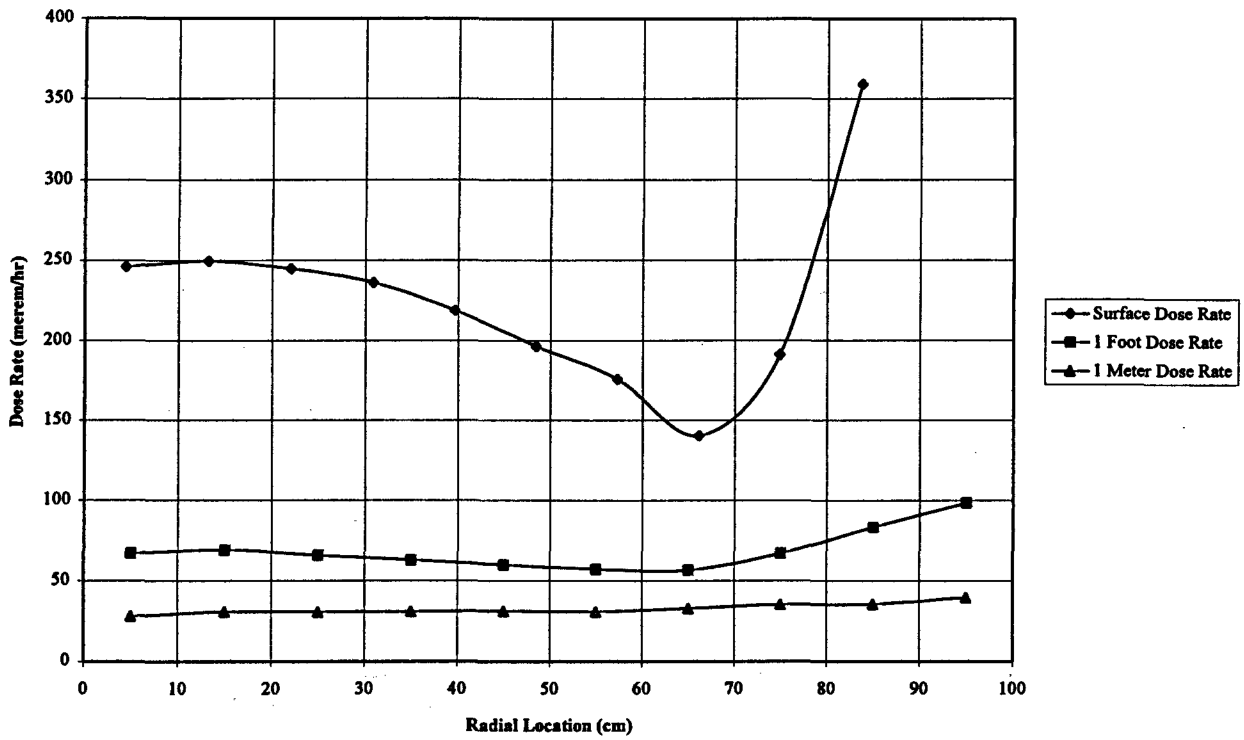


Figure 5.4-13 Transfer Cask Top Surface Dose Rate by Source Component, Shield Lid, Structural Lid, and Temporary Shield On, Dry Cavity

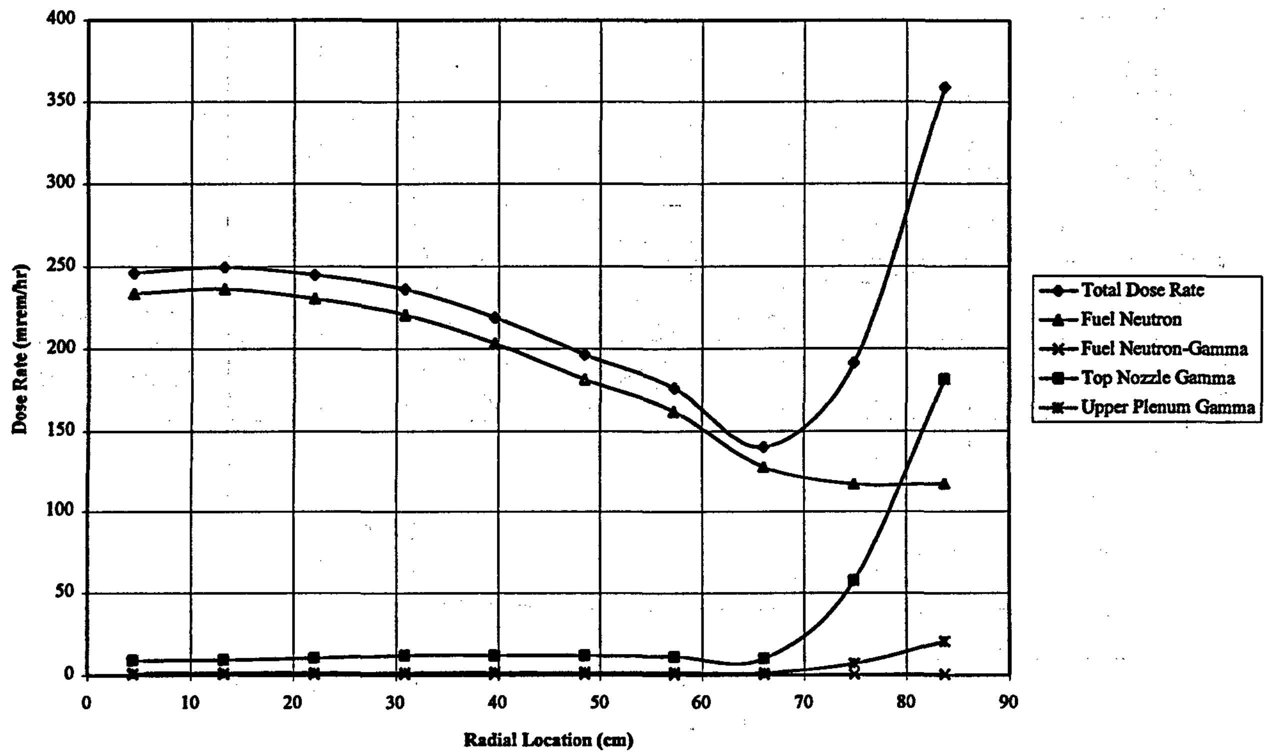


Figure 5.4-14 Transfer Cask Bottom Surface Dose Rate, Wet Cavity

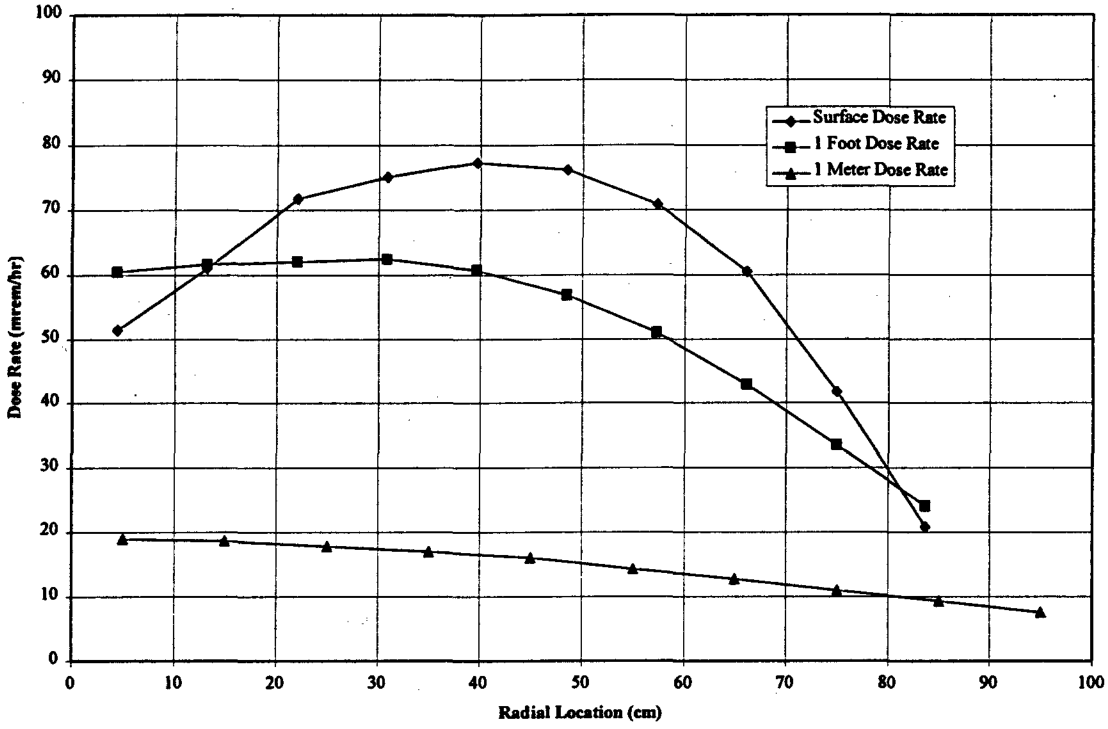


Figure 5.4-15 Transfer Cask Bottom Surface Dose Rate, Dry Cavity

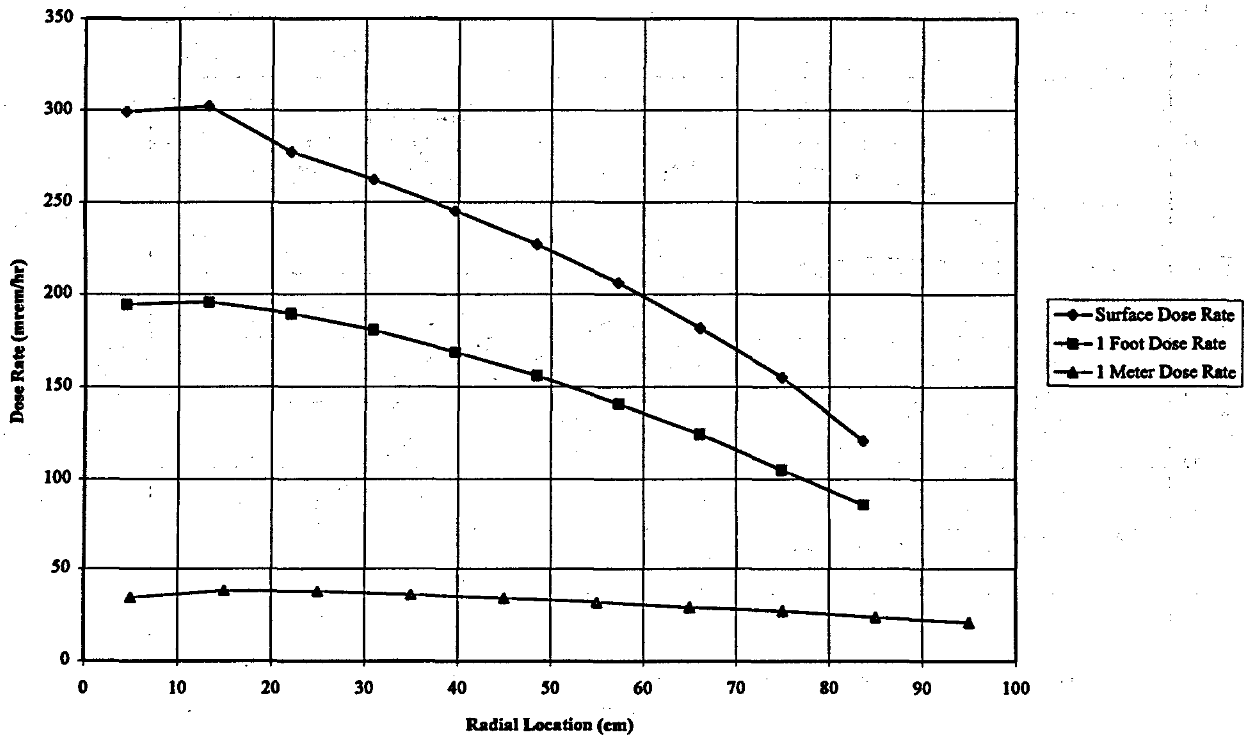


Table 5.4-1 ANSI Standard Neutron Flux-To-Dose Rate Factors

Group	(Rem/Hr)/(N/Cm^2/Sec)
1	1.49160E-04
2	1.44640E-04
3	1.27010E-04
4	1.28110E-04
5	1.29770E-04
6	1.02810E-04
7	5.11830E-05
8	1.23189E-05
9	3.83650E-06
10	3.72469E-06
11	4.01500E-06
12	4.29259E-06
13	4.47439E-06
14	4.56760E-06
15	4.55809E-06
16	4.51850E-06
17	4.48790E-06
18	4.46649E-06
19	4.43450E-06
20	4.32709E-06
21	4.19750E-06
22	4.09759E-06
23	3.83900E-06
24	3.67480E-06
25	3.67480E-06
26	3.67480E-06
27	3.67480E-06

Table 5.4-2 ANSI Standard Gamma Flux-To-Dose Rate Factors

Group	(Rem/Hr)/(γ/Cm^2/Sec)
1	8.77160E-06
2	7.47849E-06
3	6.37479E-06
4	5.41360E-06
5	4.62209E-06
6	3.95960E-06
7	3.46860E-06
8	3.01920E-06
9	2.62759E-06
10	2.20510E-06
11	1.83260E-06
12	1.52280E-06
13	1.17250E-06
14	8.75940E-07
15	6.30610E-07
16	3.83380E-07
17	2.66930E-07
18	9.34720E-07

Table 5.4-3 NAC-MPC Storage Cask One-Dimensional Projectile Accident Radial Dose Rates

Source	Surface (mrem/hr)	1 meter (mrem/hr)
Fuel Neutron	4.1	1.5
Fuel Gamma	306.0	136.0
Fuel N-Gamma	4.5	1.8
Total	315	139

Table 5.4-4 NAC-MPC Shielded Gamma Flux

Energy Group Boundary (MeV)	Radial Gamma-Ray Group Flux (γ/sec/cm²)	Axial Hardware Gamma-Ray Group Flux (γ/sec/cm²)	Axial Fuel Gamma-Ray Group Flux (γ/sec/cm²)
8.0-10.0	1.76E+00	0.00E+00	9.26E-01
6.5-8.0	1.36E+01	0.00E+00	8.63E+00
5.0-6.5	1.71E+01	0.00E+00	4.04E+00
4.0-5.0	1.98E+01	0.00E+00	3.09E+00
3.0-4.0	2.72E+01	4.52E-24	3.74E+00
2.5-3.0	1.77E+01	5.27E-05	2.59E+00
2.0-2.5	9.40E+01	1.73E-02	5.37E+00
1.66-2.0	8.15E+01	1.39E-02	4.90E+00
1.33-1.66	4.65E+02	8.23E+01	1.45E+01
1.0-1.33	1.17E+03	2.05E+02	3.48E+01
0.8-1.0	1.56E+03	1.81E+02	3.26E+01
0.6-0.8	3.10E+03	2.48E+02	4.89E+01
0.4-0.6	5.53E+03	3.42E+02	7.96E+01
0.3-0.4	4.01E+03	2.06E+02	4.83E+01
0.2-0.3	5.63E+03	2.18E+02	5.20E+01
0.1-0.2	1.38E+04	1.37E+02	3.19E+01
0.05-0.1	4.62E+03	3.48E+00	8.14E-01
0.01-0.05	1.75E+01	5.24E-03	5.39E-03
Total Group Flux	4.02E+04	1.62E+03	3.77E+02
Total Source Strength (γ/sec)	1.18E+10[1]	1.34E+08[2]	3.12E+07[2]

1. Total radial source is total flux multiplied by the radial cask area (2.905 x 10^5 cm^2).
2. Total axial source is total flux multiplied by cask axial surface area (8.301 x 10^4 cm^2).

Table 5.4-5 NAC-MPC Shielded Neutron Flux

Energy Group Boundary (MeV)	Total Radial Neutron Group Flux (n/sec/cm^2)	Total Axial Neutron Group Flux (n/sec/cm^2)
6.43 - 20.0	3.82E-02	4.25E-02
3.0 - 6.43	1.42E-01	1.79E-01
1.85 - 3.0	3.42E-01	6.21E-01
1.4 - 1.85	1.71E-01	8.13E-01
0.9 - 1.4	1.56E-01	5.60E+00
0.4 - 0.9	3.51E-01	3.94E+01
0.1 -0.4	3.98E-01	7.47E+01
1.7E-02 - 0.1	3.62E-01	5.15E+01
3.0E-03 - 1.7E-02	2.85E-01	2.78E+01
5.5E-04 - 3.0E-03	3.25E-01	1.44E+01
1.0E-04 - 5.5E-04	4.04E-01	1.46E+01
3.0E-05 -1.0E-04	3.23E-01	9.36E+00
1.0E-05 - 3.0E-05	3.43E-01	7.76E+00
3.05E-06 - 1.0E-05	4.09E-01	7.06E+00
1.77E-06 - 3.05E-06	2.08E-01	3.00E+00
1.3E-06 -1.77E-06	1.28E-01	1.55E+00
1.13E-06 - 1.3E-06	6.01E-02	6.65E-01
1.0E-06 - 1.13E-06	5.37E-02	5.49E-01
8.0E-07 - 1.0E-06	1.00E-01	9.59E-01
4.0E-07 - 8.0E-07	3.62E-01	2.69E+00
3.25E-07 - 4.0E-07	1.35E-01	6.64E-01
2.25E-07 - 3.25E-07	5.56E-01	1.00E+00
1.0E-07 - 2.25E-07	6.37E+00	1.67E+00
5.0E-08 - 1.0E-07	1.37E+01	1.05E+00
3.0E-08 - 5.0E-08	9.49E+00	4.35E-01
1.0E-08 - 3.0E-08	8.35E+00	2.26E-01
1.0E-10 - 1.0E-08	1.65E+00	3.11E-02
Total Group Flux	4.52E+01	2.68E+02
Total Source Strength (n /sec)	1.31E+07[1]	2.223E+07[2]

1. Total radial source is total flux multiplied by radial cask area of 2.905 x 10^5 cm^2.
2. Total axial source is total flux multiplied by cask axial surface area of 8.301 x 10^4 cm^2

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6.0 CRITICALITY EVALUATION

6.1 Discussion and Results

This chapter demonstrates that the NAC-MPC storage system containing 36 Yankee Class fuel assemblies is subcritical in accordance with the requirements of 10 CFR 72.124(a), 10 CFR 72.236(c) and Chapter 6 of NUREG-1536. These requirements are interpreted to mean that the effective neutron multiplication factor of the NAC-MPC system is less than 0.95 including biases and uncertainties under normal, off-normal and accident conditions.

The NAC-MPC storage system comprises a transportable storage canister (canister), a transfer cask and a vertical concrete cask (storage cask). The canister comprises a stainless steel canister and a basket. The basket comprises 36 fuel tubes held in place with stainless steel support disks and tie rods. The transfer cask containing the canister and basket is loaded underwater in the spent fuel pool. Once loaded with fuel, the canister is drained, dried, inerted, and welded shut. The transfer cask is then used to transfer the canister to the storage cask where it is stored until transported off site.

Under normal conditions, such as loading in a spent fuel pool, moderator (water) is present in the canister while it is in the transfer cask. Also, during draining and drying operations, moderator is present and its density will vary. Thus, the criticality evaluation of the transfer cask includes a variation in moderator density and a determination of optimum moderator density. Off-normal and accident conditions are bounded by assuming the most reactive mechanical basket configuration as well as moderator intrusion into the fuel cladding (100% fuel failure).

Under normal conditions, moderator is not present in the canister while it is in the storage cask. However, access to the environment is possible via the air inlets in the storage cask and the convective heat transfer annulus between the canister and the storage cask steel liner. This access provides paths for moderator intrusion during a flood. Under off-normal conditions, moderator intrusion into the convective heat transfer annulus is evaluated. Under accident conditions, it is hypothetically assumed that the canister confinement fails, and moderator intrusion into the canister and into the fuel cladding (100% fuel failure) is evaluated. This is a highly conservative assumption since, as shown in Chapters 3 and 11, there are no design basis normal, off-normal or accident conditions that result in the failure of the canister confinement boundary that would allow the intrusion of water.

Criticality control in the NAC-MPC canister basket is achieved using a flux trap principle. Each of the basket tubes in the canister basket is surrounded by four BORAL sheets with a core areal density of 0.01g $^{10}B/cm^2$ (minimum), which are held in place by stainless steel cladding. The spacing of the basket tubes is maintained by the stainless steel support disks. These disks provide water gap spacings between tubes of 0.875, 0.810, or 0.750 inches, depending on the position of the fuel tube in the basket. When the canister is flooded with water, fast neutrons leaking from the fuel assemblies are thermalized in the water gaps, and are absorbed in the BORAL sheets before causing a fission in an adjacent fuel assembly. This criticality control can accommodate up to 36 Yankee Class zircaloy clad assemblies with an initial enrichment of 4.0 wt % ^{235}U or 36 Yankee Class stainless steel clad assemblies with an initial enrichment of 4.94 wt % ^{235}U.

The criticality evaluation of the NAC-MPC is performed with the SCALE 4.3 (ORNL) Criticality Safety Analysis Sequence (CSAS)(Landers). This sequence includes KENO-Va (Petrie) Monte Carlo analysis to determine the effective neutron multiplication factor (k_{eff}). The 27 group ENDF/B-IV neutron library (Jordan) is used in all calculations. CSAS with the 27 group library is benchmarked by comparison to 63 critical experiments relevant to Light Water Reactor (LWR) fuel in storage and transport casks.

Criticality evaluations are performed for both the transfer and storage casks under normal, off-normal and accident conditions. Considerations are given to the most reactive fuel assembly type, worst case mechanical basket configuration and variations in moderator density. The maximum effective neutron multiplication factor with bias and uncertainties for the transfer cask is 0.9021 under either normal, off-normal or accident conditions. The maximum multiplication factor with bias and uncertainties for the storage cask is 0.4503 under normal dry storage conditions and 0.9018 under the hypothetical accident conditions involving full moderator intrusion. These values reflect the following conservative conditions:

1. No fuel burnup (fresh fuel assumption).
2. No fission product build up as a poison.
3. 36 Yankee Class fuel assemblies of the most reactive type.
4. UO_2 fuel density at 95% of theoretical.
5. No dissolved boron in the spent fuel pool water (water temperature 293°K).
6. 75% of nominal ^{10}B loading in the BORAL plates.
7. Infinite cask array.
8. No axial leakage.
9. A most reactive mechanical configuration involving: the fuel tubes and assemblies moved toward the center of the basket, maximum fuel tube opening, minimum disk opening, maximum disk thickness and closely packed disk openings.
10. Moderator intrusion into the fuel rod clad/pellet gap under accident conditions.

Analysis of simultaneous moderator density variation inside and outside either the transfer or storage casks shows a monotonic decrease in reactivity with decreasing moderator density. Thus, the full moderator density condition bounds any off-normal or accident situation. Analysis of moderator intrusion into the storage cask heat transfer annulus with the dry canister shows a slight decrease in reactivity from the completely dry condition.

The NAC-MPC storage system containing 36 Yankee Class fuel assemblies of the most reactive type in the most reactive configuration is well below the 0.95 regulatory criticality safety limit including all biases and uncertainties under normal, off-normal and accident conditions.

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6.2 Package Fuel Loading

The NAC-MPC storage system can safely transfer and store 36 Yankee Class fuel assemblies. As shown in Figures 6.3-2 and 6.3-3, there are 37 fuel tube positions in the support and heat transfer disks that form the canister basket. Loading of fuel in the center tube position is prevented by the design of the top weldment, which blocks this position (Drawing 455-892). The various Yankee Class assemblies to be transferred and stored in the NAC-MPC are presented in Table 6.2-1. Five vendor categories, each with two fuel rod configurations (types) are available within the Yankee Class. These are: Combustion Engineering (CE) 16x16 Type A and Type B, two categories of Exxon 16x16 Type A and Type B, United Nuclear 16x16 Type A and Type B, and Westinghouse 18x18 stainless steel clad Type A and Type B. See Figures 6.2-1, 6.2-2 and 6.2-3 for the fuel array configurations. The Combustion Engineering manufactured fuel has the same fuel rod arrays for Types A and B as the Exxon fuel. The Type A and Type B fuel array configurations allow a cruciform control rod to be inserted between assemblies during core operation. The most reactive Yankee Class fuel assembly is the United Nuclear, Type A, 16 x 16 fuel assembly with 4.0 wt % ^{235}U initial enrichment. This fuel assembly type bounds all of the Yankee Class fuel assemblies, including the Westinghouse stainless steel clad fuel with a 4.94 wt % ^{235}U initial enrichment. The United Nuclear Type A fuel assembly with 4.0 wt % ^{235}U initial enrichment is the design basis fuel assembly used in NAC-MPC storage system criticality evaluations.

A canister may contain one or more reconfigured fuel assemblies. The reconfigured fuel assembly is designed to confine the Yankee Class spent fuel rods, or portions thereof, which are classified as failed fuel and to maintain the geometric configuration of those fuel rods. This assembly can accept up to 64 full length spent fuel rods in an eight by eight array of tubes.

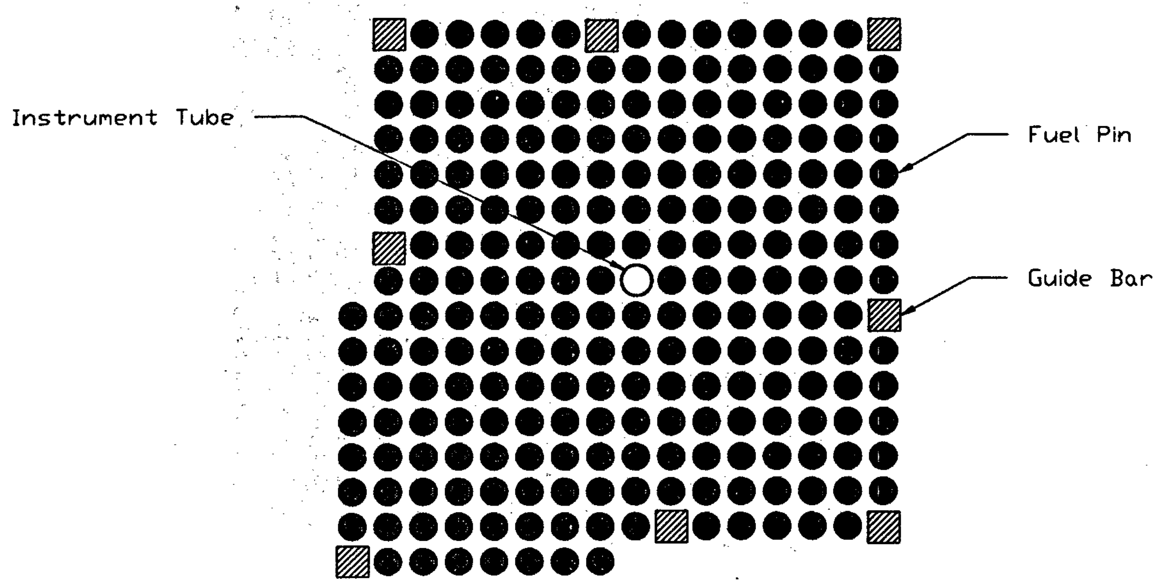
The reconfigured fuel assembly consists of a shell (square tube with end fittings), a basket assembly and 64 fuel tubes. Reconfigured fuel assembly parameters are presented in Table 6.2-2. The external dimensions of the shell are the same as those of a standard Yankee Class fuel assembly and all materials are stainless steel. It is designed such that it can be handled in the same manner as a standard Yankee Class fuel assembly. The spent fuel is confined in the fuel tubes. The tubes are supported by a basket assembly within the shell and have end plugs with drilled holes to permit draining, drying and inerting with helium. The shell has holes in the top and bottom fittings to permit draining, drying and inerting of the assembly.

The total number of full length pins that can be placed in the reconfigured fuel assembly is less than the number that are in the Yankee Class fuel assemblies (maximum of 64 versus 256 rods). Consequently, the reactivity of the reconfigured fuel assembly, even with the most reactive fuel rods, is less than the design basis fuel assembly used in criticality evaluations.

A comparison of the reactivity of the reconfigured fuel assembly to intact assemblies is made in conjunction with the most reactive assembly evaluation in Section 6.4.3.1.

Figure 6.2-1 Yankee Class Type A and Type B Exxon and CE Fuel Assembly Arrays

Type A



Type B

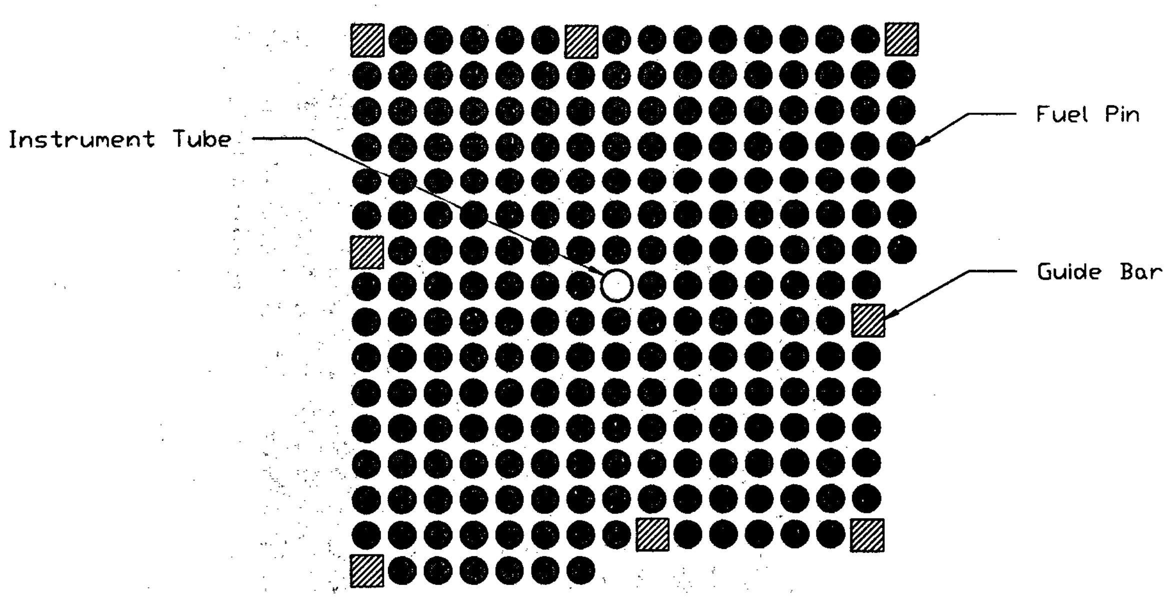
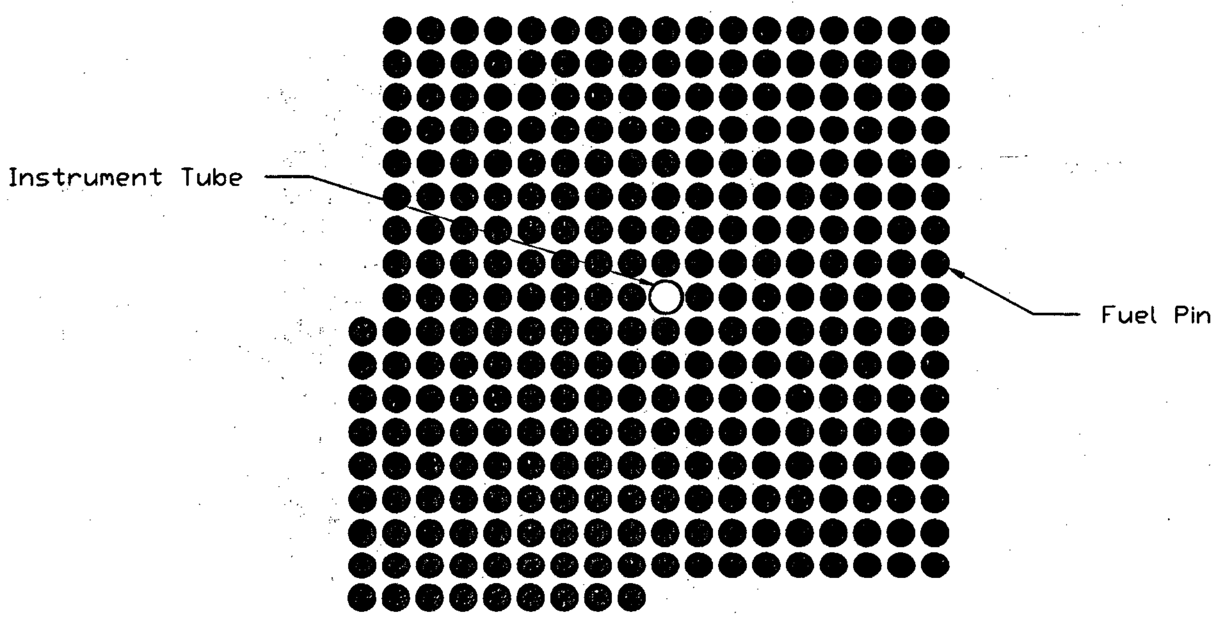


Figure 6.2-2 Yankee Class Type A and Type B Westinghouse Fuel Assembly Arrays

Type A



Type B

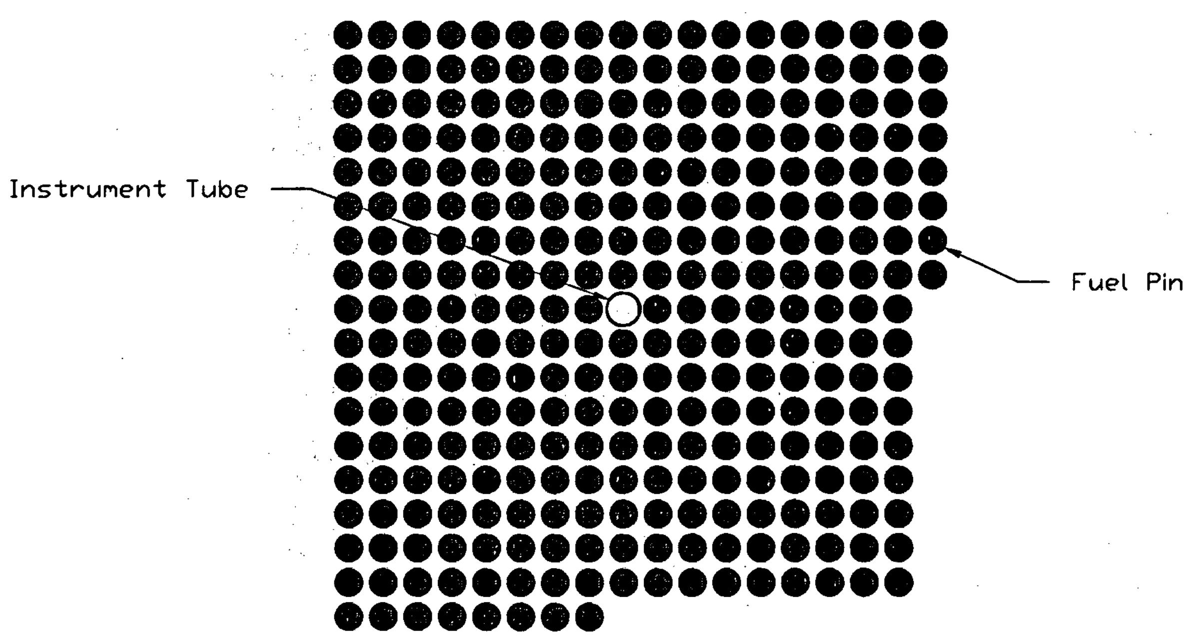
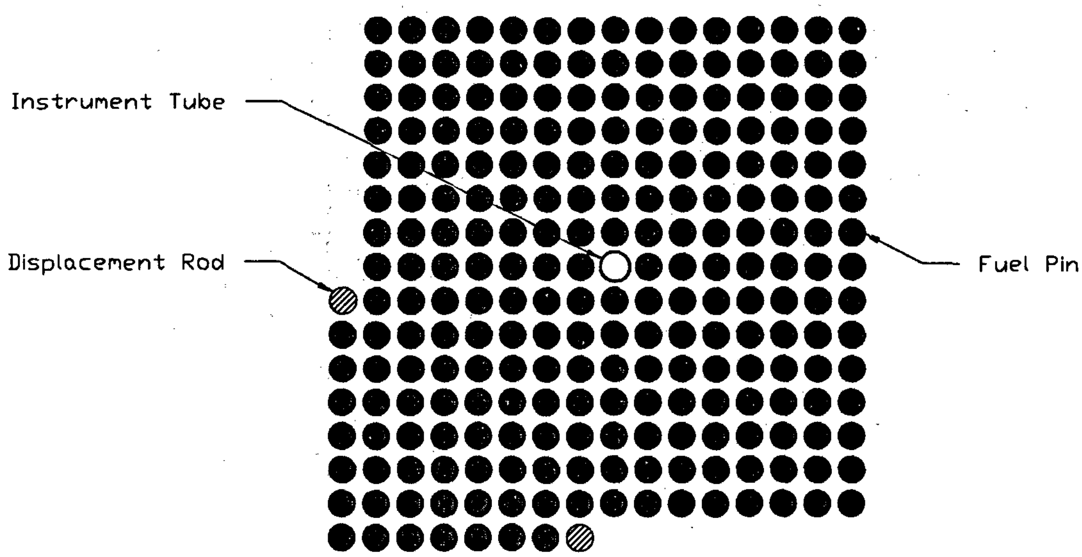


Figure 6.2-3 Yankee Class Type A and Type B United Nuclear Fuel Assembly Arrays

Type A



Type B

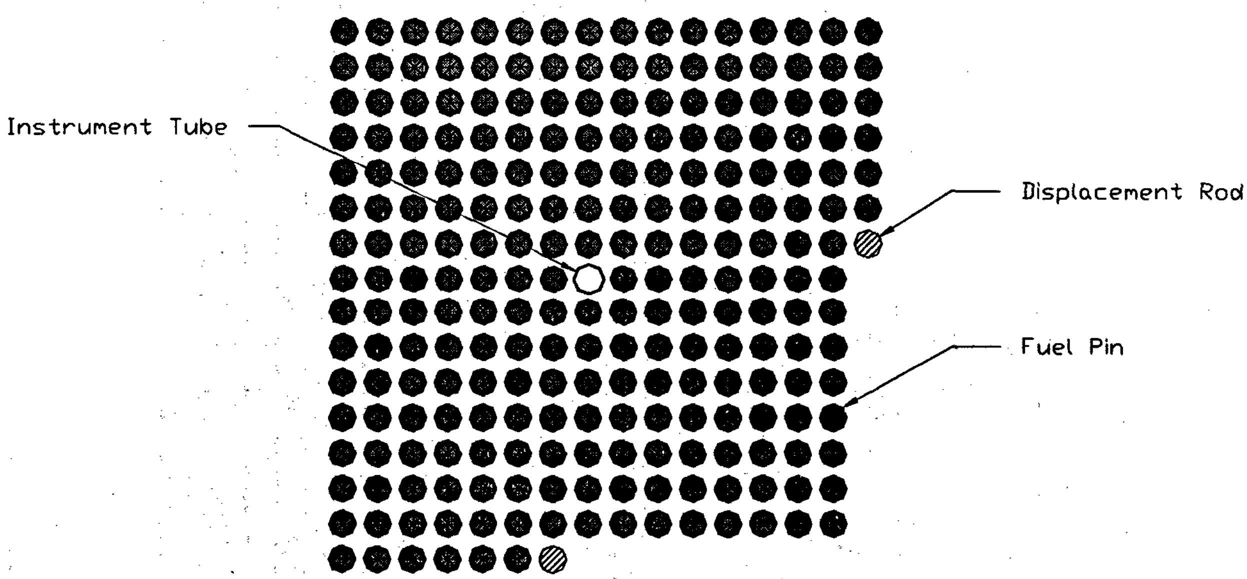


Table 6.2-1 Yankee Class Fuel Assembly Parameters

Parameter	CE Type A	CE Type B	Exxon Type A	Exxon Type B	Exxon Type A	Exxon Type B	West. Type A	West. Type B	United Nuclear Type A	United Nuclear Type B
Assembly Configuration	-	-	-	-	-	-	-	-	-	-
Assembly Array	16x16	16x16	16x16	16x16	16x16	16x16	18x18	18x18	16x16	16x16
Max. Enrichment (wt % ^{235}U)	3.90	3.90	4.00	4.00	3.70	3.70	4.94	4.94	4.00	4.00
Max. MtU*	0.2394	0.2384	0.2394	0.2384	0.2394	0.2384	0.2869	0.2860	0.2456	0.2446
Fuel Rod Configuration	-	-	-	-	-	-	-	-	-	-
Fuel Rod Pitch (cm)	1.1989	1.1989	1.1989	1.1989	1.1989	1.1989	1.0719	1.0719	1.1887	1.1887
Active Fuel Length (cm)	231.1400	231.1400	231.1400	231.1400	231.1400	231.1400	233.9975	233.9975	231.1400	231.1400
Rod OD (cm)	0.9271	0.9271	0.9271	0.9271	0.9271	0.9271	0.8636	0.8636	0.9271	0.9271
Clad ID (cm)	0.8052	0.8052	0.8052	0.8052	0.8052	0.8052	0.7569	0.7569	0.8052	0.8052
Pellet OD (cm)	0.7887	0.7887	0.7887	0.7887	0.7887	0.7887	0.7468	0.7468	0.7887	0.7887
Diametral Gap (cm)	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0102	0.0102	0.0165	0.0165
Rods per Assembly	231	230	231	230	231	230	305	304	237	236
Fuel Material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Clad Material	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	SS 348	SS 348	Zircaloy	Zircaloy
Displacement Rod Configuration	-	-	-	-	-	-	-	-	-	-
Displacement Rod Material	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Zircaloy - 4	Zircaloy - 4
Displacement Rod Diameter (cm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.9271	0.9271
Number Per Assembly	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	2
Guide Bar Configuration	-	-	-	-	-	-	-	-	-	-
Guide Bar Material	Zircaloy - 4	Zircaloy - 4	SS 304L	SS 304L	Zircaloy	Zircaloy	N/A	N/A	N/A	N/A
Guide Bar Width (cm)	1.0973	1.0973	1.0566	1.0566	1.0566	1.0566	N/A	N/A	N/A	N/A
Guide Bar Shape (cm)	Square	Square	Square	Square	Square	Square	N/A	N/A	N/A	N/A
Number Per Assembly	8	8	8	8	8	8	N/A	N/A	N/A	N/A
Instrument Tube Configuration	-	-	-	-	-	-	-	-	-	-
Instrument Tube ID (cm)	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9995	0.9995	0.9995	0.9995
Instrument Tube OD (cm)	1.1481	1.1481	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884	1.0884
Number Per Assembly	1	1	1	1	1	1	1	1	1	1
Instrument Tube Material	Zircaloy - 4	Zircaloy - 4	SS 304	SS 304	Zircaloy	Zircaloy	SS 304	SS 304	SS 304	SS 304

*Maximum MtU based on 95% of UO_2 theoretical density for the fuel pellet stack density.

Table 6.2-2 Yankee Class Reconfigured Fuel Assembly Parameters

Parameter	CE Type A/B	Exxon Type A/B	Exxon Type A/B	West. Type A/B	United Nuclear Type A/B
Assembly Configuration					
Assembly Array	8x8	8x8	8x8	8x8	8x8
Max. Enrichment (wt % ^{235}U)	3.90	4.00	3.70	4.94	4.00
Max. kgU*	66.33	66.33	66.33	60.21	66.33
Fuel Rod Configuration (Each Rod Placed Within Encapsulating Rod)					
Rod Pitch (cm)	1.905	1.905	1.905	1.905	1.905
Active Fuel Length (cm)	231.1400	231.1400	231.1400	233.9975	231.1400
Rod OD (cm)	0.9271	0.9271	0.9271	0.8636	0.9271
Clad ID (cm)	0.8052	0.8052	0.8052	0.7569	0.8052
Pellet OD (cm)	0.7887	0.7887	0.7887	0.7468	0.7887
Diametrical Gap (cm)	0.0165	0.0165	0.0165	0.0102	0.0165
Max Rods per Assembly	64	64	64	64	64
Fuel Material	UO_2	UO_2	UO_2	UO_2	UO_2
Clad Material	Zircaloy	Zircaloy	Zircaloy	SS 348	Zircaloy
Encapsulating Rod					
Rod OD (cm)	1.27	1.27	1.27	1.27	1.27
Rod ID (cm)	1.1278	1.1278	1.1278	1.1278	1.1278
Rod Material	SS-304	SS-304	SS-304	SS-304	SS-304

* Maximum kgU based on 95% of UO_2 theoretical density for the fuel pellet stack density.

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6.3 Criticality Model Specification

This section describes the KENO-Va models used in the criticality evaluation of the NAC-MPC. The geometric representation of the design basis fuel assembly, the NAC-MPC basket and the associated transfer and storage cask shield regions are described. The material densities and nuclide concentrations are also specified.

6.3.1 Description of Calculational Models

Three models are used in the NAC-MPC storage system criticality evaluations: a fuel/basket model, a transfer cask model and a storage cask model. The fuel/basket model is a single NAC-MPC basket cell containing a fuel assembly. This model is used to determine the most reactive fuel assembly type and to evaluate mechanical perturbations of the fuel and basket. The transfer cask model is an explicit representation of the NAC-MPC basket and canister containing 36 design basis fuel assemblies surrounded by the transfer cask radial shields. This model is used to evaluate the transfer cask reactivity during loading, draining and drying operations. The storage cask model is an explicit representation of the NAC-MPC basket and canister containing up to 36 design basis fuel assemblies, surrounded by the storage cask radial shields. This model is used to evaluate the storage cask during normal, off-normal and accident storage situations.

The fuel/basket model comprises a single basket cell with periodic axial and reflective radial boundary conditions. This simulates an infinite array of fuel/basket cells. The model geometry is divided into four vertical layers: an aluminum heat transfer layer; a flux trap water layer; a steel support disk layer; and a top flux trap water layer. In each of these layers, the fuel assembly array, fuel tube, BORAL sheets, flux trap water gap, steel, or aluminum disk web are modeled. Figure 6.3-1 shows a sketch of the NAC-MPC fuel/basket model.

Both of the storage and transfer cask criticality models are derived from a radial slice of the basket at the central (heat transfer) region. This section is the most reactive region due to the number of steel support disks and aluminum heat transfer disks displacing water in the flux trap gap. Each model is a stack of four slices containing one aluminum disk, two identical water regions and one steel support disk region (stacked aluminum, water, steel, water). The basket is modeled in each slice and contains design basis fuel assembly in each of 36 basket tubes with

BORAL sheets. Both cask models explicitly arrange the fuel assemblies and basket tubes in the most reactive configuration consistent with the mechanical tolerances specified by the design drawings. In all models, the fuel assemblies, basket tubes, BORAL sheets and water gaps are explicitly represented. There are no homogenizations. Each cask slice includes the cask radial shield regions surrounded by an outer CUBOID. The four slices are stacked into the KENO-Va GLOBAL UNIT.

Periodic boundary conditions are imposed on the top and bottom of the GLOBAL UNIT to simulate infinite axial extent. Reflecting boundary conditions are imposed on the sides of the GLOBAL UNIT simulating an infinite number of casks in the X-Y plane. Moderator density is varied both in the cask cavity regions normally filled with water and in the exterior CUBOID. Figures 6.3-2 and 6.3-3 show the transfer cask and storage cask criticality models, respectively.

6.3.2 Package Regional Densities

The SCALE 4.3 standard composition library (Petrie) default densities and isotopic distributions are used unless otherwise indicated. The densities used in the KENO-Va criticality analyses are:

Material	Density (g/cc)
UO_2 at 95% TD	0.412
Zircaloy	6.56
Type 348 Stainless Steel	7.92 (non-standard, Westinghouse fuel clad)
H_2O	0.9982
Type 304 Stainless Steel	7.92
Lead	11.344
Aluminum	2.702
BORAL (core)	2.623 (non-standard)
NS-4-FR	1.629 (non-standard)
Concrete	2.243 (based on 140 lb/ft^3 design spec. minimum)
Carbon Steel	7.821

6.3.2.1 Fuel Region

Fuel rod densities are:

Material	Element	Density (atoms/barn-cm)
UO_2 (at 3.9 wt %)	^{235}U	9.271×10^{-4}
	^{238}U	2.231×10^{-2}
	O	4.646×10^{-2}
UO_2 (at 4.0 wt %)	^{235}U	9.406×10^{-4}
	^{238}U	2.229×10^{-2}
	O	4.646×10^{-2}
UO_2 (at 4.9 wt %)	^{235}U	1.162×10^{-4}
	^{238}U	2.207×10^{-2}
	O	4.646×10^{-2}
Zircaloy	Zr	4.331×10^{-2}
Stainless Steel 348	Fe	5.529×10^{-2}
	Cr	1.743×10^{-2}
	Ni	1.057×10^{-2}
	C	3.180×10^{-4}
	Mn	1.736×10^{-3}
	Si	1.698×10^{-3}
	P	6.159×10^{-5}
	S	4.463×10^{-5}

6.3.2.2 Cask Material

Cask material densities are:

Material	Element	Density (atoms/barn-cm)
Boral Core	^{10}B	7.098×10^{-3}
	^{11}B	3.925×10^{-2}
	C	1.220×10^{-2}
	Al	3.358×10^{-2}
Aluminum	Al	6.03×10^{-2}
Steel 304	Cr	1.743×10^{-2}
	Fe	5.936×10^{-2}
	Ni	7.721×10^{-3}
	Mn	1.736×10^{-3}
Lead	Pb	3.297×10^{-2}
NS-4-FR	H	5.841×10^{-2}
	O	2.607×10^{-2}
	C	2.265×10^{-2}
	N	1.401×10^{-3}
	Al	7.781×10^{-3}
	^{11}B	3.565×10^{-4}
	^{10}B	9.798×10^{-5}
Concrete	O	4.494×10^{-2}
	Si	1.621×10^{-2}
	H	1.340×10^{-2}
	Na	1.704×10^{-3}
	Ca	1.483×10^{-3}
	Fe	3.386×10^{-4}
	Al	1.702×10^{-3}
Carbon Steel	Fe	8.350×10^{-2}
	C	3.925×10^{-3}

6.3.2.3 Water Reflector Densities

The material densities for the water inside and outside the storage cask under normal conditions are:

Material	Element	Density (atoms/barn-cm)
H_2O	H	6.677×10^{-2}
	O	3.338×10^{-2}

Water density is varied using the volume fraction (VF) parameter on the SCALE 4.3 material information processor card. This acts as a simple multiplier on the above densities.

Figure 6.3-1 NAC-MPC KENO-Va Fuel/Basket Model

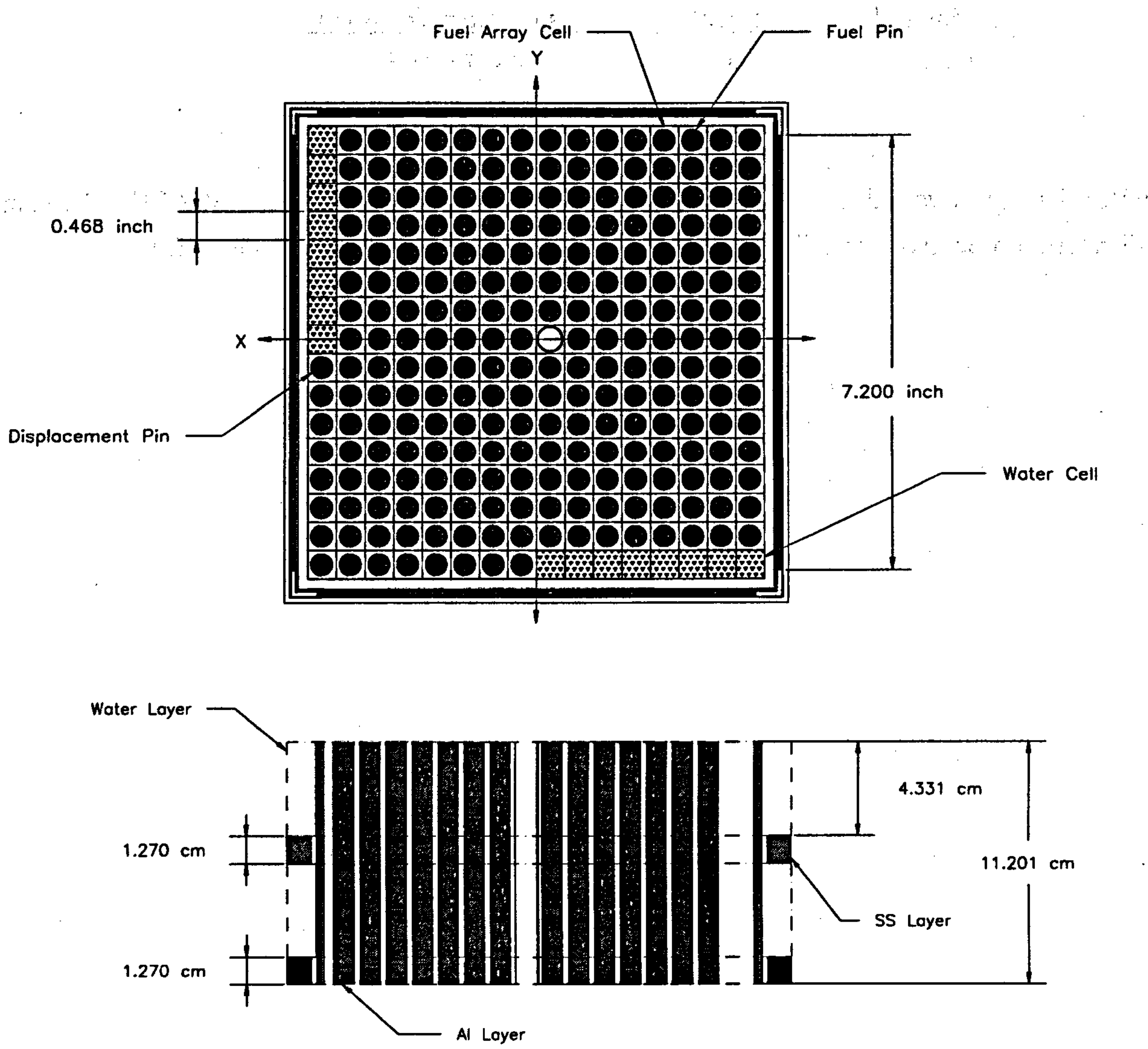
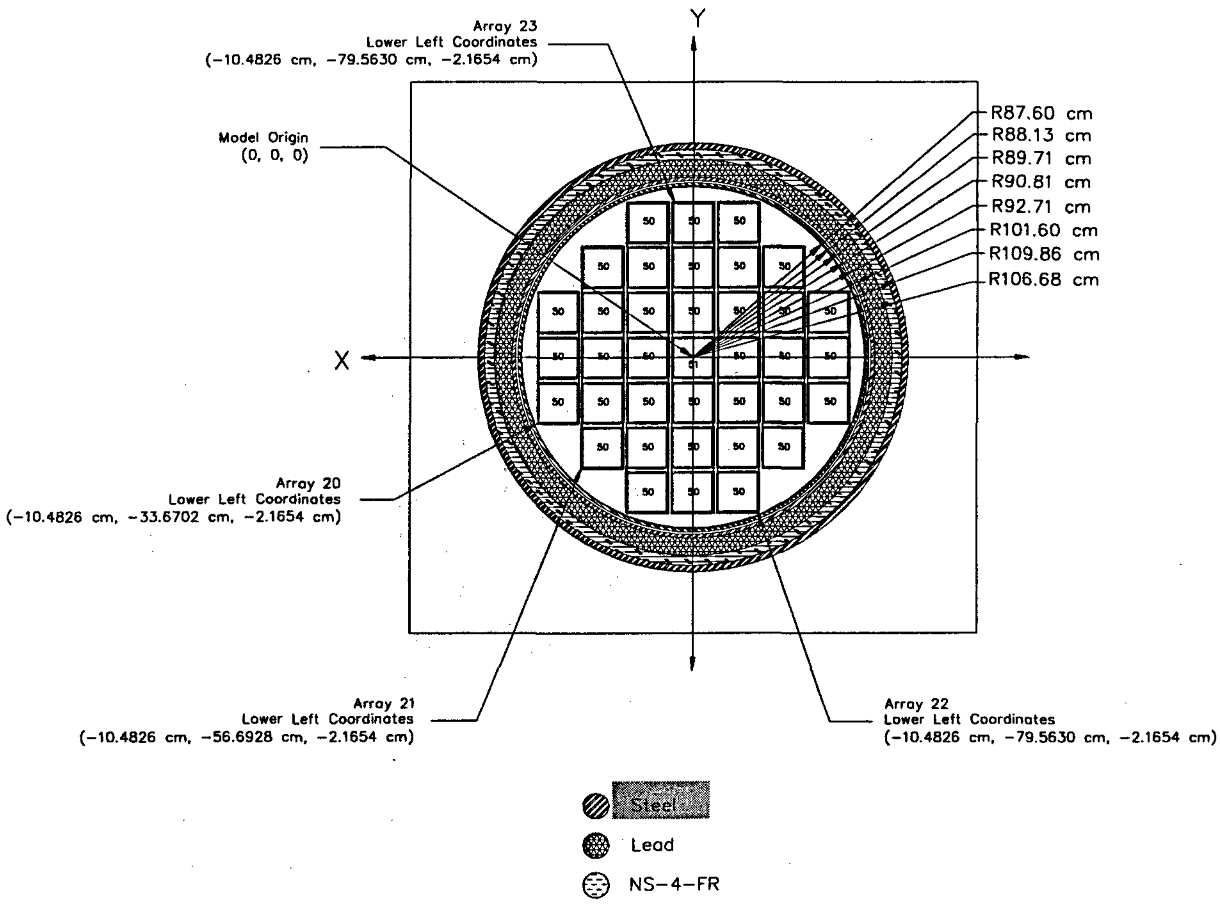
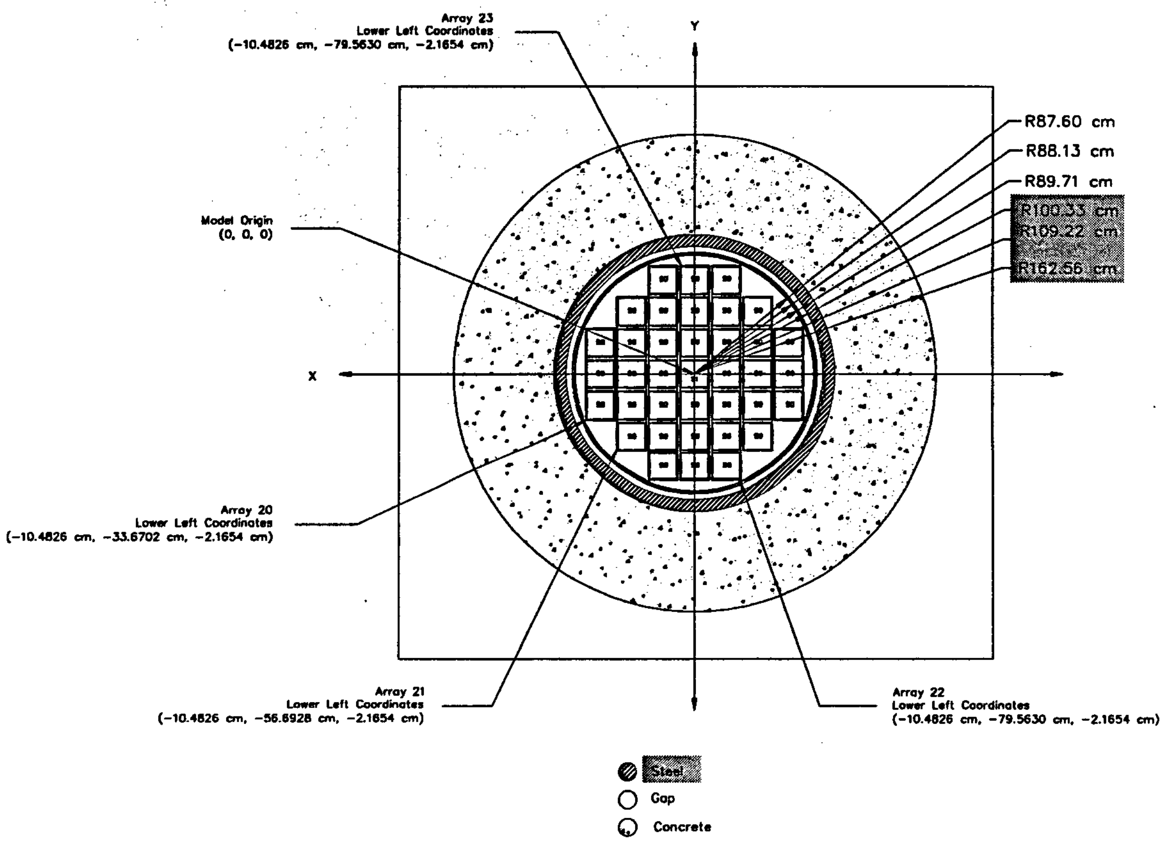


Figure 6.3-2 NAC-MPC KENO-Va Transfer Cask Model



Note: This model represents a slice between a support disk and a heat transfer disk. The center fuel tube position is filled with unit 51. This unit cell describes the vacant fuel tube. As previously stated, the criticality analysis considers 36 Yankee Class fuel assemblies, assuming the center tube is empty.

Figure 6.3-3 NAC-MPC KENO-Va Storage Cask Model



Note: This model represents a slice between a support disk and a heat transfer disk. The center fuel tube position is filled with unit 51. This unit cell describes the vacant fuel tube. As previously stated, the criticality analysis considers 36 Yankee Class fuel assemblies, assuming the center tube is empty.

6.4 Criticality Calculation

This section demonstrates that the criticality analysis of the NAC-MPC is sufficient to satisfy the requirements of 10 CFR 72.124(a), 10 CFR 72.236(c) and Chapter 6 of NUREG 1536. The calculational method is described. Criticality calculations are performed to determine: the most reactive Yankee Class fuel assembly type; the most reactive mechanical configuration in the NAC-MPC basket; and, the most reactive moderator density under normal, off-normal and accident conditions.

6.4.1 Calculational Method

The criticality evaluation of the NAC-MPC is performed with the SCALE 4.3 (ORNL) Criticality Safety Analysis Sequence (CSAS) (Landers) for the PC. CSAS includes: the SCALE Material Information Processor (Bucholz), BONAMI (Greene), NITAWL-II (Westfall), and KENO-Va (Petrie). The Material Information Processor generates number densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross section processing codes. The BONAMI and NITAWL-II codes are used to prepare a resonance-corrected cross section library in AMPX working format. The KENO-Va code calculates the model k_{eff} using Monte Carlo techniques. The 27 group ENDF/B-IV neutron cross section library (Jordan) is used in this calculation. The NAC-MPC KENO-Va models are described in further detail below.

6.4.2 Fuel Loading Optimization

The fuel loading is optimized in the NAC-MPC cask criticality models by using: 1) fresh fuel, 2) the most reactive Yankee Class fuel assembly type, 3) the highest possible fuel stack density (95 % of theoretical) and 4) the most reactive basket configuration. The cask models represent fully loaded baskets with 36 design basis fuel assemblies. The models use reflecting boundary conditions on the sides and periodic boundary conditions on the top and bottom. These boundary conditions simulate an infinite array of casks of infinite axial extent.

6.4.3 Criticality Results

This section establishes the most reactive Yankee Class fuel and the most reactive configuration of the fuel within the canister basket. These results are used to calculate the effective neutron multiplication factor for the transfer cask and storage cask assuming full moderation.

6.4.3.1 Most Reactive Assembly

Using the fuel/basket model of the NAC-MPC basket, each of the Yankee Class fuel assembly vendor categories shown in Table 6.2-1 is evaluated. Each particular fuel rod array is explicitly modelled. This includes the Westinghouse 18x18 Types A and B at 4.94 wt % ^{235}U, United Nuclear 16x16 Types A and B at 4.0 wt % ^{235}U, Exxon 16x16 Types A and B with steel guide bars and instrument tube at 4.0 wt % ^{235}U, and CE Type A and B at 3.90 wt % ^{235}U, as well as the reconfigured fuel assembly with the most reactive fuel rods. Note, the Exxon 16x16 Types A and B with Zircaloy guide bars and instrument tube is identical to the CE configuration. In order to standardize the comparison, each assembly is evaluated with the fuel UO_2 at 95% theoretical density.

Table 6.4-1 shows the multiplication factor for each Yankee Class fuel type in the NAC-MPC basket. This table shows that either the United Nuclear Type A or Type B has the highest multiplication factor of the Yankee Class fuel assembly vendor categories. Table 6.4-1 also shows that it is difficult to resolve the difference between Type A and Type B fuel assemblies. There is only one fuel rod difference in loading. However, since the United Nuclear Type A has the highest UO_2 mass, this fuel rod array is chosen as the most reactive design basis fuel assembly for the NAC-MPC. This design basis fuel assembly is used in all subsequent transfer and storage cask evaluations.

6.4.3.2 Most Reactive Mechanical Configuration

Using the fuel/basket model with the design basis fuel assembly, an evaluation of the effect of different NAC-MPC basket perturbations is made. This criticality analysis determines the most reactive basket mechanical configuration by altering the nominal fuel/basket model with the design basis assembly and comparing the perturbed k_{eff} to the nominal result. If Δk_{eff} ($k_{perturbed}$ - $k_{nominal}$) is positive, the tolerance causes an increase in reactivity. Conversely, if Δk_{eff} is negative, the tolerance causes a decrease in reactivity. Two sets of perturbations are assessed in this

evaluation of the criticality control: fabrication tolerances and component movement within the basket.

Four major fabrication tolerances are evaluated: the fuel tube opening, the disk opening, the disk thickness and the disk opening placement. Modifications to the nominal fuel/basket model dimensions are made based on the basket and fuel tube tolerances given on the NAC-MPC drawings provided in Chapter 1.0. The tolerance analysis results are shown in Table 6.4-2. Table 6.4-2 shows that the most reactive set of basket tolerances are maximum fuel tube opening, minimum disk opening, maximum disk thickness and minimum (close packed) disk opening placement.

Increasing the fuel tube opening brings more moderator into the gap between the assembly and the tube lowering the efficiency of the BORAL sheets, hence increasing the reactivity of the system. Minimizing the disk opening and maximizing the disk thickness removes water from the flux trap, consequently increasing k_{eff}. Finally, decreasing the web thickness, decreases the flux trap size and also moves assemblies closer together producing an increase in k_{eff}. With respect to fabrication tolerances, this is the most reactive configuration.

Two major component movements within the basket are evaluated: the assembly within the tube and the tube within the basket. Unique to this package is the Yankee Class diagonally symmetric fuel assembly. Consequently, movement toward three corners must be evaluated as opposed to one corner for a fully symmetric assembly. This assembly produces five movement perturbations: fuel tube movement to the upper right corner, the upper left corner, the lower left corner and side to side. Table 6.4-3 shows the assembly movement analysis results. These results show that the most reactive assembly position is centered within the basket tube. This centering provides the most optimum moderating water gap within the tube.

Similar to the fuel assembly movement analysis, five possible fuel tube movements are evaluated: the upper right corner, the upper left corner, the lower left corner and side to side. Mirror and periodic boundary conditions on the sides of the model are evaluated. Table 6.4-4 shows the tube movement evaluations. These results indicate that the most reactive fuel tube location is shifted to the right side of the tube with mirrored boundary conditions. This result is reasonable given the orientation of the assembly. Shifting the tube to the right side with mirrored boundary conditions moves a complete fuel pin row of two assemblies closer together, hence, pushing the largest amount of fuel together and minimizing the flux trap gap between tubes. In

general, these results show that moving the tubes towards each other with the fuel assembly centered in the tube is the most reactive component configuration.

Thus, the following most reactive mechanical configuration is imposed on the NAC-MPC basket model: assemblies centered in the tubes, fuel tubes moved toward the center of the basket, maximum fuel tube opening, minimum disk opening, maximum disk thickness and close packed disk opening locations. The reactivity penalty associated with this configuration versus the nominal configuration is discussed in the transfer cask and storage cask criticality evaluations below.

The fuel/basket model clusters the fuel in groups of four (mirrored boundary), or shifts the fuel to one side of the tube (periodic boundary) and therefore does not represent the closest fuel material approach feasible in a model with fuel moved radial inward. To document the maximum reactivity configuration both tube and assembly movement analyses are repeated in the full cask model. The k_{eff} of these analyses are compared to the nominal cask model. Based on the storage cask and transfer cask reactivity evaluation, the shield configuration of the transport cask does not impact k_{eff} significantly. Therefore, the results of the transport cask analysis, shown below, are applicable to the storage and transfer cask results.

Position	k_{eff}	σ	Δk_{eff}
Nominal	0.8637	0.0007	--
Tubes Moved Toward the Basket Center	0.8689	0.0008	0.0052
Tubes Moved Toward the Basket Shell	0.8596	0.0008	-0.0041
Assemblies Moved Toward the Basket Center	0.8677	0.0007	0.0040
Assemblies Moved Toward the Basket Shell	0.8590	0.0008	-0.0047

Based on the cask analysis, the assembly moved towards the cask center configuration adds a Δk_{eff} of 0.004 to the reactivity of the nominal configuration. The model documented as worst case mechanical configuration in the fuel/basket evaluation, and employed in optimum moderator studies, is not adjusted from its assembly centered configuration. The Δk_{eff} associated with the assembly movement is accounted for by adding the Δk_{eff} of 0.004 to the KENO-Va neutron multiplication factor (k_{eff}) during k_s calculations.

6.4.3.3 Transfer Cask Criticality Evaluation

Under normal conditions, such as loading in a spent fuel pool, moderator (water) is present in the canister while it is in the transfer cask. Also, during draining and drying operations, moderator is

present and its density will vary. Thus, the criticality evaluation of the transfer cask includes an evaluation of the reactivity effects of moderator density variation inside the cask. Off-normal and accident conditions are bounded by assuming the most reactive mechanical basket configuration as well as moderator intrusion into the fuel cladding (100% fuel failure).

Using the transfer cask criticality model, an evaluation of the assumption of 75% of ^{10}B in BORAL, the cumulative effect of worst case mechanical perturbations and the effect of moderator density variation is made. Table 6.4-5 shows transfer cask multiplication factors at various conditions. Table 6.4-5 shows that the assumption of 75% of the BORAL ^{10}B loading results in a 1.5% reactivity penalty and the cumulative effect of the worst case mechanical configuration results in an additional 1% reactivity penalty from the nominal configuration. Table 6.4-5 also shows that reactivity decreases monotonically with decreasing moderator density, and the optimum moderator density is at 1 g/cc. Under normal conditions involving loading, draining and drying, the maximum k_{eff} including bias and uncertainties is 0.8929. The CSAS output file (including an input listing) is shown in Figure 6.7-1. In the off-normal or accident situation involving fuel failure and moderator intrusion, the maximum k_{eff} including biases and uncertainties is 0.9021. The CSAS output file (including an output listing) is shown in Figure 6.7-2. Thus, the NAC-MPC transfer cask containing 36 Yankee Class fuel assemblies of the most reactive type in the most reactive configuration is well below the 0.95 NRC criticality safety limit including all biases and uncertainties under normal, off-normal and accident conditions.

6.4.3.4 Storage Cask Criticality Evaluation

Under normal conditions, moderator is not present in the storage cask. However, access to the environment is possible via air inlets and the convective heat transfer annulus between the canister and the storage cask steel liner. This access provides paths for moderator intrusion during a flood. Off-normal conditions evaluate moderator intrusion into the convective heat transfer annulus. Under accident conditions, it is assumed that the canister confinement fails, and moderator intrudes into the canister and fuel cladding (100% failure) is evaluated along with moderator density variation. The accident condition analyses also examine the effect of interior/exterior moderator density variations.

Using the storage cask criticality model, an evaluation is performed of moderator intrusion into the heat transfer annulus under off-normal conditions and into the canister under accident

conditions. Table 6.4-6 shows the storage cask multiplication factors at various conditions. Under normal dry conditions, maximum k_{eff} including biases and uncertainty is 0.4488, which is well subcritical. The CSAS output file (including an input listing) is shown in Figure 6.7-3. Under off-normal conditions involving flooding of the heat transfer annulus, the k_{eff} of the cask is even less. Under accident conditions involving full moderator intrusion into the canister and fuel clad gap, the maximum k_{eff} of the cask is 0.9018. The CSAS output file (including an input listing) is shown in Figure 6.7-4. Similar to the transfer cask analysis, the storage cask accident condition moderator density study evaluates a monotonic decrease in reactivity with moderator density inside and outside the cask. Thus, the NAC-MPC storage cask containing 36 fuel assemblies of the most reactive Yankee Class type in the most reactive configuration is well below the 0.95 NRC criticality safety limit including all biases and uncertainties under normal, off-normal and accident conditions.

Based on the results of the criticality analysis for the transfer cask, and the storage cask, presented in Tables 6.4-5 and 6.4-6 respectively, there is no significant impact on system reactivity when changing reflector dimensions and material composition. Therefore, the results of the storage cask evaluation are not impacted by the potential addition of the canister overpack configuration to the storage cask.

Table 6.4-1 Assembly Type Reactivity Evaluations

Assembly	Initial Enrichment (wt % ^{235}U)	In Basket k_{eff}	σ
Westinghouse Type A	4.94	0.8642	0.00105
Westinghouse Type B	4.94	0.8664	0.00102
United Nuclear Type A	**4.00**	**0.8974**	**0.00087**
United Nuclear Type B	4.00	0.8974	0.00106
Exxon Type A	4.00	0.8870	0.00111
Exxon Type B	4.00	0.8877	0.00111
Combustion Engineering Type A	3.90	0.8943	0.00060
Combustion Engineering Type B	3.90	0.8939	0.00163
Reconfigured Fuel Assembly	4.00	0.6280	0.0007

Table 6.4-2 Basket Tolerance Reactivity Evaluations

Analysis	k_{eff}	σ	Δk_{eff}
Nominal	**0.8981**	**0.0007**	**-**
Fuel Tube Maximum Opening	**0.9018**	**0.0007**	**0.0037**
Fuel Tube Minimum Opening	0.8916	0.0007	-0.0065
Disk Maximum Opening	0.8972	0.0007	-0.0009
Disk Minimum Opening	**0.8991**	**0.0008**	**0.0010**
Disk Maximum Thickness	**0.8987**	**0.0008**	**0.0006**
Disk Minimum Thickness	0.8972	0.0008	-0.0009
Loose Packed Disk Opening	0.8974	0.0008	-0.0007
Close Packed Disk Opening	**0.8993**	**0.0007**	**0.0012**

Table 6.4-3 Fuel Movement Reactivity Evaluations

Assembly Movement	Boundary Conditions	k_{eff}	σ	Δk_{eff}
Nominal	**Reflective**	**0.8981**	**0.0007**	**-**
Upper Right Corner	Mirrored	0.8954	0.0007	-0.0027
Upper Right Corner	Periodic	0.8943	0.0007	-0.0038
Lower Left Corner	Mirrored	0.8977	0.0007	-0.0004
Lower Left Corner	Periodic	0.8978	0.0008	-0.0003
Upper Left Corner	Mirrored	0.8963	0.0007	-0.0018
Upper Left Corner	Periodic	0.8961	0.0008	-0.0020
Right Side	Mirrored	0.8949	0.0007	-0.0032
Right Side	Periodic	0.8951	0.0007	-0.0030
Left Side	Mirrored	0.8978	0.0007	-0.0003
Left Side	Periodic	0.8972	0.0007	-0.0009

Table 6.4-4 Tube Movement Reactivity Evaluations

Tube Movement	Boundary Conditions	k_{eff}	σ	Δk_{eff}
Nominal	**Reflective**	**0.8981**	**0.0007**	**-**
Upper Right Corner	**Mirrored**	**0.8999**	**0.0007**	**0.0018**
Upper Right Corner	Periodic	0.8979	0.0007	-0.0002
Lower Left Corner	**Mirrored**	**0.8984**	**0.0008**	**0.0003**
Lower Left Corner	Periodic	0.8962	0.0007	-0.0019
Upper Left Corner	**Mirrored**	**0.8991**	**0.0008**	**0.0010**
Upper Left Corner	Periodic	0.8959	0.0007	-0.0022
Right Side	**Mirrored**	**0.9005**	**0.0008**	**0.0024**
Right Side	Periodic	0.8966	0.0007	-0.0015
Left Side	Mirrored	0.8968	0.0007	-0.0013
Left Side	Periodic	0.8976	0.0007	-0.0005

Table 6.4-5 Criticality Results for Transfer Cask

Cask Pitch (cm)	Basket Configuration	H_2O Inside (density g/cc)	H_2O Outside (density g/cc)	^{10}B in BORAL	k_{eff}	σ	k_s 1
319.71	Nominal	1.0	1.0	100%	0.85035	0.00076	0.8684
319.71	Nominal	1.0	1.0	75%	0.86504	0.00070	0.8831
319.71	Worst Case	1.0	1.0	75%	0.87422	0.00076	0.8923
319.71	**Worst Case**	**1.0**	**0.0001**	**75%**	**0.87488**	**0.00076**	0.8929
319.71	Worst Case	0.8	0.0001	75%	0.82355	0.00074	0.8416
319.71	Worst Case	0.6	0.0001	75%	0.76550	0.00069	0.7835
319.71	Worst Case	0.4	0.0001	75%	0.69378	0.00064	0.7118
319.71	Worst Case	0.2	0.0001	75%	0.60267	0.00051	0.6206
319.71	Worst Case	0.1	0.0001	75%	0.55065	0.00042	0.5686
319.71	Worst Case	0.05	0.0001	75%	0.51859	0.00034	0.5365
319.71	Worst Case	0.01	0.0001	75%	0.46634	0.00032	0.4843
319.71	**Worst Case + Water in Gap**	**1.0**	**1.0**	**75%**	**0.88403**	**0.00074**	0.9021

1. Includes a Δk of 0.004 due to radial movement of fuel assembly toward basket center.

Table 6.4-6 Criticality Results for Storage Cask

Cask Pitch (cm)	Basket Configuration	H_2O Inside (density g/cc)	H_2O[1] Outside (density g/cc)	^{10}B	k	σ	k_s[2]
457.2	Nominal	0.0001	0.0001	75%	0.43088	0.00029	0.4488
457.2	Worst Case	0.0001	1.0	75%	0.39800	0.00030	0.4159
457.2	"	0.0001	0.8	75%	0.39906	0.00031	0.4170
457.2	"	0.0001	0.6	75%	0.39869	0.00032	0.4166
457.2	"	0.0001	0.4	75%	0.40071	0.00031	0.4186
457.2	"	0.0001	0.2	75%	0.40963	0.00031	0.4276
457.2	"	0.0001	0.1	75%	0.42134	0.00031	0.4393
457.2	"	0.0001	0.05	75%	0.42924	0.00031	0.4472
457.2	**"**	**0.0001**	**0.01**	**75%**	**0.43241**	**0.00030**	**0.4503**
457.2	**Worst Case + water in gap**	**1.0**	**1.0**	**75%**	**0.88376**	**0.00072**	**0.9018**
457.2	"	0.8	0.8	75%	0.83228	0.00072	0.8503
457.2	"	0.6	0.6	75%	0.77378	0.00068	0.7918
457.2	"	0.4	0.4	75%	0.69781	0.00062	0.7158
457.2	"	0.2	0.2	75%	0.59996	0.00053	0.6179
457.2	"	0.1	0.1	75%	0.54264	0.00042	0.5606
457.2	"	0.05	0.05	75%	0.51048	0.00036	0.5284
457.2	"	0.01	0.01	75%	0.46246	0.00031	0.4804

1. Includes heat transfer annulus region.
2. Includes a Δk of 0.004 due to radial movement of fuel assembly toward basket center.

6.5 Critical Benchmark Experiments

This section provides the validation of the CSAS25 criticality analysis sequence contained in Version 4.3 of the SCALE package. This validation is required by the criticality safety standards ANSI/ANS-8.1 The section describes the method, computer program and cross section libraries used, the experimental data, the areas of applicability and the bias and margins of safety.

ANSI/ANS-8.17 prescribes the criteria to establish sub-criticality safety margins. This criteria is as follows:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad (1)$$

where,

k_s = the calculated allowable maximum multiplication factor, k_{eff}, of the system being evaluated for all normal or credible abnormal conditions or events.

k_c = the mean k_{eff} that results from the calculation of the benchmark criticality experiments using a particular calculational method. If the calculated k_{eff} for the criticality experiments exhibit a trend with a parameter, then k_c shall be determined by extrapolation on the basis of a best fit to the calculated values. The criticality experiments used as benchmarks in computing k_c should have physical compositions, configurations, and nuclear characteristics (including reflectors) similar to those of the system being evaluated.

Δk_s = an allowance for

(a) statistical or convergence uncertainties, or both, in the computation of k_s,
(b) material and fabrication tolerances, and
(c) geometric or material representations used in the computational method.

Δk_c = a margin for uncertainty in k_c which includes allowance for

(a) uncertainties in the critical experiments,
(b) statistical or convergence uncertainties, or both, in the computation of k_c,
(c) uncertainties due to extrapolation of k_c outside the range of experimental data, and

(d) uncertainties due to limitations in the geometrical or material representations used in the computational method.

Δk_m = an arbitrary margin to ensure the subcriticality of k_s

The various uncertainties are combined statistically if they are independent. Correlated uncertainties are combined additively.

The above equation can be rewritten as:

$$k_s \leq 1 - \Delta k_m - \Delta k_s - (1-k_c) - \Delta k_c \qquad (2)$$

Noting that the NRC requires a 5% subcriticality margin ($\Delta k_m = 0.05$) and the definition of the bias ($\beta = 1-k_c$), the above equation can then be written as:

$$k_s \leq 0.95 - \Delta k_s - \beta - \Delta\beta \qquad (3)$$

where $\Delta\beta = \Delta k_c$. Thus, k_s (the maximum allowable value for k_{eff}) must be below 0.95 minus the bias, uncertainties in the bias and uncertainties in the system being analyzed (i.e. Monte Carlo, mechanical and modeling). This is an upper safety limit criterion often used in the DOE criticality safety community.

Alternatively, this equation can be rewritten applying the bias and uncertainties to the k_{eff} of the system being analyzed as:

$$k_s \equiv k_{eff} + \Delta k_s + \beta + \Delta\beta \leq 0.95 \qquad (4)$$

In equation 4, k_{eff} replaces k_s, and k_s has been redefined as the effective multiplication factor of the system being analyzed, including the method bias and all uncertainties. This is a maximum calculated k_{eff} criteria often used in LWR spent fuel storage and transport analyses.

Both β and $\Delta\beta$ are evaluated below for KENO-Va with the 27 group ENDF/B-IV library for use in criticality evaluations of LWR fuel in storage and transport casks.

6.5.1 Benchmark Experiments and Applicability

The criticality safety method is CSAS25 embedded in SCALE version 4.3 for the PC. CSAS25 includes: the SCALE Material Information Processor, BONAMI, NITAWL-II, and KENO-Va. The Material Information Processor generates number densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross section processing codes. The BONAMI and NITAWL-II codes are used to prepare a resonance-corrected cross section library in AMPX working format. The KENO-Va code calculates the model k_{eff} using Monte Carlo techniques. The 27 group ENDF/B-IV neutron cross section library is used in this validation.

6.5.1.1 Description of Experiments

Sixty three critical experiments were selected; nine Babcox and Wilcox (B&W) 2.46 wt % ^{235}U fuel storage (Baldwin), ten Pacific Northwest Laboratory (PNL) 4.31 wt % ^{235}U lattice (Bierman, 1980), twenty one PNL 2.35 and 4.31 wt % ^{235}U with metal reflectors (Bierman, 1979 & 1981), twelve PNL flux trap (Bierman 1980 & 1988) and eleven Valduc Critical Mass Laboratory (VCML) 4.74 wt % ^{235}U experiments, some involving moderator density variations (Manaranche). These experiments span a range of fuel enrichments, fuel rod pitches, neutron absorber sheet characteristics, shielding materials and geometries that are typical of LWR fuel in a cask.

The experiments are evaluated using three-dimensional models, as close to the actual experiment as possible, to achieve accurate results. Stochastic Monte Carlo error is kept within ±0.1 percent by executing at least 1000 neutrons/generation for more than 400 generations.

6.5.1.2 Applicability of Experiments

All of the experiments chosen in this validation are applicable to either PWR, including Yankee Class, or BWR fuel. Fuel enrichments have covered a range from 2.35 up to 4.74 wt % ^{235}U typical of LWR fuel presently used. The experiment fuel rod and pitch characteristics are within the range of standard PWR or BWR fuel rods (i.e. pellet diameters from 0.78 to 1.2 cm, rod outside diameters from 0.95 to 1.88 cm and pitches from 1.26 to 1.87 cm). This is particularly true of the VCML (PWR rod type) and B&W experiments (BWR rod type). The H/U volume ratios of the experimental fuel arrays are within the range of PWR fuel assemblies (1.6 to 2.32) and BWR fuel assemblies (1.6 to 1.9).

For Yankee Class fuel, the majority of the Zircalloy clad fuel is enriched below 4.0 wt % ^{235}U. For the stainless steel clad fuel, the enrichment is 4.94 wt % ^{235}U, which is just outside the benchmark experimental range. However, the stainless steel clad fuel is much less reactive than the Zircalloy clad and is not limiting. Also, in the case of the Yankee Class fuel, the pellet diameter varies from 0.747 to 0.789 cm, the rod outside diameter varies from 0.864 to 0.927 cm and the pitch varies from 1.07 to 1.20 cm, and the resultant H/U volume ratio varies from 1.28 to 1.57. These fuel parameters are all slightly outside of the range of experiments, but given the lack of statistically significant trends as demonstrated in Figures 6.5-2 through 6.5-7, confidence in criticality prediction by extrapolation to the Yankee fuel parameters is high.

Experiments covered the geometry and neutron absorber sheet arrangements typical of NAC basket designs. This included flux trap gap spacings of 3.81 cm such as in the NAC-STC basket, and gap spacing as low as 1.91 cm as in the NAC-MPC. The ^{10}B neutron absorber loadings are also typical of NAC basket designs (0.005 to 0.025). The experiments covered the influence of water and metal reflector regions, including steel and lead, which are present in storage and transport cask shielding.

Confidence in predicting criticality, including bias and uncertainty, has been demonstrated for LWR fuel with enrichments up to 4.74 wt % ^{235}U and, based on the lack of significant trend with enrichment, confidence in extrapolating up to 5 wt % ^{235}U is high. Confidence in predicting criticality has been demonstrated for storage and transport arrays using flux trap or single neutron absorber sheet or simple spacing criticality control. Confidence in predicting criticality has been demonstrated for LWR fuel storage and transport arrays next to water and metal reflector regions.

6.5.2 Results of Benchmark Calculations

The k-effective results for the experiments are shown in Table 6.5-1 and a frequency distribution plot is provided in Figure 6.5-1. Five sets of cases are presented: Set 1 - B&W, Set 2 - PNL lattice, Set 3 - PNL reflector, Set 4 - PNL flux trap and Set 5 - VCML critical experiments.

The overall average and standard deviation of the sixty three cases is 0.9948±0.0044. The average Monte Carlo error (statistical convergence) is ±0.0012 for the sixty three cases. This uncertainty component is statistically subtracted from the uncertainties, because it is previously included in the above standard deviation. The KENO-Va models are three dimensional, fully explicit representations (no homogenization) of the experimental geometry. Therefore, the uncertainty due

to limitations of geometrical modeling is taken to be 0.0. The experiments modeled cover the range of fuel types, enrichments, neutron absorber configurations, neutron absorber ^{10}B loading and metal reflector effects so there are no extrapolations necessary outside of the range of data, and the uncertainty due to this is also taken to be 0.0. Based on the reported experimental error for the B&W cases, the reported error of the critical size number of rods for the PNL cases and the reported error for the critical height in the VCML cases, the experimental error is conservatively taken to be ±0.001. Criticality can then be represented as 1.000±0.001. This uncertainty component is statistically added to the sum of the other uncertainties, because the bias is the difference between two random variates (i.e. criticality and code prediction, and the uncertainty in the difference between two random variates is the statistical sum (rms) of their individual uncertainties).

Thus, the bias or average difference between code calculated and critical is β=1-0.9948 = 0.0052. The uncertainty in the bias, accounting for the statistical convergence (Monte Carlo error) and the uncertainty in criticality is $(0.0044^2 - 0.0012^2 + 0.0010^2)^{1/2} = 0.0043$. For sixty three samples of criticality, the 95/95 one side tolerance factor is 2.012 (Owen). This results in a 95/95 one sided uncertainty in the bias of $\Delta\beta$=2.012x0.0043=0.0087. Equation 4 now becomes:

$$k_{eff} + \Delta k_s + 0.0052 + 0.0087 \leq 0.95 \qquad (5)$$

where Δk_s becomes the uncertainty in k_s due to Monte Carlo error, mechanical and material tolerances, and geometric or material representations. If the nominal representation of the system is evaluated for k_s, then the mechanical and material perturbation can be evaluated independently and can be combined statistically as the root sum of squares. If the worst case mechanical and material tolerances are used in the calculations of k_s (e. g. 75% of boron loading and most reactive positioning of fuel or basket components), then Δk_s becomes 0.0 and the Monte Carlo error, σ_{mc}, can be combined statistically, since it is independent, with the uncertainty in the bias as:

$$k_{eff} + 0.0052 + \sqrt{0.0087^2 + (2\sigma)^2} \leq 0.95 \qquad (6)$$

6.5.2.1 Trends

Scatter plots of k_{eff} versus wt % ^{235}U, rod pitch, H/U volume ratio, average neutron group causing fission, ^{10}B loading for flux trap cases, and flux trap gap thickness are shown in Figures 6.5-2 through 6.5-7. Included in these scatter plots are linear regression lines with a corresponding correlation coefficient. This statistically indicates any trend or lack thereof. In particular, the correlation coefficient is a measure of the linear relationship between k_{eff} and a critical experiment parameter. If r is +1, a perfect linear relationship with a positive slope is indicated, and if r is -1, a perfect linear relationship with a negative slope is indicated. When r is 0, no linear relationship is indicated. The largest correlation coefficient indicated in the plots is 0.1302 (k_{eff} versus enrichment) and the lowest is 0.0048 (k_{eff} versus ^{10}B loading in flux trap experiments). Based on the correlation coefficients, no statistically significant trends exist over the range of variables studied. Most importantly, no trend is shown with flux trap gap spacing and/or ^{10}B loading. This is the major criticality control feature of the NAC-STC and the NAC-MPC basket.

Figure 6.5-1 KENO-Va Validation - 27 Group Library Results Frequency Distribution of K_{eff} Values

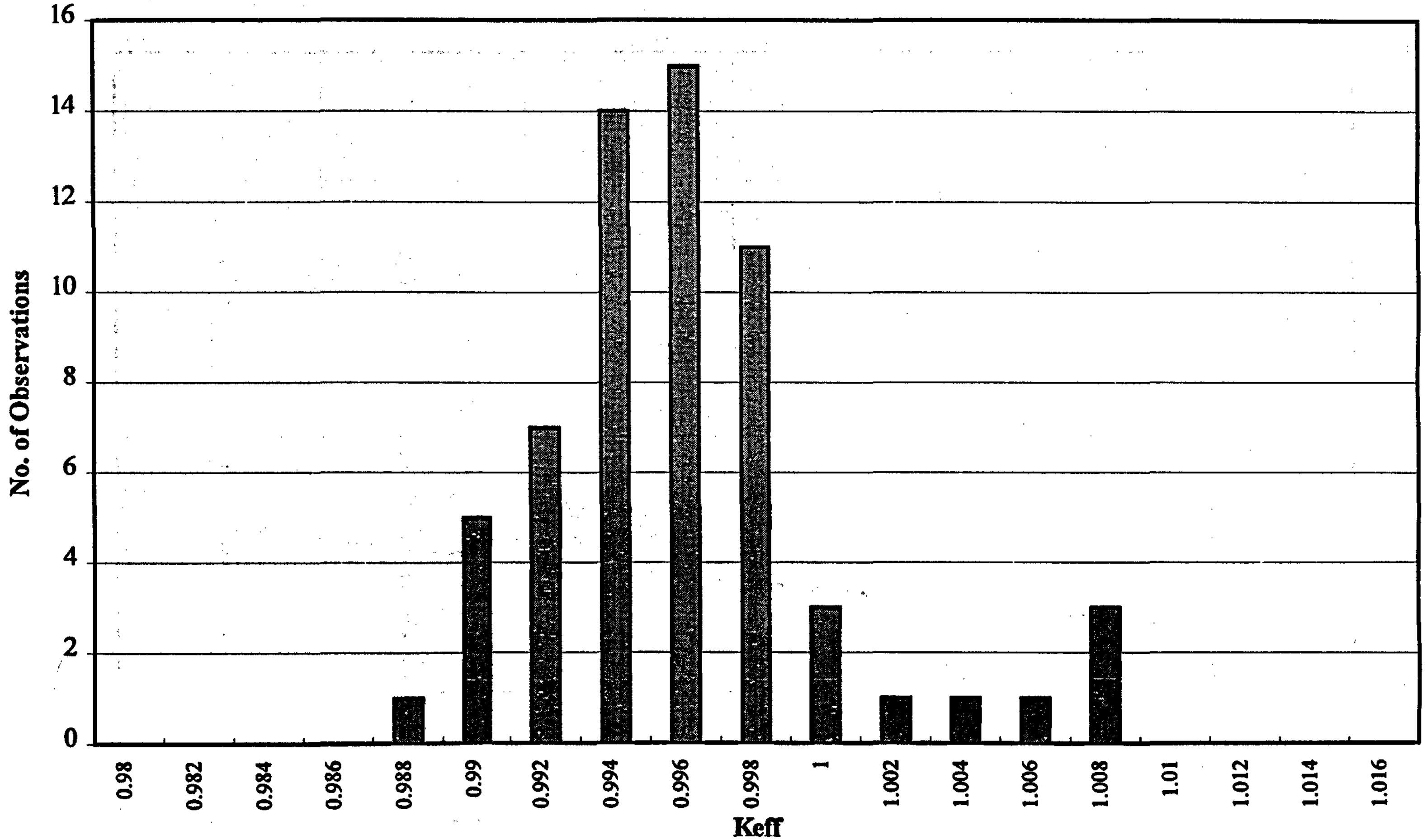


Figure 6.5-2 KENO-Va Validation -27 Group Library K_{eff} versus Enrichment

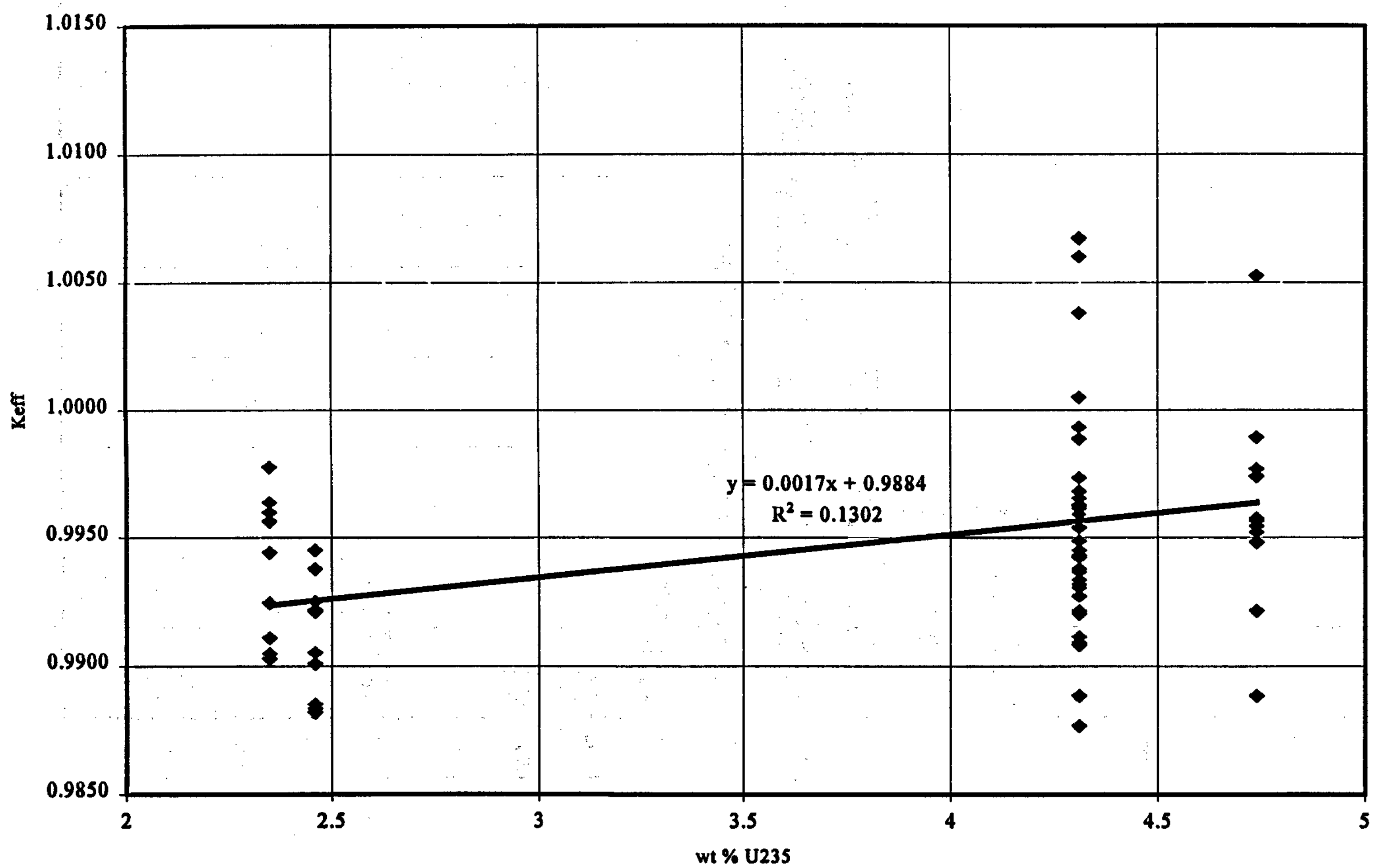


Figure 6.5-3 KENO-Va Validation - 27 Group Library K_{eff} versus Rod Pitch

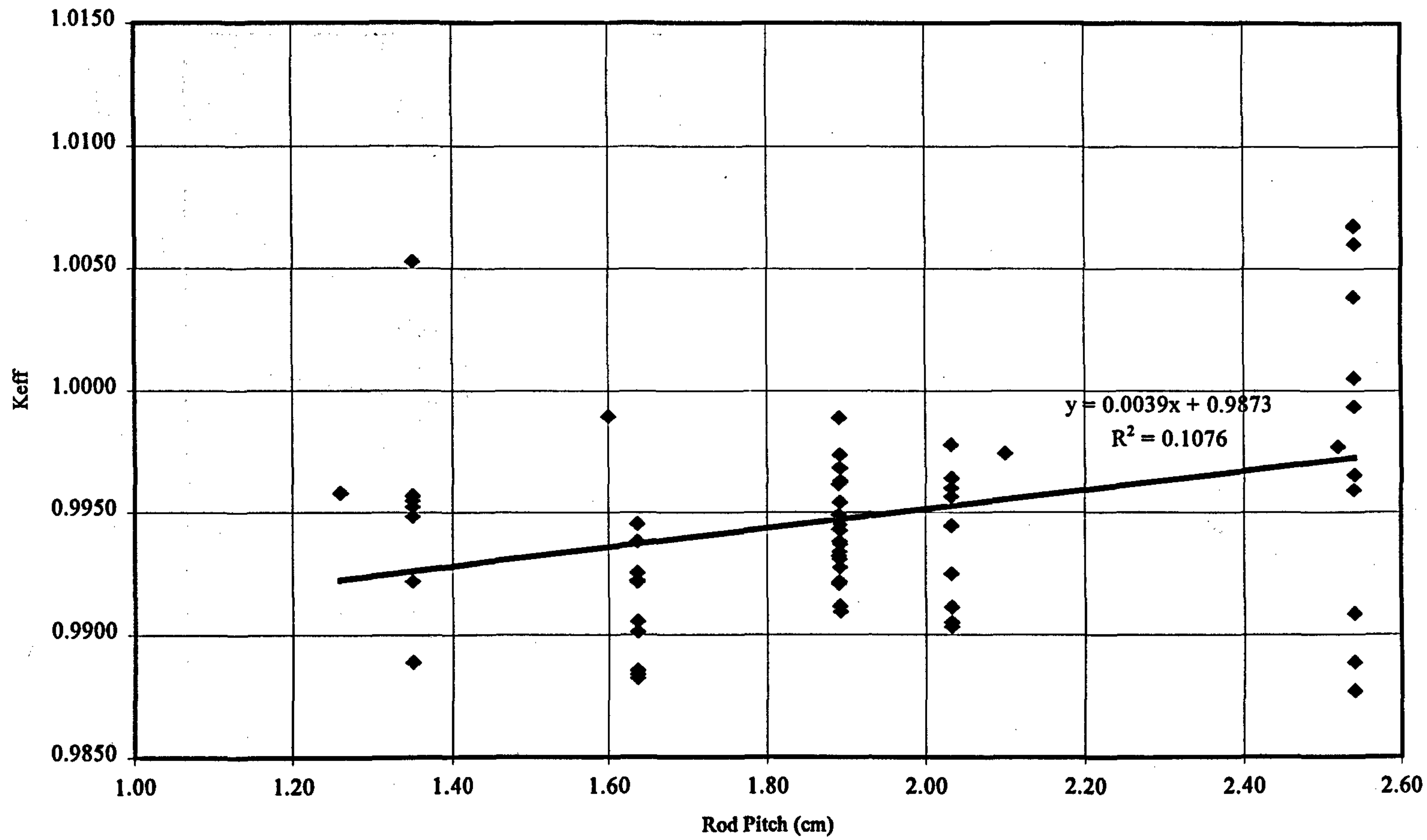


Figure 6.5-4 KENO-Va Validation -27 Group Library K_{eff} versus H/U Volume Ratio

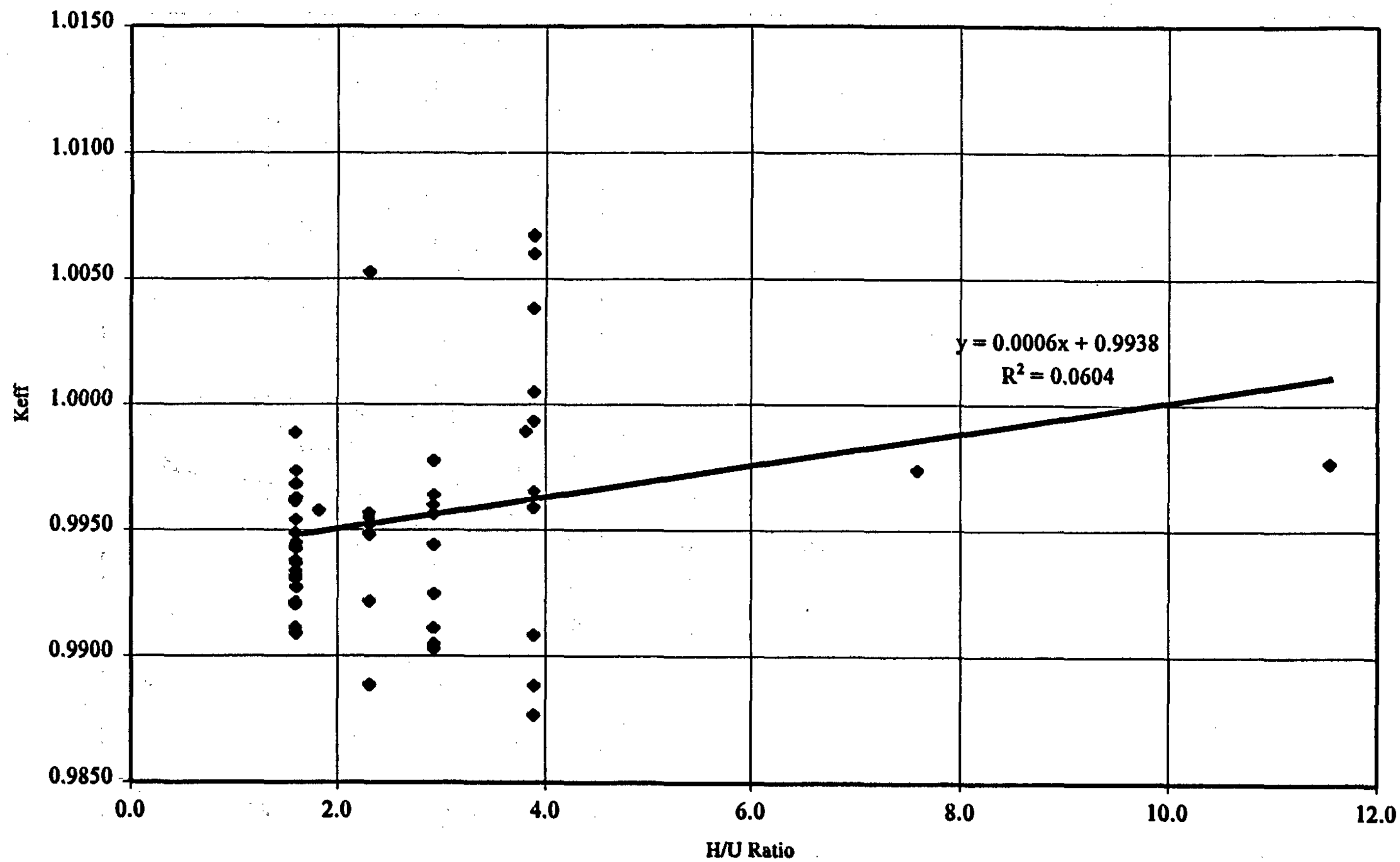


Figure 6.5-5 KENO-Va Validation -27 Group Library K_{eff} versus Average Group of Fission

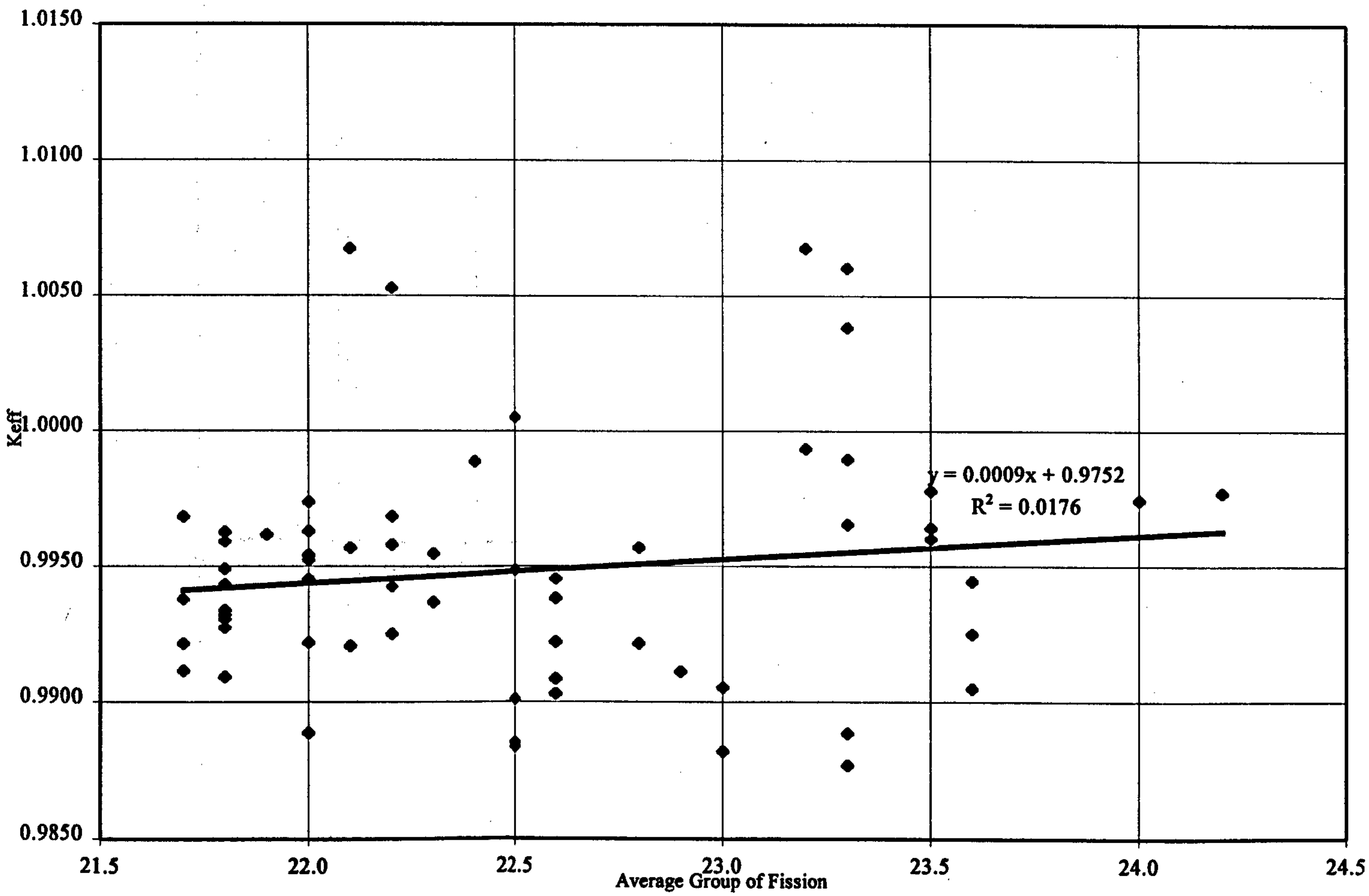


Figure 6.5-6 KENO-Va Validation - 27 Group Library K_{eff} versus ^{10}B Loading For Flux Trap Criticals

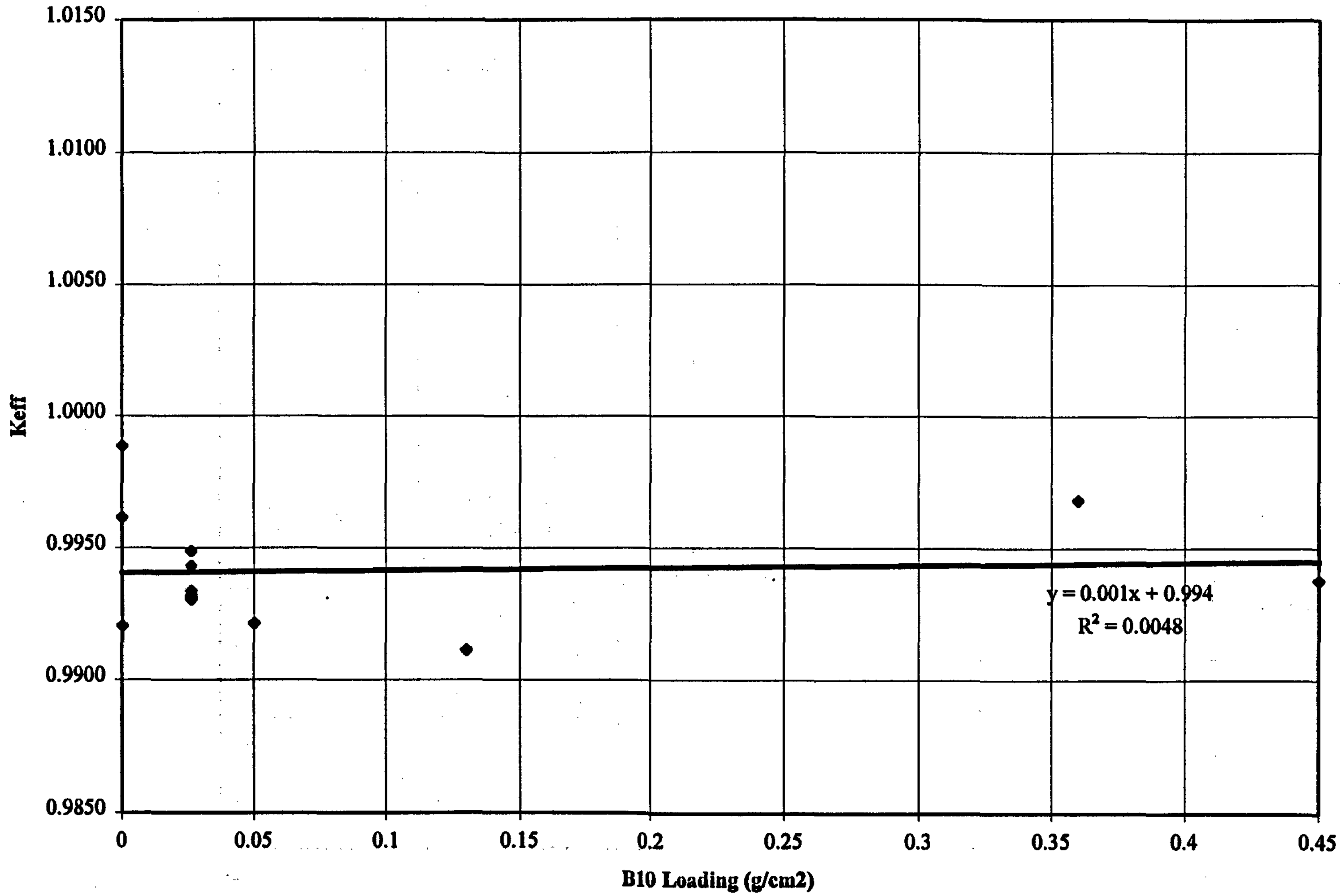


Figure 6.5-7 KENO-Va Validation -27 Group Library Results K_{eff} versus Flux Trap Critical Gap Thickness

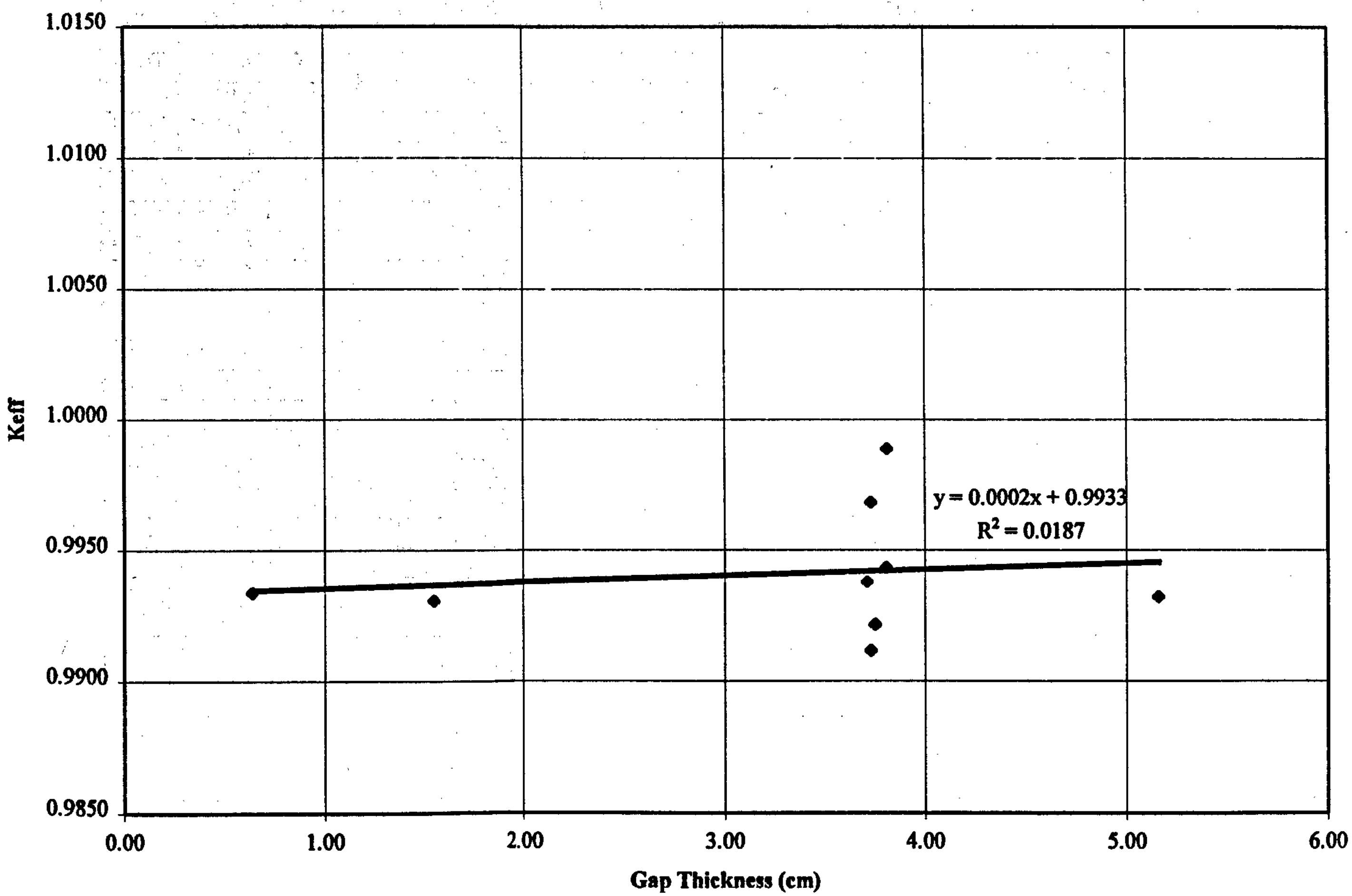


Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g $^{10}B/cm2$	Gap(cm)	Gap Den.	Ave. Gfis	K_{eff}	σ
Set 1														
B&W-I	Cylindrical	2.46	1.636	1.206	1.03	1.6	0	na	na	0		22.8	0.9921	0.0011
B&W-II	3X3-14X14	2.46	1.636	1.206	1.03	1.6	1037	na	na	0		22.2	0.9925	0.0009
B&W-III	3X3-14X14	2.46	1.636	1.206	1.03	1.6	764	na	na	1.636		22.6	0.9938	0.0009
B&W-IX	3X3-14X14	2.46	1.636	1.206	1.03	1.6	0	na	na	6.543		23	0.9905	0.0010
B&W-X	3X3-14X14	2.46	1.636	1.206	1.03	1.6	143	na	na	4.907		23	0.9882	0.0010
B&W-XI	3X3-14X14	2.46	1.636	1.206	1.03	1.6	514	Steel	0	1.636		22.6	0.9945	0.0010
B&W-XIII	3X3-14X14	2.46	1.636	1.206	1.03	1.6	15	B-Al	0.0052	1.636		22.6	0.9922	0.0010
B&W-XIV	3X3-14X14	2.46	1.636	1.206	1.03	1.6	92	B-Al	0.0040	1.636		22.5	0.9885	0.0010
B&W-XVII	3X3-14X14	2.46	1.636	1.206	1.03	1.6	487	B-Al	0.0008	1.636		22.5	0.9884	0.0010
B&W-XIX	3X3-14X14	2.46	1.636	1.206	1.03	1.6	634	B-Al	0.0003	1.636		22.5	0.9901	0.0009
												Average	0.9911	0.0023
Set 2														
PNL-043	17X13 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9954	0.0014
PNL-044	16X14 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9945	0.0013
PNL-045	14X16 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9974	0.0013
PNL-046	12x19 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9963	0.0013
PNL-087	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.066	2.83		21.8	0.9927	0.0012
PNL-079	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.030	2.83		21.8	0.9909	0.0012
PNL-093	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.026	2.83		21.8	0.9962	0.0012
PNL-115	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Aluminum	0	2.83		22.3	0.9937	0.0013
PNL-064	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.302)	0	2.83		22.2	0.9942	0.0012
PNL-071	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.485)	0	2.83		22.2	0.9968	0.0012
												Average	0.9948	0.0020

Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics (continued)

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g $^{10}B/cm2$	Gap(cm)	Gap Den.	Ave. Gfis	K_{eff}	σ
Set 3										Cluster	Wall/Cluster			
PNL-STA	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	10.65	0.00	23.5	0.9964	0.0010
PNL-STB	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.20	1.32	23.6	0.9944	0.0010
PNL-STC	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	10.36	2.62	23.6	0.9905	0.0010
PNL-PBA	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.84	0.00	23.5	0.9960	0.0011
PNL-PBB	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.72	0.66	23.5	0.9978	0.0010
PNL_PBC	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.25	2.62	23.6	0.9925	0.0010
PNL-DUA	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.83	0.00	22.6	0.9903	0.0009
PNL-DUB	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	14.11	1.96	22.8	0.9957	0.0010
PNL-DUC	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.70	2.62	22.9	0.9911	0.0010
PNL-H20	3X1 H2O Refl	4.31	2.54	1.415	1.265	3.9	0	na	na	8.24	inf	23.3	0.9877	0.0023
PNL-ST0	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	12.89	0	23.2	0.9993	0.0012
PNL-ST1	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	14.12	1.32	23.3	1.0060	0.0022
PNL-ST26	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	12.44	2.62	23.3	0.9965	0.0011
PNL-PB0	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	20.62	0	23.2	1.0068	0.0021
PNL-PB13	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	19.04	1.32	23.3	1.0038	0.0012
PNL-PB5	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	10.3	5.41	23.3	0.9889	0.0011
PNL-DU0	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	15.38	0	21.8	0.9959	0.0011
PNL-DU13	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	19.04	1.32	22.1	1.0067	0.0010
PNL-DU39	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	18.05	3.91	22.5	1.0005	0.0011
PNL-DU54	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	13.49	5.41	22.6	0.9908	0.0011
												Average	0.9964	0.0060

Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics (continued)

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g $^{10}B/cm2$	Gap(cm)	Gap Den.	Ave. Gfis	K_{eff}	σ
Set 4														
PNL-229	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Aluminum	0	3.81	0.9982	22.4	0.9989	0.0012
PNL-230	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.05	3.75	0.9982	21.7	0.9921	0.0012
PNL-228	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.13	3.73	0.9982	21.7	0.9911	0.0012
PNL-214	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.36	3.73	0.9982	21.7	0.9968	0.0013
PNL-231	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.45	3.71	0.9982	21.7	0.9938	0.0012
PNL-127	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	0.64	0.9982	21.8	0.9934	0.0010
PNL-126	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	1.54	0.9982	21.8	0.9931	0.0010
PNL-123	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	3.80	0.9982	21.8	0.9943	0.0010
PNL-125	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	5.16	0.9982	21.8	0.9932	0.0010
PNL-124	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	INF	0.9982	21.8	0.9949	0.0010
PNL-123-S	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Steel	0	3.80	0.9982	22.1	0.9920	0.0010
PNL-124-S	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Steel	0	INF	0.9982	21.9	0.9962	0.0010
												Average	0.9941	0.0022
Set 5														
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0	22.0	0.9922	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.0323	22.0	0.9889	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.2879	22.1	0.9957	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.5540	22.2	1.0053	0.0011
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	2.50	0.9982	22.3	0.9955	0.0012
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	5.00	0.9982	22.5	0.9948	0.0013
VCML	Square Lattice	4.74	1.26	0.94	0.79	1.8	0	na	na	na	na	22.2	0.9958	0.0012
VCML	Square Lattice	4.74	1.35	0.94	0.79	2.3	0	na	na	na	na	22.0	0.9952	0.0012
VCML	Square Lattice	4.74	1.60	0.94	0.79	3.8	0	na	na	na	na	23.3	0.9989	0.0013
VCML	Square Lattice	4.74	2.10	0.94	0.79	7.6	0	na	na	na	na	24.0	0.9974	0.0012
VCML	Square Lattice	4.74	2.52	0.94	0.79	11.5	0	na	na	na	na	24.2	0.9977	0.0011
												Average	0.9961	0.0041

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6.7 Supplemental Data

This section contains the CSAS25 input/output for the criticality analysis of the NAC-MPC transfer and storage casks under normal and accident conditions. These summaries include: the input file echo, the CSAS25 and the KENO-Va output sections. BONAMI and NITAWL-II output sections are not included for brevity.

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions

```
      PRIMARY MODULE ACCESS AND INPUT RECORD ( SCALE DRIVER - 95/03/29 - 09:06:37 )
   MODULE CSAS25    WILL BE CALLED
    TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M
    '
    '      File tfn-1000.in
    '
    '      THIS IS A MODEL OF THE YNPS NAC-MPC BASKET IN THE TRANSFER CASK
    '              LOADED WITH 36 UNITED NUCLEAR TYPE A ASSEMBLIES
    '
    '           PRODUCED FOR THE YANKEE ROWE
    '              STC LICENSE AMENDMENT
    '
    '      INTERIOR MODERATOR (MATERIAL  3) VOLUME FRACTION = 1.000
    '      EXTERIOR MODERATOR (MATERIAL 10) VOLUME FRACTION = 0.0001
    '
    27GROUPNDF4 LATTICECELL
    UO2          1              0.95    293.0 92235 4.0 92238 96.0 END
    ZIRCALLOY    2              1.0     293.0                      END
    H2O          3              1.0     293.0                      END
    AL           4              1.0     293.0                      END
    SS304        5              1.0     293.0                      END
    B-10         6  DEN=2.6226 0.0450  293.0                      END
    B-11         6  DEN=2.6226 0.2736  293.0                      END
    C            6  DEN=2.6226 0.0927  293.0                      END
    AL           6  DEN=2.6226 0.5737  293.0                      END
    PB           7              1.0     293.0                      END
    H            8  DEN=1.6291 0.060   293.0                      END
    O            8  DEN=1.6291 0.425   293.0                      END
    C            8  DEN=1.6291 0.277   293.0                      END
    N            8  DEN=1.6291 0.020   293.0                      END
    AL           8  DEN=1.6291 0.214   293.0                      END
    B-10         8  DEN=1.6291 0.001   293.0                      END
    B-11         8  DEN=1.6291 0.004   293.0                      END
    CARBONSTEEL 9               1.0     293.0                      END
    H2O         10              0.0001  293.0                      END
    END COMP
    SQUAREPITCH  1.1887 0.7887 1 3 0.9271 2 0.8052 0 END
    TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M
    READ PARAM RUN=yes PLT=NO  GEN=1003 NPG=1000 TME=500 END PARAM
    READ GEOM
    '
    '  WATER LEVEL UNIT CELLS
    '
    UNIT  1
    COM='FUEL PIN CELL - BETWEEN DISKS'
    CYLINDER  1 1  0.3943     2P2.1400
    CYLINDER  0 1  0.4026     2P2.1400
    CYLINDER  2 1  0.4635     2P2.1400
    CUBOID    3 1  4P0.5944  2P2.1400
    UNIT  2
    COM='WATER CELL - BETWEEN DISKS'
    CUBOID    3 1  4P0.5944  2P2.1400
    UNIT  3
    COM='DISPLACEMENT CELL - BETWEEN DISKS'
    CYLINDER  2 1  0.4635     2P2.1400
    CUBOID    3 1  4P0.5944  2P2.1400
    UNIT  4
    COM='INSTRUMENT TUBE CELL - BETWEEN DISKS'
    CYLINDER  3 1  0.4998     2P2.1400
    CYLINDER  5 1  0.5442     2P2.1400
    CUBOID    3 1  4P0.5944  2P2.1400
    '
    '  DISK LEVEL UNIT CELLS (BOTH SS AND AL)
    '
    UNIT  5
    COM='FUEL PIN CELL - WITH SS DISK'
    CYLINDER  1 1  0.3943    2P0.6604
    CYLINDER  0 1  0.4026    2P0.6604
    CYLINDER  2 1  0.4635    2P0.6604
    CUBOID    3 1  4P0.5944 2P0.6604
    UNIT  6
    COM='WATER CELL - WITH SS DISK'
    CUBOID    3 1  4P0.5944 2P0.6604
    UNIT  7
    COM='DISPLACEMENT CELL - WITH SS DISK'
    CYLINDER  2 1  0.4635    2P0.6604
    CUBOID    3 1  4P0.5944 2P0.6604
    UNIT  8
    COM='INSTRUMENT TUBE CELL - WITH SS DISK'
    CYLINDER  3 1  0.4998    2P0.6604
    CYLINDER  5 1  0.5442    2P0.6604
    CUBOID    3 1  4P0.5944 2P0.6604
    '
    '  WATER LEVEL BORAL SHEETS
    '
    UNIT 14
    COM='X-X BORAL SHEET BETWEEN DISKS'
    CUBOID 6 1 2P9.144 2P0.0318 2P2.1400
    CUBOID 4 1 2P9.144 2P0.0953 2P2.1400
    UNIT 15
    COM='Y-Y BORAL SHEET BETWEEN DISKS'
    CUBOID 6 1 2P0.0318 2P9.144 2P2.1400
    CUBOID 4 1 2P0.0953 2P9.144 2P2.1400
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
'
'  DISK LEVEL BORAL SHEETS (AL AND SS)
'
UNIT 16
COM='X-X BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P9.144 2P0.0318 2P0.6604
CUBOID 4 1 2P9.144 2P0.0953 2P0.6604
UNIT 17
COM='Y-Y BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P0.0318 2P9.144 2P0.6604
CUBOID 4 1 2P0.0953 2P9.144 2P0.6604
'
' WATER LEVEL WEB MATERIAL
'
UNIT 20
COM='WATER LEVEL WEB MATERIAL (SMALL) X-X'
CUBOID    3 1 2P10.4635 2P0.9716 2P2.1400
UNIT 21
COM='WATER LEVEL WEB MATERIAL (MEDIUM) X-X'
CUBOID    3 1 2P10.4635 2P1.0478 2P2.1400
UNIT 22
COM='WATER LEVEL WEB MATERIAL (LARGE) X-X'
CUBOID    3 1 2P10.4635 2P1.1208 2P2.1400
UNIT 23
COM='WATER LEVEL WEB MATERIAL (LONG) Y-Y'
CUBOID    3 1 2P1.1208 2P79.5249 2P2.1400
'
'  SUPPORT DISK WEB MATERIAL
'
UNIT 30
COM='SUPPORT DISK WEB MATERIAL (SMALL) X-X'
CUBOID    5 1 2P10.4635 2P0.9716 2P0.6604
UNIT 31
COM='SUPPORT DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    5 1 2P10.4635 2P1.0478 2P0.6604
UNIT 32
COM='SUPPORT DISK WEB MATERIAL (LARGE) X-X'
CUBOID    5 1 2P10.4635 2P1.1208 2P0.6604
UNIT 33
COM='SUPPORT DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    5 1 2P1.1208 2P79.5249 2P0.6604
'
'  HEAT TRANSFER DISK WEB MATERIAL
'
UNIT 40
COM='HEAT TRANSFER DISK WEB MATERIAL (SMALL) X-X'
CUBOID    4 1 2P10.4635 2P0.9716 2P0.6604
UNIT 41
COM='HEAT TRANSFER DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    4 1 2P10.4635 2P1.0478 2P0.6604
UNIT 42
COM='HEAT TRANSFER DISK WEB MATERIAL (LARGE) X-X'
CUBOID    4 1 2P10.4635 2P1.1208 2P0.6604
UNIT 43
COM='HEAT TRANSFER DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    4 1 2P1.1208 2P79.5249 2P0.6604
'
'  WATER LEVEL ASSEMBLY ARRAYS
'
UNIT 50
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL'
ARRAY  1  -9.5104 -9.5104 -2.1400
CUBOID 3 1 4P9.9441                              2P2.1400
CUBOID 5 1 4P10.0661                             2P2.1400
CUBOID 3 1 4P10.25681                            2P2.1400
HOLE  14   0.0       10.1615  0.0
HOLE  14   0.0      -10.1615  0.0
HOLE  15   10.1615  0.0       0.0
HOLE  15   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                             2P2.1400
UNIT 51
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.0      -0.1584       0.0
UNIT 52
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.0       0.1584       0.0
UNIT 53
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   -0.1584   0.0           0.0
UNIT 54
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.1584    0.0          0.0
UNIT 55
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.1584    0.1584       0.0
UNIT 56
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   -0.1584   0.1584       0.0
UNIT 57
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X -Y'
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
CUBOID 3 1 4P10.4635                        2P2.1400
HOLE  50   0.1584   -0.1584       0.0
UNIT 58
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X -Y'
CUBOID 3 1 4P10.4635                        2P2.1400
HOLE  50   -0.1584   -0.1584       0.0
UNIT 59
COM='WATER LEVEL CENTRAL HOLE'
CUBOID 3 1 4P10.4636                        2P2.1400
'
'   SUPPORT DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 60
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                         2P0.6604
CUBOID 5 1 4P10.0661                        2P0.6604
CUBOID 3 1 4P10.25681                       2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0       -10.1615 0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                        2P0.6604
UNIT 61
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   0.0       -0.1584       0.0
UNIT 62
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   0.0       0.1584        0.0
UNIT 63
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   -0.1584   0.0           0.0
UNIT 64
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   0.1584   0.0            0.0
UNIT 65
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   0.1584   0.1584         0.0
UNIT 66
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X +Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   -0.1584   0.1584        0.0
UNIT 67
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   0.1584   -0.1584        0.0
UNIT 68
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  60   -0.1584   -0.1584        0.0
UNIT 69
COM='SUPPORT DISK CENTRAL HOLE'
CUBOID 3 1 4P10.4636   2P0.6604
'
'   HEAT TRANSFER DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 70
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                         2P0.6604
CUBOID 5 1 4P10.0661                        2P0.6604
CUBOID 3 1 4P10.25681                       2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0       -10.1615 0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                        2P0.6604
UNIT 71
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   0.0       -0.1584       0.0
UNIT 72
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   0.0       0.1584        0.0
UNIT 73
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   -0.1584   0.0           0.0
UNIT 74
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   0.1584   0.0            0.0
UNIT 75
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   0.1584   0.1584         0.0
UNIT 76
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                        2P0.6604
HOLE  70   -0.1584   0.1584        0.0
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
UNIT 77
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                          2P0.6604
HOLE  70   0.1584   -0.1584        0.0
UNIT 78
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                          2P0.6604
HOLE  70   -0.1584   -0.1584       0.0
UNIT 79
COM='HEAT TRANSFER CENTRAL HOLE'
CUBOID 3 1 4P10.4636                          2P0.6604
'
'  WATER LEVEL BASKET ARRAYS
'
UNIT 80
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 20 -10.4636 -33.6323 -2.1400
UNIT 81
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 21 -10.4636 -33.6323 -2.1400
UNIT 82
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 22 -10.4636 -56.6549 -2.1400
UNIT 83
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 23 -10.4636 -56.6549 -2.1400
UNIT 84
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 24 -10.4636 -79.5251 -2.1400
UNIT 85
COM='13X1 WATER LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 25 -10.4636 -79.5251 -2.1400
UNIT 86
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 26 -10.4636 -79.5251 -2.1400
'
'  SUPPORT DISK LEVEL BASKET ARRAYS
'
UNIT 90
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 30 -10.4636 -33.6323 -0.6604
UNIT 91
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 31 -10.4636 -33.6323 -0.6604
UNIT 92
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 32 -10.4636 -56.6549 -0.6604
UNIT 93
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 33 -10.4636 -56.6549 -0.6604
UNIT 94
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 34 -10.4636 -79.5251 -0.6604
UNIT 95
COM='13X1 SUPPORT DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 35 -10.4636 -79.5251 -0.6604
UNIT 96
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 36 -10.4636 -79.5251 -0.6604
'
'  HEAT TRANSFER DISK LEVEL BASKET ARRAYS
'
UNIT 100
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 40 -10.4636 -33.6323 -0.6604
UNIT 101
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 41 -10.4636 -33.6323 -0.6604
UNIT 102
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 42 -10.4636 -56.6549 -0.6604
UNIT 103
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 43 -10.4636 -56.6549 -0.6604
UNIT 104
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 44 -10.4636 -79.5251 -0.6604
UNIT 105
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 45 -10.4636 -79.5251 -0.6604
UNIT 106
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 46 -10.4636 -79.5251 -0.6604
'
'  BASKET ARRAY IN TRANSFER CASK OVERPACK (LEVEL CONSTRUCTION)
'
UNIT 110
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - WATER LEVEL'
ARRAY 50 -33.6323 -79.5251 -2.1400
CYLINDER 3 1 88.1253      2P2.1400
HOLE 80      -69.0614 0.0 0.0
HOLE 82      -46.1912 0.0 0.0
HOLE 81       69.0614 0.0 0.0
HOLE 83       46.1912 0.0 0.0
CYLINDER  5 1  89.7128     2P2.1400
CYLINDER  0 1  90.805      2P2.1400
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
CYLINDER  9 1  92.71       2P2.1400
CYLINDER  7 1 101.6        2P2.1400
CYLINDER  8 1 106.68       2P2.1400
CYLINDER  9 1 109.855      2P2.1400
CUBOID   10 1 4P159.855    2P2.1400
UNIT 111
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - SUPPORT DISK LEVEL'
ARRAY 51 -33.6323 -79.5251 -0.6604
CYLINDER 5 1 87.6046     2P0.6604
HOLE 90      -69.0614 0.0 0.0
HOLE 92      -46.1912 0.0 0.0
HOLE 91       69.0614 0.0 0.0
HOLE 93       46.1912 0.0 0.0
CYLINDER  3 1  88.1253     2P0.6604
CYLINDER  5 1  89.7128     2P0.6604
CYLINDER  0 1  90.805      2P0.6604
CYLINDER  9 1  92.71       2P0.6604
CYLINDER  7 1 101.6        2P0.6604
CYLINDER  8 1 106.68       2P0.6604
CYLINDER  9 1 109.855      2P0.6604
CUBOID   10 1 4P159.855    2P0.6604
UNIT 112
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - HEAT TRANSFER DISK LEVEL'
ARRAY 52 -33.6323 -79.5251 -0.6604
CYLINDER 4 1 87.249      2P0.6604
HOLE 100     -69.0614 0.0 0.0
HOLE 102     -46.1912 0.0 0.0
HOLE 101      69.0614 0.0 0.0
HOLE 103      46.1912 0.0 0.0
CYLINDER  3 1  88.1253     2P0.6604
CYLINDER  5 1  89.7128     2P0.6604
CYLINDER  0 1  90.805      2P0.6604
CYLINDER  9 1  92.71       2P0.6604
CYLINDER  7 1 101.6        2P0.6604
CYLINDER  8 1 106.68       2P0.6604
CYLINDER  9 1 109.855      2P0.6604
CUBOID   10 1 4P159.855    2P0.6604
'
'  GLOBAL UNIT
'
GLOBAL UNIT 120
ARRAY 60 -159.855 -159.855 0.0
END GEOM
READ ARRAY
ARA=1 NUX=16 NUY=16 NUZ=1  FILL
1 1 1 1 1 1 1 3 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 4 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
END FILL
ARA=2 NUX=16 NUY=16 NUZ=1  FILL
5 5 5 5 5 5 5 7 6 6 6 6 6 6 6 6
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
7 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 8 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
END FILL
'
'  WATER LEVEL ARRAYS
'
ARA=20  NUX=1 NUY=5 NUZ=1
FILL
55
22
54
22
57
END FILL
ARA=21  NUX=1 NUY=5 NUZ=1
FILL
56
22
53
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
22
58
END FILL
ARA=22  NUX=1 NUY=9 NUZ=1
FILL
55
21
55
22
54
22
57
21
57
END FILL
ARA=23  NUX=1 NUY=9 NUZ=1
FILL
56
21
56
22
53
22
58
21
58
END FILL
ARA=24  NUX=1 NUY=13 NUZ=1
FILL
55
20
55
21
55
22
54
22
57
21
57
20
57
END FILL
ARA=25  NUX=1 NUY=13 NUZ=1
FILL
52
20
52
21
52
22
59
22
51
21
51
20
51
END FILL
ARA=26  NUX=1 NUY=13 NUZ=1
FILL
56
20
56
21
56
22
53
22
58
21
58
20
58
END FILL
'
'  SUPPOR DISK LEVEL ARRAYS
'
ARA=30  NUX=1 NUY=5 NUZ=1
FILL
65
32
64
32
67
END FILL
ARA=31  NUX=1 NUY=5 NUZ=1
FILL
66
32
63
32
68
END FILL
ARA=32  NUX=1 NUY=9 NUZ=1
FILL
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
65
31
65
32
64
32
67
31
67
END FILL
ARA=33  NUX=1 NUY=9 NUZ=1
FILL
66
31
66
32
63
32
68
31
68
END FILL
ARA=34  NUX=1 NUY=13 NUZ=1
FILL
65
30
65
31
65
32
64
32
67
31
67
30
67
END FILL
ARA=35  NUX=1 NUY=13 NUZ=1
FILL
62
30
62
31
62
32
69
32
61
31
61
30
61
END FILL
ARA=36  NUX=1 NUY=13 NUZ=1
FILL
66
30
66
31
66
32
63
32
68
31
68
30
68
END FILL
'
'  HEAT TRANSFER DISK LEVEL ARRAYS
'
ARA=40  NUX=1 NUY=5 NUZ=1
FILL
75
42
74
42
77
END FILL
ARA=41  NUX=1 NUY=5 NUZ=1
FILL
76
42
73
42
78
END FILL
ARA=42  NUX=1 NUY=9 NUZ=1
FILL
75
41
75
42
74
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
42
77
41
77
END FILL
ARA=43  NUX=1 NUY=9 NUZ=1
FILL
76
41
76
42
73
42
78
41
78
END FILL
ARA=44  NUX=1 NUY=13 NUZ=1
FILL
75
40
75
41
75
42
74
42
77
41
77
40
77
END FILL
ARA=45  NUX=1 NUY=13 NUZ=1
FILL
72
40
72
41
72
42
79
42
71
41
71
40
71
END FILL
ARA=46  NUX=1 NUY=13 NUZ=1
FILL
76
40
76
41
76
42
73
42
78
41
78
40
78
END FILL
'
'  MAJOR ARRAYS
'
ARA=50 NUX=5 NUY=1 NUZ=1
FILL
84 23 85 23 86
END FILL
ARA=51 NUX=5 NUY=1 NUZ=1
FILL
94 33 95 33 96
END FILL
ARA=52 NUX=5 NUY=1 NUZ=1
FILL
104 43 105 43 106
END FILL
'
'  GLOBAL ARRAY
'
ARA=60 NUX=1 NUY=1 NUZ=4
FILL
112
110
111
110
END FILL
END ARRAY

READ BOUNDS ZFC=PER YXF=REFLECT END BOUNDS

END DATA
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
 CCCCCCCCCCC     SSSSSSSSSSS      AAAAAAAAA      SSSSSSSSSSS     22222222222    5555555555555
CCCCCCCCCCCCC   SSSSSSSSSSSSS    AAAAAAAAAAA    SSSSSSSSSSSSS   2222222222222   5555555555555
CC         CC   SS         SS   AA         AA   SS         SS   22         22   55
CC              SS              AA         AA   SS                         22   55
CC              SS              AA         AA   SS                         22   55
CC              SSSSSSSSSSSS    AAAAAAAAAAAAA   SSSSSSSSSSSS              22    555555555555
CC               SSSSSSSSSSSS   AAAAAAAAAAAAA    SSSSSSSSSSSS           22      5555555555555
CC                         SS   AA         AA              SS         22                   55
CC                         SS   AA         AA              SS       22                     55
CC         CC   SS         SS   AA         AA   SS         SS     22            55         55
CCCCCCCCCCCCC   SSSSSSSSSSSSS   AA         AA   SSSSSSSSSSSSS   2222222222222   5555555555555
 CCCCCCCCCCC     SSSSSSSSSSS    AA         AA    SSSSSSSSSSS    2222222222222    55555555555

 SSSSSSSSSSS     CCCCCCCCCCC      AAAAAAAAA     LL              EEEEEEEEEEEEE                   PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS   CCCCCCCCCCCCC    AAAAAAAAAAA    LL              EEEEEEEEEEEEE                   PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS   CC         CC   AA         AA   LL              EE                              PP         PP   CC         CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SSSSSSSSSSSS    CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPP    CC
           SS   CC              AA         AA   LL              EE                              PP              CC
           SS   CC              AA         AA   LL              EE                              PP              CC
SS         SS   CC         CC   AA         AA   LL              EE                              PP              CC         CC
SSSSSSSSSSSSS   CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLL    EEEEEEEEEEEEE                   PP              CCCCCCCCCCCCC
 SSSSSSSSSSS     CCCCCCCCCCC    AA         AA   LLLLLLLLLLLL    EEEEEEEEEEEEE                   PP               CCCCCCCCCCC

    11              11                     //       11          7777777777777              //    99999999999     666666666666
   111             111                    //       111          777777777777              //    9999999999999   6666666666666
  1111            1111                   //       1111          77         77            //     99         99   66
    11              11                  //          11                    77            //      99         99   66
    11              11                 //           11                   77            //       99         99   66
    11              11                //            11                  77            //        9999999999999   666666666666
    11              11               //             11                  77           //          999999999999   6666666666666
    11              11              //              11                 77           //                     99   66         66
    11              11             //               11                 77          //                      99   66         66
    11              11            //                11                77          //                       99   66         66
11111111        11111111         //             11111111              77         //             9999999999999   6666666666666
11111111        11111111        //              11111111              77        //              999999999999     66666666666

    11           666666666666                    33333333333    5555555555555                       11           33333333333
   111          6666666666666                   3333333333333   5555555555555                      111          3333333333333
  1111          66                   :::        33         33   55                   :::          1111          33         33
    11          66                   :::                   33   55                   :::            11                     33
    11          66                   :::                   33   55                   :::            11                     33
    11          666666666666                             333    555555555555                        11                   333
    11          6666666666666                            333    5555555555555                       11                   333
    11          66         66        :::                   33              55        :::            11                     33
    11          66         66        :::                   33              55        :::            11                     33
    11          66         66        :::        33         33   55         55        :::            11          33         33
11111111        6666666666666                   3333333333333   5555555555555                   11111111        3333333333333
11111111         66666666666                     33333333333     55555555555                    11111111         33333333333
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
 SSSSSSSSSSS     CCCCCCCCCCC      AAAAAAAAA    LL           EEEEEEEEEEEEE                 PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS   CCCCCCCCCCCCC    AAAAAAAAAAA   LL           EEEEEEEEEEEEE                 PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS   CC         CC   AA         AA  LL           EE                            PP         PP   CC         CC
SS              CC              AA         AA  LL           EE                            PP         PP   CC
SS              CC              AA         AA  LL           EE                            PP         PP   CC
SSSSSSSSSSSS    CC              AAAAAAAAAAAAA  LL           EEEEEEEEE     -------------   PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA  LL           EEEEEEEEE     -------------   PPPPPPPPPPPP    CC
           SS   CC              AA         AA  LL           EE                            PP              CC
           SS   CC              AA         AA  LL           EE                            PP              CC
SS         SS   CC         CC   AA         AA  LL           EE                            PP              CC         CC
SSSSSSSSSSSSS   CCCCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL EEEEEEEEEEEEE                PP              CCCCCCCCCCCCC
 SSSSSSSSSSS     CCCCCCCCCCC    AA         AA  LLLLLLLLLLLLL EEEEEEEEEEEEE                PP               CCCCCCCCCCC


********************************************************************************
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                  PROGRAM VERIFICATION INFORMATION                    *****
*****                                                                      *****
*****                CODE SYSTEM:   SCALE-PC VERSION:   4.3                *****
*****                                                                      *****
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                                                                      *****
*****              PROGRAM:  CSAS                                          *****
*****                                                                      *****
*****        CREATION DATE:  03-08-96                                      *****
*****                                                                      *****
*****               VOLUME:  ENG                                           *****
*****                                                                      *****
*****              LIBRARY:  G:\scale43\exe                                *****
*****                                                                      *****
*****                                                                      *****
*****      PRODUCTION CODE:  CSAS                                          *****
*****                                                                      *****
*****              VERSION:  3.1                                           *****
*****                                                                      *****
*****              JOBNAME:  SCALE-PC                                      *****
*****                                                                      *****
*****    DATE OF EXECUTION:  11/17/96                                      *****
*****                                                                      *****
*****    TIME OF EXECUTION:  16:35:13                                      *****
*****                                                                      *****
*****                                                                      *****
********************************************************************************
********************************************************************************
********************************************************************************
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M

    **** PROBLEM PARAMETERS ****

    LIB 27GROUPNDF4  LIBRARY
    MXX             10 MIXTURES
    MSC             19 COMPOSITION SPECIFICATIONS
    IZM              4 MATERIAL ZONES
    GE   LATTICECELL  GEOMETRY
    MORE             0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
    MSLN             0 FUEL SOLUTIONS

    **** PROBLEM COMPOSITION DESCRIPTION ****

    SC  UO2           STANDARD COMPOSITION
    MX               1 MIXTURE NO.
    VF          0.9500 VOLUME FRACTION
    ROTH       10.9600 THEORETICAL DENSITY
    NEL              2 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 92000      1.00 ATOM/MOLECULE
                                92235      4.000 WT%
                                92238     96.000 WT%
                  8016      2.00 ATOMS/MOLECULE
    END

    SC  ZIRCALLOY     STANDARD COMPOSITION
    MX               2 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        6.5600 THEORETICAL DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 40302      1.00 ATOM/MOLECULE
    END

    SC  H2O           STANDARD COMPOSITION
    MX               3 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        0.9982 THEORETICAL DENSITY
    NEL              2 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  1001      2.00 ATOMS/MOLECULE
                  8016      1.00 ATOM/MOLECULE
    END

    SC  AL            STANDARD COMPOSITION
    MX               4 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        2.7020 THEORETICAL DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 13027      1.00 ATOM/MOLECULE
    END

    SC  SS304         STANDARD COMPOSITION
    MX               5 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        7.9200 THEORETICAL DENSITY
    NEL              4 NO. ELEMENTS
    ICP              0 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 24304    19.000 WT%
                 25055     2.000 WT%
                 26304    69.500 WT%
                 28304     9.500 WT%
    END

    SC  B-10          STANDARD COMPOSITION
    MX               6 MIXTURE NO.
    VF          0.0450 VOLUME FRACTION
    ROTH        2.6226 SPECIFIED DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  5010      1.00 ATOM/MOLECULE
    END

    SC  B-11          STANDARD COMPOSITION
    MX               6 MIXTURE NO.
    VF          0.2736 VOLUME FRACTION
    ROTH        2.6226 SPECIFIED DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  5011      1.00 ATOM/MOLECULE
    END

    SC  C             STANDARD COMPOSITION
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
MX            6 MIXTURE NO.
VF       0.0927 VOLUME FRACTION
ROTH     2.6226 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           6012       1.00 ATOM/MOLECULE
END

SC  AL          STANDARD COMPOSITION
MX            6 MIXTURE NO.
VF       0.5737 VOLUME FRACTION
ROTH     2.6226 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
          13027       1.00 ATOM/MOLECULE
END

SC  PB          STANDARD COMPOSITION
MX            7 MIXTURE NO.
VF       1.0000 VOLUME FRACTION
ROTH    11.3440 THEORETICAL DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
          82000       1.00 ATOM/MOLECULE
END

SC  H           STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.0600 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           1001       1.00 ATOM/MOLECULE
END

SC  O           STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.4250 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           8016       1.00 ATOM/MOLECULE
END

SC  C           STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.2770 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           6012       1.00 ATOM/MOLECULE
END

SC  N           STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.0200 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           7014       1.00 ATOM/MOLECULE
END

SC  AL          STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.2140 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
          13027       1.00 ATOM/MOLECULE
END

SC  B-10        STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.0010 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
           5010       1.00 ATOM/MOLECULE
END

SC  B-11        STANDARD COMPOSITION
MX            8 MIXTURE NO.
VF       0.0040 VOLUME FRACTION
ROTH     1.6291 SPECIFIED DENSITY
NEL           1 NO. ELEMENTS
ICP           1 0/1 MIXTURE/COMPOUND
TEMP      293.0 DEG KELVIN
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
              5011       1.00 ATOM/MOLECULE
END

SC  CARBONSTEEL   STANDARD COMPOSITION
MX              9 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       7.8212 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             0 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            26000     99.000 WT%
             6012      1.000 WT%
END

SC  H2O           STANDARD COMPOSITION
MX             10 MIXTURE NO.
VF         0.0001 VOLUME FRACTION
ROTH       0.9982 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             1001       2.00 ATOMS/MOLECULE
             8016       1.00 ATOM/MOLECULE
END

**** PROBLEM GEOMETRY ****

CTP SQUAREPITCH   CELL TYPE
PITCH      1.1887 CM CENTER TO CENTER SPACING
FUELOD     0.7887 CM FUEL DIAMETER OR SLAB THICKNESS
MFUEL           1 MIXTURE NO. OF FUEL
MMOD            3 MIXTURE NO. OF MODERATOR
CLADOD     0.9271 CM CLAD OUTER DIAMETER
MCLAD           2 MIXTURE NO. OF CLAD
GAPOD      0.8052 CM GAP OUTER DIAMETER
MGAP            0 MIXTURE NO. OF GAP

ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

               ZONE  1 IS FUEL
               ZONE  2 IS GAP
               ZONE  3 IS CLAD
               ZONE  4 IS MOD
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
*********************************************************************************************************************
***                                                                                                               ***
***                         TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M***
***                                                                                                               ***
*********************************************************************************************************************
*********************************************************************************************************************
***                                                                                                               ***
***                              ********** DATA LIBRARY INFORMATION **********                                   ***
***                                                                                                               ***
***        UNIT                                                  VOLUME                                           ***
***       NUMBER              DATA SET NAME                       NAME        UNIT FUNCTION                       ***
***       ------              -------------                       ----        -------------                       ***
***                                                                                                               ***
***         89     G:\scale43\DATALIB\FT89F001                                STANDARD COMPOSITION LIBRARY        ***
***                                                                                                               ***
***         82     G:\scale43\DATALIB\FT82F001                                CROSS SECTION LIBRARY               ***
***                                                                                                               ***
***         11     C:\svv\yankee\wrr5402\tfn-1000\FT11F001                    SHORT CROSS SECTION LIBRARY         ***
***                                                                                                               ***
***         90     C:\svv\yankee\wrr5402\tfn-1000\FT90F001                    INPUT DATA DIRECT ACCESS            ***
***                                                                                                               ***
*********************************************************************************************************************
*********************************************************************************************************************
***                                                                                                               ***
***                                                                                                               ***
***                                    STANDARD COMPOSITION LIBRARY DATA                                          ***
***                                    ---------------------------------                                          ***
***                                                                                                               ***
***         UNIT NUMBER  :  89                                                                                    ***
***                                                                                                               ***
***         DATASET NAME :  G:\scale43\DATALIB\FT89F001                                                           ***
***                                                                                                               ***
***         LIBRARY TITLE:  SCALE-4 STANDARD COMPOSITION LIBRARY                                                  ***
***                         637 STANDARD COMPOSITIONS, 490 NUCLIDES                                               ***
***                         90 ELEMENTS WITH VARIABLE ISOTOPIC DISTRBUTIONS.                                      ***
***                                                                                                               ***
***         CREATION DATE:   6/30/95                                                                              ***
***                                                                                                               ***
***                                                                                                               ***
***                                                                                                               ***
***                                        CROSS SECTION LIBRARY DATA                                             ***
***                                        ---------------------------                                            ***
***                                                                                                               ***
***         UNIT NUMBER  :  82                                                                                    ***
***                                                                                                               ***
***         DATASET NAME :  G:\scale43\DATALIB\FT82F001                                                           ***
***                                                                                                               ***
***         LIBRARY TITLE:  SCALE 4.2 - 27 GROUP NEUTRON GROUP LIBRARY                                            ***
***                            BASED ON ENDF-B VERSION 4 DATA                                                     ***
***                               COMPILED FOR NRC     1/27/89                                                    ***
***                                  LAST UPDATED                                                    08/12/94     ***
***                                     L.M.PETRIE   -   ORNL                                                     ***
***                                                                                                               ***
***                                                                                                               ***
***                                                                                                               ***
***                                                                                                               ***
*********************************************************************************************************************
*********************************************************************************************************************

CONTROL MODULE CSAS25   IS COMPLETE.
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
                KK        KK  EEEEEEEEEEEEE  NN        NN   OOOOOOOOOOO                  VV          VV
                KK       KK   EEEEEEEEEEEEE  NNN       NN  OOOOOOOOOOOOO                 VV          VV
                KK      KK    EE             NNNN      NN  OO         OO                 VV          VV
                KK     KK     EE             NN NN     NN  OO         OO                 VV          VV
                KK    KK      EE             NN  NN    NN  OO         OO                 VV          VV
                KKKKKKKK      EEEEEEEEE      NN   NN   NN  OO         OO  -------------  VV          VV
                KKKKKKKK      EEEEEEEEE      NN    NN  NN  OO         OO  -------------   VV        VV
                KK    KK      EE             NN     NN NN  OO         OO                   VV      VV
                KK     KK     EE             NN      NN NN OO         OO                    VV    VV
                KK      KK    EE             NN       NNNN OO         OO                     VV  VV
                KK       KK   EEEEEEEEEEEEE  NN        NNN OOOOOOOOOOOOO                      VVV
                KK        KK  EEEEEEEEEEEEE  NN         NN  OOOOOOOOOOO                        V

 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL             EEEEEEEEEEEEE                 PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL             EEEEEEEEEEEEE                 PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS  CC         CC  AA         AA   LL             EE                            PP         PP   CC         CC
SS             CC             AA         AA   LL             EE                            PP         PP   CC
SS             CC             AA         AA   LL             EE                            PP         PP   CC
SSSSSSSSSSSS   CC             AAAAAAAAAAAAA   LL             EEEEEEEEE      -------------  PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS  CC             AAAAAAAAAAAAA   LL             EEEEEEEEE      -------------  PPPPPPPPPPPP    CC
           SS  CC             AA         AA   LL             EE                            PP              CC
           SS  CC             AA         AA   LL             EE                            PP              CC
SS         SS  CC         CC  AA         AA   LL             EE                            PP              CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC  AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP              CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP               CCCCCCCCCCC

      11             11                 //       11       7777777777777               //  99999999999    666666666666
     111            111                //       111       777777777777               //  9999999999999  6666666666666
    1111           1111               //       1111       77         77             //   99         99  66
      11             11              //          11                 77             //    99         99  66
      11             11             //           11                77             //     99         99  66
      11             11            //            11               77             //      9999999999999  666666666666
      11             11           //             11              77             //        999999999999  6666666666666
      11             11          //              11             77             //                   99  66         66
      11             11         //               11            77             //                    99  66         66
      11             11        //                11           77             //                     99  66         66
   11111111       11111111    //              11111111        77            //          9999999999999  6666666666666
   11111111       11111111   //               11111111        77           //           999999999999    66666666666

      11        666666666666                  33333333333  5555555555555              22222222222    99999999999
     111       6666666666666                 3333333333333 5555555555555             2222222222222  9999999999999
    1111       66                  :::       33         33 55                 :::    22         22  99         99
      11       66                  :::                  33 55                 :::               22  99         99
      11       66                  :::                  33 55                 :::               22  99         99
      11       666666666666                            333 555555555555                       22    9999999999999
      11       6666666666666                           333 5555555555555                    22       999999999999
      11       66         66       :::                  33            55      :::         22                   99
      11       66         66       :::                  33            55      :::       22                     99
      11       66         66       :::       33         33 55         55      :::     22                       99
   11111111    6666666666666                 3333333333333 5555555555555             2222222222222  9999999999999
   11111111     66666666666                   33333333333   55555555555              2222222222222  999999999999
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
  SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL              EEEEEEEEEEEEE                   PPPPPPPPPPPP    CCCCCCCCCCC
 SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL              EEEEEEEEEEEEE                   PPPPPPPPPPPPP  CCCCCCCCCCCCC
 SS         SS  CC         CC   AA         AA  LL              EE                              PP          PP CC         CC
 SS             CC              AA         AA  LL              EE                              PP          PP CC
 SS             CC              AA         AA  LL              EE                              PP          PP CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA  LL              EEEEEEEEE       -------------   PPPPPPPPPPPPP  CC
  SSSSSSSSSSSS  CC              AAAAAAAAAAAAA  LL              EEEEEEEEE       -------------   PPPPPPPPPPPP   CC
            SS  CC              AA         AA  LL              EE                              PP             CC
            SS  CC              AA         AA  LL              EE                              PP             CC
 SS         SS  CC         CC   AA         AA  LL              EE                              PP             CC         CC
 SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP             CCCCCCCCCCCCC
  SSSSSSSSSSS    CCCCCCCCCCC    AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP              CCCCCCCCCCC
```

```
*******************************************************************************
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                  PROGRAM VERIFICATION INFORMATION                   *****
*****                                                                     *****
*****               CODE SYSTEM:   SCALE-PC VERSION:  4.3                 *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                                                                     *****
*****                PROGRAM:  000009                                     *****
*****                                                                     *****
*****          CREATION DATE:  03-08-96                                   *****
*****                                                                     *****
*****                 VOLUME:  ENG                                        *****
*****                                                                     *****
*****                LIBRARY:  G:\scale43\exe                             *****
*****                                                                     *****
*****                                                                     *****
*****        PRODUCTION CODE:  KENOVA                                     *****
*****                                                                     *****
*****                VERSION:  3.1                                        *****
*****                                                                     *****
*****                JOBNAME:  SCALE-PC                                   *****
*****                                                                     *****
*****      DATE OF EXECUTION:  11/17/96                                   *****
*****                                                                     *****
*****      TIME OF EXECUTION:  16:35:29                                   *****
*****                                                                     *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*******************************************************************************
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M

****** NUMERIC PARAMETERS ******
```

TME	MAXIMUM PROBLEM TIME (MIN)	500.00
TBA	TIME PER GENERATION (MIN)	0.50
GEN	NUMBER OF GENERATIONS	1003
NPG	NUMBER PER GENERATION	1000
NSK	NUMBER OF GENERATIONS TO BE SKIPPED	3
BEG	BEGINNING GENERATION NUMBER	1
RES	GENERATIONS BETWEEN CHECKPOINTS	0
X1D	NUMBER OF EXTRA 1-D CROSS SECTIONS	1
NBK	NEUTRON BANK SIZE	1025
XNB	EXTRA POSITIONS IN NEUTRON BANK	0
NFB	FISSION BANK SIZE	1000
XFB	EXTRA POSITIONS IN FISSION BANK	0
WTA	DEFAULT VALUE OF WEIGHT AVERAGE	0.5000
WTH	WEIGHT HIGH FOR SPLITTING	3.0000
WTL	WEIGHT LOW FOR RUSSIAN ROULETTE	0.3333
RND	STARTING RANDOM NUMBER	BB827100001
NB8	NUMBER OF D.A. BLOCKS ON UNIT 8	200
NL8	LENGTH OF D.A. BLOCKS ON UNIT 8	512
ADJ	MODE OF CALCULATION	FORWARD
	INPUT DATA WRITTEN ON RESTART UNIT	NO
	BINARY DATA INTERFACE	YES

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
********************************************************************************************************************************
********************************************************************************************************************************
***                                                                                                                          ***
***                    TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M***
***                                                                                                                          ***
********************************************************************************************************************************
***                                 ******    LOGICAL PARAMETERS      ******                                                 ***
***                                                                                                                          ***
***  RUN  EXECUTE PROBLEM AFTER CHECKING DATA      YES           PLT  PLOT PICTURE MAP(S)                          NO ***
***                                                                                                                          ***
***  FLX  COMPUTE FLUX                              NO           FDN  COMPUTE FISSION DENSITIES                    NO ***
***                                                                                                                          ***
***  SMU  COMPUTE AVG UNIT SELF-MULTIPLICATION      NO           NUB  COMPUTE NU-BAR & AVG FISSION GROUP          YES ***
***                                                                                                                          ***
***  MKU  COMPUTE MATRIX K-EFF BY UNIT NUMBER       NO           MKP  COMPUTE MATRIX K-EFF BY UNIT LOCATION        NO ***
***                                                                                                                          ***
***  CKU  COMPUTE COFACTOR K-EFF BY UNIT NUMBER     NO           CKP  COMPUTE COFACTOR K-EFF BY UNIT LOCATION      NO ***
***                                                                                                                          ***
***  FMU  PRINT FISS PROD MATRIX BY UNIT NUMBER     NO           FMP  PRINT FISS PROD MATRIX BY UNIT LOCATION      NO ***
***                                                                                                                          ***
***  MKH  COMPUTE MATRIX K-EFF BY HOLE NUMBER       NO           MKA  COMPUTE MATRIX K-EFF BY ARRAY NUMBER         NO ***
***                                                                                                                          ***
***  CKH  COMPUTE COFACTOR K-EFF BY HOLE NUMBER     NO           CKA  COMPUTE COFACTOR K-EFF BY ARRAY NUMBER       NO ***
***                                                                                                                          ***
***  FMH  PRINT FISS PROD MATRIX BY HOLE NUMBER     NO           FMA  PRINT FISS PROD MATRIX BY ARRAY NUMBER       NO ***
***                                                                                                                          ***
***  HHL  COLLECT MATRIX BY HIGHEST HOLE LEVEL      NO           HAL  COLLECT MATRIX BY HIGHEST ARRAY LEVEL        NO ***
***                                                                                                                          ***
***  AMX  PRINT ALL MIXED CROSS SECTIONS            NO           FAR  PRINT FIS. AND ABS. BY REGION                NO ***
***                                                                                                                          ***
***  XS1  PRINT 1-D MIXTURE X-SECTIONS              NO           GAS  PRINT FAR BY GROUP                           NO ***
***                                                                                                                          ***
***  XS2  PRINT 2-D MIXTURE X-SECTIONS              NO           PAX  PRINT XSEC-ALBEDO CORRELATION TABLES         NO ***
***                                                                                                                          ***
***  XAP  PRINT MIXTURE ANGLES & PROBABILITIES      NO           PWT  PRINT WEIGHT AVERAGE ARRAY                   NO ***
***                                                                                                                          ***
***  PKI  PRINT FISSION SPECTRUM                    NO           PGM  PRINT INPUT GEOMETRY                         NO ***
***                                                                                                                          ***
***  P1D  PRINT EXTRA 1-D CROSS SECTIONS            NO           BUG  PRINT DEBUG INFORMATION                      NO ***
***                                                                                                                          ***
***                                                              TRK  PRINT TRACKING INFORMATION                   NO ***
***                                                                                                                          ***
***                                                                                                                          ***
********************************************************************************************************************************
********************************************************************************************************************************
********************************************************************************************************************************
                                          PARAMETER INPUT COMPLETED

                          ........     0 IO'S WERE USED READING THE PARAMETER DATA      ........

                          *************** DATA READING COMPLETED ***************
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
***********************************************************************************************************
***                                                                                                     ***
***                TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M***
***                                                                                                     ***
***********************************************************************************************************
***********************************************************************************************************
***                                                                                                     ***
***        UNIT                                                   VOLUME                                ***
***       NUMBER               DATA SET NAME                       NAME      UNIT FUNCTION              ***
***       ------               -------------                       ----      -------------              ***
***                                                                                                     ***
***     XSC  14    C:\svv\yankee\wrr5402\tfn-1000\FT14F001                   MIXED CROSS SECTIONS       ***
***                                                                                                     ***
***     ALB  79    G:\scale43\DATALIB\FT79F001                               INPUT ALBEDOS              ***
***                                                                                                     ***
***     WTS  80    G:\scale43\DATALIB\FT80F001                               INPUT WEIGHTS              ***
***                                                                                                     ***
***     SKT  16     UNKNOWN                                                  WRITE SCRATCH DATA         ***
***                                                                                                     ***
***     BIN  95    C:\svv\yankee\wrr5402\tfn-1000\FT95F001                   BINARY INPUT DATA          ***
***                                                                                                     ***
***     RST  95    C:\svv\yankee\wrr5402\tfn-1000\FT95F001                   READ RESTART DATA          ***
***                                                                                                     ***
***     LIB   4    C:\svv\yankee\wrr5402\tfn-1000\FT04F001                   INPUT AMPX WORKING LIBRARY ***
***                                                                                                     ***
***           8    C:\svv\yankee\wrr5402\tfn-1000\FT08F001                   INPUT DATA DIRECT ACCESS   ***
***                                                                                                     ***
***           9     UNKNOWN                                                  SUPER GROUPED DIRECT ACCESS ***
***                                                                                                     ***
***          10     UNKNOWN                                                  XSEC MIXING DIRECT ACCESS  ***
***                                                                                                     ***
***********************************************************************************************************

                 ........    0 IO'S WERE USED PREPARING INPUT DATA    ........

                 CROSS SECTIONS READ FROM THE AMPX WORKING LIBRARY ON UNIT     4
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
                     TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M
                                       MIXING TABLE
                                  NUMBER OF SCATTERING ANGLES =  2
                             CROSS SECTION MESSAGE THRESHOLD =3.0E-05

MIXTURE =      1           DENSITY(G/CC) =  10.412
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   1008016  4.64617E-02  1.18487E-01   8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                  UPDATED
08/12/94
   1092235  9.40641E-04  3.52606E-02  92235   235.0441     URANIUM-235     ENDF/B-IV MAT 1261                  UPDATED
08/12/94
   1092238  2.22902E-02  8.46253E-01  92238   238.0510     URANIUM-238     ENDF/B-IV MAT 1262                  UPDATED
08/12/94

MIXTURE =      2           DENSITY(G/CC) =  6.5600
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   2040302  4.33078E-02  1.00000E+00  40000    91.2196     ZIRCALLOY       ENDF/B-IV MAT 1284                  UPDATED
08/12/94

MIXTURE =      3           DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   3001001  6.67692E-02  1.11927E-01   1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002         UPDATED
08/12/94
   3008016  3.33846E-02  8.88074E-01   8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                  UPDATED
08/12/94

MIXTURE =      4           DENSITY(G/CC) =  2.7020
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   4013027  6.03066E-02  1.00000E+00  13027    26.9818   AL-27 1193 218 GP 040375(5)                           UPDATED
08/12/94

MIXTURE =      5           DENSITY(G/CC) =  7.9200
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   5024304  1.74286E-02  1.90000E-01  24000    51.9957   CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'      UPDATED
08/12/94
   5025055  1.73633E-03  1.99999E-02  25055    54.9379     MANGANESE-55    ENDF/B-IV MAT 1197                  UPDATED
08/12/94
   5026304  5.93579E-02  6.95000E-01  26000    55.8447   FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'      UPDATED
08/12/94
   5028304  7.72070E-03  9.50001E-02  28000    58.6872   NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'      UPDATED
08/12/94

MIXTURE =      6           DENSITY(G/CC) =  2.5833
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   6005010  7.09799E-03  4.56855E-02   5010    10.0130   B-10 1273 218NGP 042375 P-3 293K                      UPDATED
08/12/94
   6005011  3.92499E-02  2.77771E-01   5011    11.0096     BORON-11        ENDF/B-IV MAT 1160                  UPDATED
08/12/94
   6006012  1.22006E-02  9.41116E-02   6000    12.0001     CARBON-12       ENDF/B-IV MAT 1274/THRM1065         UPDATED
08/12/94
   6013027  3.35812E-02  5.82432E-01  13027    26.9818   AL-27 1193 218 GP 040375(5)                           UPDATED
08/12/94

MIXTURE =      7           DENSITY(G/CC) =  11.344
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   7082000  3.29690E-02  1.00000E+00  82000   207.2100   PB   1288 218NGP 042375 P-3 293K                      UPDATED
08/12/94

MIXTURE =      8           DENSITY(G/CC) =  1.6307
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   8001001  5.84084E-02  5.99323E-02   1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002         UPDATED
08/12/94
   8005010  9.79802E-05  9.99025E-04   5010    10.0130   B-10 1273 218NGP 042375 P-3 293K                      UPDATED
08/12/94
   8005011  3.56450E-04  3.99615E-03   5011    11.0096     BORON-11        ENDF/B-IV MAT 1160                  UPDATED
08/12/94
   8006012  2.26463E-02  2.76729E-01   6000    12.0001     CARBON-12       ENDF/B-IV MAT 1274/THRM1065         UPDATED
08/12/94
   8007014  1.40121E-03  1.99805E-02   7014    14.0033     NITROGEN-14     ENDF/B-IV MAT 1275                  UPDATED
08/12/94
   8008016  2.60749E-02  4.24574E-01   8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                  UPDATED
08/12/94
   8013027  7.78110E-03  2.13789E-01  13027    26.9818   AL-27 1193 218 GP 040375(5)                           UPDATED
08/12/94

MIXTURE =      9           DENSITY(G/CC) =  7.8212
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
   9006012  3.92503E-03  1.00001E-02   6000    12.0001     CARBON-12       ENDF/B-IV MAT 1274/THRM1065         UPDATED
08/12/94
   9026000  8.34982E-02  9.90000E-01  26000    55.8447     IRON            ENDF/B-IV MAT 1192                  UPDATED
08/12/94

MIXTURE =     10           DENSITY(G/CC) = 0.99817E-04
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA        AWT                NUCLIDE TITLE
  10001001  6.67692E-06  1.11927E-01   1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002         UPDATED
08/12/94
  10008016  3.33846E-06  8.88074E-01   8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                  UPDATED
08/12/94
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
*****************************************************************************************************
***                                                                                               ***
***        TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M       ***
***                                                                                               ***
*****************************************************************************************************
*****************************************************************************************************
***                                                                                               ***
***                              ****** ADDITIONAL INFORMATION ******                             ***
***                                                                                               ***
***  NUMBER OF ENERGY GROUPS                27      USE LATTICE GEOMETRY                    YES  ***
***                                                                                               ***
***  NO. OF FISSION SPECTRUM SOURCE GROUP  1       GLOBAL ARRAY NUMBER                      60  ***
***                                                                                               ***
***  NO. OF SCATTERING ANGLES IN XSECS      2       NUMBER OF UNITS IN THE GLOBAL X DIR.      1  ***
***                                                                                               ***
***  ENTRIES/NEUTRON IN THE NEUTRON BANK   33      NUMBER OF UNITS IN THE GLOBAL Y DIR.      1  ***
***                                                                                               ***
***  ENTRIES/NEUTRON IN THE FISSION BANK   26      NUMBER OF UNITS IN THE GLOBAL Z DIR.      4  ***
***                                                                                               ***
***  NUMBER OF MIXTURES USED               10      USE A GLOBAL REFLECTOR                  YES  ***
***                                                                                               ***
***  NUMBER OF BIAS ID'S USED               1      USE NESTED HOLES                        YES  ***
***                                                                                               ***
***  NUMBER OF DIFFERENTIAL ALBEDOS USED    0      NUMBER OF HOLES                          48  ***
***                                                                                               ***
***  TOTAL INPUT GEOMETRY REGIONS         133      MAXIMUM HOLE NESTING LEVEL                3  ***
***                                                                                               ***
***  NUMBER OF GEOMETRY REGIONS USED      133      USE NESTED ARRAYS                       YES  ***
***                                                                                               ***
***  LARGEST GEOMETRY UNIT NUMBER         120      NUMBER OF ARRAYS USED                    27  ***
***                                                                                               ***
***  LARGEST ARRAY NUMBER                  60      MAXIMUM ARRAY NESTING LEVEL               4  ***
***                                                                                               ***
***                                                                                               ***
***  +X BOUNDARY CONDITION            REFLECT      -X BOUNDARY CONDITION               REFLECT  ***
***                                                                                               ***
***  +Y BOUNDARY CONDITION            REFLECT      -Y BOUNDARY CONDITION               REFLECT  ***
***                                                                                               ***
***  +Z BOUNDARY CONDITION                PER      -Z BOUNDARY CONDITION                   PER  ***
***                                                                                               ***
*****************************************************************************************************
```

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 948 INDEPENDENT FISSION POINTS WERE GENERATED				
1	8.37406E-01	1.12667E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 963 INDEPENDENT FISSION POINTS WERE GENERATED				
2	8.81055E-01	1.54667E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 948 INDEPENDENT FISSION POINTS WERE GENERATED				
3	8.74792E-01	1.98667E-01	8.74792E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	8.50188E-01	2.40833E-01	8.62490E-01	1.23022E-02	0.00000E+00	0.00000E+00
5	8.77478E-01	2.85667E-01	8.67486E-01	8.68389E-03	0.00000E+00	0.00000E+00
6	8.70684E-01	3.29500E-01	8.68285E-01	6.19227E-03	0.00000E+00	0.00000E+00
7	8.43849E-01	3.69000E-01	8.63398E-01	6.84774E-03	0.00000E+00	0.00000E+00
8	8.65031E-01	4.10167E-01	8.63670E-01	5.59777E-03	0.00000E+00	0.00000E+00
9	8.84015E-01	4.50333E-01	8.66577E-01	5.55243E-03	0.00000E+00	0.00000E+00
10	8.94879E-01	4.89833E-01	8.70115E-01	5.96979E-03	0.00000E+00	0.00000E+00
11	8.78442E-01	5.30000E-01	8.71040E-01	5.34555E-03	0.00000E+00	0.00000E+00
12	8.71619E-01	5.70333E-01	8.71098E-01	4.78155E-03	0.00000E+00	0.00000E+00
13	8.55536E-01	6.10667E-01	8.69683E-01	4.55058E-03	0.00000E+00	0.00000E+00
14	8.82806E-01	6.50000E-01	8.70777E-01	4.29561E-03	0.00000E+00	0.00000E+00
15	9.06408E-01	6.89333E-01	8.73518E-01	4.80895E-03	0.00000E+00	0.00000E+00
16	8.76440E-01	7.29667E-01	8.73726E-01	4.45711E-03	0.00000E+00	0.00000E+00
17	8.88423E-01	7.69833E-01	8.74706E-01	4.26345E-03	0.00000E+00	0.00000E+00
18	8.69526E-01	8.08333E-01	8.74382E-01	4.00121E-03	0.00000E+00	0.00000E+00
19	8.96770E-01	8.48667E-01	8.75699E-01	3.98252E-03	0.00000E+00	0.00000E+00
20	9.28071E-01	8.87000E-01	8.78609E-01	4.75012E-03	0.00000E+00	0.00000E+00
21	8.62794E-01	9.27333E-01	8.77776E-01	4.56961E-03	0.00000E+00	0.00000E+00
22	8.55005E-01	9.66667E-01	8.76638E-01	4.48213E-03	0.00000E+00	0.00000E+00
23	9.00226E-01	1.00517E+00	8.77761E-01	4.40885E-03	0.00000E+00	0.00000E+00
24	9.05733E-01	1.04450E+00	8.79033E-01	4.39174E-03	0.00000E+00	0.00000E+00
25	8.73779E-01	1.08667E+00	8.78804E-01	4.20267E-03	0.00000E+00	0.00000E+00
26	8.52265E-01	1.12783E+00	8.77698E-01	4.17293E-03	0.00000E+00	0.00000E+00
27	8.85402E-01	1.16717E+00	8.78006E-01	4.01438E-03	0.00000E+00	0.00000E+00
28	8.91452E-01	1.20750E+00	8.78524E-01	3.89141E-03	0.00000E+00	0.00000E+00
29	9.02320E-01	1.24767E+00	8.79405E-01	3.84683E-03	0.00000E+00	0.00000E+00
30	9.03355E-01	1.28617E+00	8.80260E-01	3.80430E-03	0.00000E+00	0.00000E+00
31	9.06389E-01	1.32550E+00	8.81161E-01	3.77974E-03	0.00000E+00	0.00000E+00
32	8.66698E-01	1.36583E+00	8.80679E-01	3.68326E-03	0.00000E+00	0.00000E+00
33	8.65915E-01	1.40517E+00	8.80203E-01	3.59416E-03	0.00000E+00	0.00000E+00
34	8.79578E-01	1.44550E+00	8.80183E-01	3.48008E-03	0.00000E+00	0.00000E+00
35	8.44839E-01	1.48483E+00	8.79112E-01	3.53894E-03	0.00000E+00	0.00000E+00
36	8.69605E-01	1.52417E+00	8.78833E-01	3.44465E-03	0.00000E+00	0.00000E+00
37	8.92265E-01	1.56267E+00	8.79216E-01	3.36672E-03	0.00000E+00	0.00000E+00
38	8.85513E-01	1.60300E+00	8.79391E-01	3.27654E-03	0.00000E+00	0.00000E+00
39	8.59417E-01	1.64233E+00	8.78852E-01	3.23216E-03	0.00000E+00	0.00000E+00
40	8.59963E-01	1.67983E+00	8.78354E-01	3.18498E-03	0.00000E+00	0.00000E+00
41	8.41635E-01	1.71917E+00	8.77413E-01	3.24197E-03	0.00000E+00	0.00000E+00
42	8.28632E-01	1.75767E+00	8.76193E-01	3.38704E-03	0.00000E+00	0.00000E+00
43	8.76950E-01	1.79617E+00	8.76212E-01	3.30345E-03	0.00000E+00	0.00000E+00
44	8.54718E-01	1.83550E+00	8.75700E-01	3.26420E-03	0.00000E+00	0.00000E+00
45	8.75969E-01	1.87383E+00	8.75706E-01	3.18739E-03	0.00000E+00	0.00000E+00
46	8.51691E-01	1.91417E+00	8.75161E-01	3.16158E-03	0.00000E+00	0.00000E+00
47	8.88452E-01	1.95350E+00	8.75456E-01	3.10461E-03	0.00000E+00	0.00000E+00
48	8.66703E-01	1.99467E+00	8.75266E-01	3.04232E-03	0.00000E+00	0.00000E+00
49	9.09273E-01	2.03417E+00	8.75989E-01	3.06356E-03	0.00000E+00	0.00000E+00
50	9.25346E-01	2.07433E+00	8.77017E-01	3.17043E-03	0.00000E+00	0.00000E+00
.						
.						
.						
950	9.12580E-01	3.79325E+01	8.74693E-01	7.88441E-04	0.00000E+00	0.00000E+00
951	8.77250E-01	3.79728E+01	8.74696E-01	7.87614E-04	0.00000E+00	0.00000E+00
952	8.25017E-01	3.80130E+01	8.74643E-01	7.88521E-04	0.00000E+00	0.00000E+00
953	8.91366E-01	3.80523E+01	8.74661E-01	7.87888E-04	0.00000E+00	0.00000E+00
954	8.87194E-01	3.80927E+01	8.74674E-01	7.87170E-04	0.00000E+00	0.00000E+00
955	8.86207E-01	3.81338E+01	8.74686E-01	7.86436E-04	0.00000E+00	0.00000E+00
956	8.45087E-01	3.81750E+01	8.74655E-01	7.86224E-04	0.00000E+00	0.00000E+00
957	8.91207E-01	3.82145E+01	8.74673E-01	7.85591E-04	0.00000E+00	0.00000E+00
958	8.60877E-01	3.82547E+01	8.74658E-01	7.84902E-04	0.00000E+00	0.00000E+00
959	8.46833E-01	3.82958E+01	8.74629E-01	7.84620E-04	0.00000E+00	0.00000E+00
960	8.96081E-01	3.83380E+01	8.74652E-01	7.84121E-04	0.00000E+00	0.00000E+00
961	8.93618E-01	3.83792E+01	8.74671E-01	7.83552E-04	0.00000E+00	0.00000E+00
962	8.75231E-01	3.84195E+01	8.74672E-01	7.82736E-04	0.00000E+00	0.00000E+00
963	8.82148E-01	3.84588E+01	8.74680E-01	7.81960E-04	0.00000E+00	0.00000E+00
964	8.83276E-01	3.84992E+01	8.74689E-01	7.81197E-04	0.00000E+00	0.00000E+00
965	9.39025E-01	3.85403E+01	8.74755E-01	7.83240E-04	0.00000E+00	0.00000E+00
966	8.54465E-01	3.85807E+01	8.74734E-01	7.82710E-04	0.00000E+00	0.00000E+00
967	8.62119E-01	3.86208E+01	8.74721E-01	7.82008E-04	0.00000E+00	0.00000E+00
968	9.00442E-01	3.86620E+01	8.74748E-01	7.81652E-04	0.00000E+00	0.00000E+00
969	9.06123E-01	3.87023E+01	8.74780E-01	7.81517E-04	0.00000E+00	0.00000E+00
970	8.80081E-01	3.87427E+01	8.74786E-01	7.80728E-04	0.00000E+00	0.00000E+00
971	8.84026E-01	3.87828E+01	8.74795E-01	7.79980E-04	0.00000E+00	0.00000E+00
972	8.94924E-01	3.88232E+01	8.74816E-01	7.79452E-04	0.00000E+00	0.00000E+00
973	8.85826E-01	3.88625E+01	8.74827E-01	7.78732E-04	0.00000E+00	0.00000E+00
974	8.68249E-01	3.89020E+01	8.74821E-01	7.77959E-04	0.00000E+00	0.00000E+00
975	8.54260E-01	3.89432E+01	8.74800E-01	7.77447E-04	0.00000E+00	0.00000E+00
976	8.57751E-01	3.89843E+01	8.74782E-01	7.76845E-04	0.00000E+00	0.00000E+00
977	8.82894E-01	3.90237E+01	8.74790E-01	7.76093E-04	0.00000E+00	0.00000E+00
978	8.72030E-01	3.90630E+01	8.74788E-01	7.75302E-04	0.00000E+00	0.00000E+00
979	8.78149E-01	3.91033E+01	8.74791E-01	7.74516E-04	0.00000E+00	0.00000E+00
980	8.44656E-01	3.91427E+01	8.74760E-01	7.74337E-04	0.00000E+00	0.00000E+00
981	8.61601E-01	3.91820E+01	8.74747E-01	7.73662E-04	0.00000E+00	0.00000E+00
982	8.43346E-01	3.92213E+01	8.74715E-01	7.73536E-04	0.00000E+00	0.00000E+00
983	8.84908E-01	3.92617E+01	8.74725E-01	7.72817E-04	0.00000E+00	0.00000E+00
984	9.07479E-01	3.93010E+01	8.74758E-01	7.72750E-04	0.00000E+00	0.00000E+00
985	8.60259E-01	3.93385E+01	8.74744E-01	7.72105E-04	0.00000E+00	0.00000E+00

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

986	8.88639E-01	3.93788E+01	8.74758E-01	7.71449E-04	0.00000E+00	0.00000E+00
987	8.55669E-01	3.94182E+01	8.74738E-01	7.70909E-04	0.00000E+00	0.00000E+00
988	8.79341E-01	3.94575E+01	8.74743E-01	7.70141E-04	0.00000E+00	0.00000E+00
989	8.67160E-01	3.94970E+01	8.74735E-01	7.69398E-04	0.00000E+00	0.00000E+00
990	9.00607E-01	3.95353E+01	8.74762E-01	7.69065E-04	0.00000E+00	0.00000E+00
991	9.00635E-01	3.95757E+01	8.74788E-01	7.68732E-04	0.00000E+00	0.00000E+00
992	8.65557E-01	3.96160E+01	8.74778E-01	7.68012E-04	0.00000E+00	0.00000E+00
993	8.94843E-01	3.96553E+01	8.74799E-01	7.67504E-04	0.00000E+00	0.00000E+00
994	8.91900E-01	3.96947E+01	8.74816E-01	7.66924E-04	0.00000E+00	0.00000E+00
995	8.95329E-01	3.97340E+01	8.74837E-01	7.66429E-04	0.00000E+00	0.00000E+00
996	8.69236E-01	3.97725E+01	8.74831E-01	7.65679E-04	0.00000E+00	0.00000E+00
997	8.88701E-01	3.98128E+01	8.74845E-01	7.65036E-04	0.00000E+00	0.00000E+00
998	8.67711E-01	3.98522E+01	8.74838E-01	7.64301E-04	0.00000E+00	0.00000E+00
999	8.86853E-01	3.98905E+01	8.74850E-01	7.63629E-04	0.00000E+00	0.00000E+00
1000	9.24879E-01	3.99300E+01	8.74900E-01	7.64509E-04	0.00000E+00	0.00000E+00
1001	9.02462E-01	3.99683E+01	8.74928E-01	7.64241E-04	0.00000E+00	0.00000E+00
1002	8.44655E-01	4.00068E+01	8.74897E-01	7.64076E-04	0.00000E+00	0.00000E+00
1003	8.62537E-01	4.00462E+01	8.74885E-01	7.63413E-04	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123 EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M

LIFETIME = 3.47632E-05 + OR - 7.31644E-08 GENERATION TIME = 2.46340E-05 + OR - 3.61676E-08
NU BAR = 2.44326E+00 + OR - 6.80982E-05 AVERAGE FISSION GROUP = 2.15520E+01 + OR - 3.93530E-03
ENERGY(EV) OF THE AVERAGE LETHARGY CAUSING FISSION = 3.17412E-01 + OR - 9.89744E-04

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.87488	+ OR - 0.00076	0.87412 TO 0.87565	0.87336 TO 0.87641	0.87259 TO 0.87718	1000000
4	0.87491	+ OR - 0.00076	0.87415 TO 0.87567	0.87338 TO 0.87644	0.87262 TO 0.87720	999000
5	0.87491	+ OR - 0.00077	0.87414 TO 0.87567	0.87338 TO 0.87644	0.87261 TO 0.87720	998000
6	0.87491	+ OR - 0.00077	0.87415 TO 0.87568	0.87338 TO 0.87644	0.87261 TO 0.87721	997000
7	0.87494	+ OR - 0.00077	0.87418 TO 0.87571	0.87341 TO 0.87647	0.87264 TO 0.87724	996000
8	0.87495	+ OR - 0.00077	0.87419 TO 0.87572	0.87342 TO 0.87649	0.87265 TO 0.87725	995000
9	0.87494	+ OR - 0.00077	0.87418 TO 0.87571	0.87341 TO 0.87648	0.87264 TO 0.87725	994000
10	0.87492	+ OR - 0.00077	0.87416 TO 0.87569	0.87339 TO 0.87646	0.87262 TO 0.87723	993000
11	0.87492	+ OR - 0.00077	0.87415 TO 0.87569	0.87338 TO 0.87646	0.87261 TO 0.87723	992000
12	0.87492	+ OR - 0.00077	0.87415 TO 0.87569	0.87338 TO 0.87646	0.87261 TO 0.87723	991000
17	0.87489	+ OR - 0.00077	0.87412 TO 0.87566	0.87334 TO 0.87643	0.87257 TO 0.87721	986000
22	0.87485	+ OR - 0.00077	0.87408 TO 0.87562	0.87330 TO 0.87640	0.87253 TO 0.87717	981000
27	0.87480	+ OR - 0.00078	0.87403 TO 0.87558	0.87325 TO 0.87636	0.87248 TO 0.87713	976000
32	0.87471	+ OR - 0.00078	0.87393 TO 0.87548	0.87315 TO 0.87626	0.87237 TO 0.87704	971000
37	0.87473	+ OR - 0.00078	0.87395 TO 0.87551	0.87317 TO 0.87629	0.87238 TO 0.87707	966000
42	0.87483	+ OR - 0.00078	0.87405 TO 0.87561	0.87326 TO 0.87640	0.87248 TO 0.87718	961000
47	0.87486	+ OR - 0.00079	0.87407 TO 0.87564	0.87329 TO 0.87643	0.87250 TO 0.87722	956000
52	0.87474	+ OR - 0.00079	0.87396 TO 0.87553	0.87317 TO 0.87632	0.87238 TO 0.87710	951000
57	0.87470	+ OR - 0.00079	0.87391 TO 0.87549	0.87312 TO 0.87628	0.87233 TO 0.87707	946000
62	0.87473	+ OR - 0.00079	0.87393 TO 0.87552	0.87314 TO 0.87631	0.87235 TO 0.87710	941000
67	0.87464	+ OR - 0.00079	0.87384 TO 0.87543	0.87305 TO 0.87623	0.87226 TO 0.87702	936000
72	0.87462	+ OR - 0.00080	0.87383 TO 0.87542	0.87303 TO 0.87622	0.87223 TO 0.87701	931000
77	0.87463	+ OR - 0.00080	0.87383 TO 0.87543	0.87303 TO 0.87623	0.87223 TO 0.87703	926000
82	0.87460	+ OR - 0.00080	0.87380 TO 0.87541	0.87300 TO 0.87621	0.87220 TO 0.87701	921000
87	0.87460	+ OR - 0.00081	0.87379 TO 0.87540	0.87299 TO 0.87621	0.87218 TO 0.87701	916000
92	0.87462	+ OR - 0.00081	0.87381 TO 0.87542	0.87300 TO 0.87623	0.87220 TO 0.87704	911000

Figure 6.7-1 CSAS Input/Output Summary for Transfer Cask - Normal Conditions (Continued)

```
TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - EXT MOD = 0.0001, INT M

                    FREQUENCY FOR GENERATIONS    4 TO 1003
0.7909 TO 0.7949     *
0.7949 TO 0.7990     *
0.7990 TO 0.8030
0.8030 TO 0.8070     *
0.8070 TO 0.8111
0.8111 TO 0.8151     *
0.8151 TO 0.8192     **
0.8192 TO 0.8232     *****
0.8232 TO 0.8273     ***********
0.8273 TO 0.8313     ***************
0.8313 TO 0.8354     **********
0.8354 TO 0.8394     *********************
0.8394 TO 0.8435     *********************************
0.8435 TO 0.8475     ************************************
0.8475 TO 0.8516     ************************************
0.8516 TO 0.8556     *****************************************
0.8556 TO 0.8597     **************************************
0.8597 TO 0.8637     **************************************************************
0.8637 TO 0.8678     *****************************************************************
0.8678 TO 0.8718     ******************************************************************************
0.8718 TO 0.8759     *******************************************************************
0.8759 TO 0.8799     ***************************************************************
0.8799 TO 0.8840     *************************************************************
0.8840 TO 0.8880     ****************************************************************
0.8880 TO 0.8921     ******************************************************
0.8921 TO 0.8961     **********************************************
0.8961 TO 0.9001     **************************************
0.9001 TO 0.9042     *****************************************
0.9042 TO 0.9082     *****************************
0.9082 TO 0.9123     ***********************
0.9123 TO 0.9163     *****************
0.9163 TO 0.9204     **********
0.9204 TO 0.9244     ********
0.9244 TO 0.9285     ********
0.9285 TO 0.9325     ***
0.9325 TO 0.9366     ***
0.9366 TO 0.9406     **
0.9406 TO 0.9447     ***
0.9447 TO 0.9487
0.9487 TO 0.9528
0.9528 TO 0.9568     **
0.9568 TO 0.9609
0.9609 TO 0.9649
0.9649 TO 0.9690     *
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions

```
       PRIMARY MODULE ACCESS AND INPUT RECORD ( SCALE DRIVER - 95/03/29 - 09:06:37 )
MODULE CSAS25   WILL BE CALLED
  TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - water in fuel clad gap
  '
  '       File tf-mr-wg.in
  '
  '       THIS IS A MODEL OF THE YNPS NAC-MPC BASKET IN THE TRANSFER CASK
  '               LOADED WITH 36 UNITED NUCLEAR TYPE A ASSEMBLIES
  '                       WITH WATER IN THE FUEL CLAD GAP
  '
  '            PRODUCED FOR THE YANKEE ROWE
  '               STC LICENSE AMENDMENT
  '
  '       INTERIOR MODERATOR (MATERIAL  3) VOLUME FRACTION = 1.0
  '       EXTERIOR MODERATOR (MATERIAL 10) VOLUME FRACTION = 1.0
  '      WATER GAP MODERATOR (MATERIAL 11) VOLUME FRACTION = 1.0
  '
  27GROUPNDF4 LATTICECELL
  UO2          1            0.95    293.0 92235 4.0 92238 96.0 END
  ZIRCALLOY    2            1.0     293.0                      END
  H2O          3            1.0     293.0                      END
  AL           4            1.0     293.0                      END
  SS304        5            1.0     293.0                      END
  B-10         6  DEN=2.6226 0.0450  293.0                      END
  B-11         6  DEN=2.6226 0.2736  293.0                      END
  C            6  DEN=2.6226 0.0927  293.0                      END
  AL           6  DEN=2.6226 0.5737  293.0                      END
  PB           7            1.0     293.0                      END
  H            8  DEN=1.6291 0.060   293.0                      END
  O            8  DEN=1.6291 0.425   293.0                      END
  C            8  DEN=1.6291 0.277   293.0                      END
  N            8  DEN=1.6291 0.020   293.0                      END
  AL           8  DEN=1.6291 0.214   293.0                      END
  B-10         8  DEN=1.6291 0.001   293.0                      END
  B-11         8  DEN=1.6291 0.004   293.0                      END
  CARBONSTEEL 9             1.0     293.0                      END
  H2O         10            1.0     293.0                      END
  H2O         11            1.0     293.0                      END
  END COMP
  SQUAREPITCH  1.1887 0.7887 1 3 0.9271 2 0.8052 11 END
  TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - water in fuel clad gap
  READ PARAM RUN=yes PLT=NO  GEN=1003 NPG=1000 TME=500 END PARAM
  READ GEOM
  '
  '  WATER LEVEL UNIT CELLS
  '
  UNIT  1
  COM='FUEL PIN CELL - BETWEEN DISKS'
  CYLINDER  1 1  0.3943    2P2.1400
  CYLINDER 11 1  0.4026    2P2.1400
  CYLINDER  2 1  0.4635    2P2.1400
  CUBOID     3 1  4P0.5944  2P2.1400
  UNIT  2
  COM='WATER CELL - BETWEEN DISKS'
  CUBOID     3 1  4P0.5944  2P2.1400
  UNIT  3
  COM='DISPLACEMENT CELL - BETWEEN DISKS'
  CYLINDER  2 1  0.4635    2P2.1400
  CUBOID     3 1  4P0.5944  2P2.1400
  UNIT  4
  COM='INSTRUMENT TUBE CELL - BETWEEN DISKS'
  CYLINDER  3 1  0.4998    2P2.1400
  CYLINDER  5 1  0.5442    2P2.1400
  CUBOID     3 1  4P0.5944  2P2.1400
  '
  '  DISK LEVEL UNIT CELLS (BOTH SS AND AL)
  '
  UNIT  5
  COM='FUEL PIN CELL - WITH SS DISK'
  CYLINDER  1 1  0.3943   2P0.6604
  CYLINDER 11 1  0.4026   2P0.6604
  CYLINDER  2 1  0.4635   2P0.6604
  CUBOID     3 1  4P0.5944 2P0.6604
  UNIT  6
  COM='WATER CELL - WITH SS DISK'
  CUBOID     3 1  4P0.5944 2P0.6604
  UNIT  7
  COM='DISPLACEMENT CELL - WITH SS DISK'
  CYLINDER  2 1  0.4635   2P0.6604
  CUBOID     3 1  4P0.5944 2P0.6604
  UNIT  8
  COM='INSTRUMENT TUBE CELL - WITH SS DISK'
  CYLINDER  3 1  0.4998   2P0.6604
  CYLINDER  5 1  0.5442   2P0.6604
  CUBOID     3 1  4P0.5944 2P0.6604
  '
  '  WATER LEVEL BORAL SHEETS
  '
  UNIT 14
  COM='X-X BORAL SHEET BETWEEN DISKS'
  CUBOID 6 1 2P9.144 2P0.0318 2P2.1400
  CUBOID 4 1 2P9.144 2P0.0953 2P2.1400
  UNIT 15
  COM='Y-Y BORAL SHEET BETWEEN DISKS'
  CUBOID 6 1 2P0.0318 2P9.144 2P2.1400
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
CUBOID 4 1 2P0.0953 2P9.144 2P2.1400
'
'  DISK LEVEL BORAL SHEETS (AL AND SS)
'
UNIT 16
COM='X-X BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P9.144 2P0.0318 2P0.6604
CUBOID 4 1 2P9.144 2P0.0953 2P0.6604
UNIT 17
COM='Y-Y BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P0.0318 2P9.144 2P0.6604
CUBOID 4 1 2P0.0953 2P9.144 2P0.6604
'
' WATER LEVEL WEB MATERIAL
'
UNIT 20
COM='WATER LEVEL WEB MATERIAL (SMALL) X-X'
CUBOID    3 1 2P10.4635 2P0.9716 2P2.1400
UNIT 21
COM='WATER LEVEL WEB MATERIAL (MEDIUM) X-X'
CUBOID    3 1 2P10.4635 2P1.0478 2P2.1400
UNIT 22
COM='WATER LEVEL WEB MATERIAL (LARGE) X-X'
CUBOID    3 1 2P10.4635 2P1.1208 2P2.1400
UNIT 23
COM='WATER LEVEL WEB MATERIAL (LONG) Y-Y'
CUBOID    3 1 2P1.1208 2P79.5249 2P2.1400
'
'  SUPPORT DISK WEB MATERIAL
'
UNIT 30
COM='SUPPORT DISK WEB MATERIAL (SMALL) X-X'
CUBOID    5 1 2P10.4635 2P0.9716 2P0.6604
UNIT 31
COM='SUPPORT DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    5 1 2P10.4635 2P1.0478 2P0.6604
UNIT 32
COM='SUPPORT DISK WEB MATERIAL (LARGE) X-X'
CUBOID    5 1 2P10.4635 2P1.1208 2P0.6604
UNIT 33
COM='SUPPORT DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    5 1 2P1.1208 2P79.5249 2P0.6604
'
'  HEAT TRANSFER DISK WEB MATERIAL
'
UNIT 40
COM='HEAT TRANSFER DISK WEB MATERIAL (SMALL) X-X'
CUBOID    4 1 2P10.4635 2P0.9716 2P0.6604
UNIT 41
COM='HEAT TRANSFER DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    4 1 2P10.4635 2P1.0478 2P0.6604
UNIT 42
COM='HEAT TRANSFER DISK WEB MATERIAL (LARGE) X-X'
CUBOID    4 1 2P10.4635 2P1.1208 2P0.6604
UNIT 43
COM='HEAT TRANSFER DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    4 1 2P1.1208 2P79.5249 2P0.6604
'
'  WATER LEVEL ASSEMBLY ARRAYS
'
UNIT 50
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL'
ARRAY  1  -9.5104 -9.5104 -2.1400
CUBOID 3 1 4P9.9441                            2P2.1400
CUBOID 5 1 4P10.0661                           2P2.1400
CUBOID 3 1 4P10.25681                          2P2.1400
HOLE  14   0.0       10.1615  0.0
HOLE  14   0.0      -10.1615  0.0
HOLE  15   10.1615  0.0       0.0
HOLE  15   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                           2P2.1400
UNIT 51
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -Y'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   0.0       -0.1584      0.0
UNIT 52
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +Y'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   0.0       0.1584       0.0
UNIT 53
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   -0.1584   0.0           0.0
UNIT 54
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   0.1584    0.0          0.0
UNIT 55
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X +Y'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   0.1584    0.1584       0.0
UNIT 56
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X +Y'
CUBOID 3 1 4P10.4635                           2P2.1400
HOLE  50   -0.1584   0.1584        0.0
UNIT 57
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X -Y'
CUBOID 3 1 4P10.4635                              2P2.1400
HOLE  50   0.1584   -0.1584       0.0
UNIT 58
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X -Y'
CUBOID 3 1 4P10.4635                              2P2.1400
HOLE  50   -0.1584   -0.1584       0.0
UNIT 59
COM='WATER LEVEL CENTRAL HOLE'
CUBOID 3 1 4P10.4636                              2P2.1400
'
'   SUPPORT DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 60
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                               2P0.6604
CUBOID 5 1 4P10.0661                              2P0.6604
CUBOID 3 1 4P10.25681                             2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0      -10.1615 0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                              2P0.6604
UNIT 61
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   0.0       -0.1584       0.0
UNIT 62
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   0.0       0.1584        0.0
UNIT 63
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   -0.1584   0.0            0.0
UNIT 64
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   0.1584   0.0            0.0
UNIT 65
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   0.1584   0.1584         0.0
UNIT 66
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X +Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   -0.1584   0.1584         0.0
UNIT 67
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   0.1584   -0.1584        0.0
UNIT 68
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  60   -0.1584   -0.1584        0.0
UNIT 69
COM='SUPPORT DISK CENTRAL HOLE'
CUBOID 3 1 4P10.4636   2P0.6604
'
'   HEAT TRANSFER DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 70
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                               2P0.6604
CUBOID 5 1 4P10.0661                              2P0.6604
CUBOID 3 1 4P10.25681                             2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0      -10.1615 0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                              2P0.6604
UNIT 71
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  70   0.0       -0.1584       0.0
UNIT 72
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  70   0.0       0.1584        0.0
UNIT 73
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  70   -0.1584   0.0            0.0
UNIT 74
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  70   0.1584   0.0            0.0
UNIT 75
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                              2P0.6604
HOLE  70   0.1584   0.1584         0.0
UNIT 76
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                              2P0.6604
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
HOLE  70   -0.1584   0.1584        0.0
UNIT 77
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                          2P0.6604
HOLE  70   0.1584   -0.1584        0.0
UNIT 78
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                          2P0.6604
HOLE  70   -0.1584   -0.1584       0.0
UNIT 79
COM='HEAT TRANSFER CENTRAL HOLE'
CUBOID 3 1 4P10.4636                          2P0.6604
'
'  WATER LEVEL BASKET ARRAYS
'
UNIT 80
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 20 -10.4636 -33.6323 -2.1400
UNIT 81
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 21 -10.4636 -33.6323 -2.1400
UNIT 82
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 22 -10.4636 -56.6549 -2.1400
UNIT 83
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 23 -10.4636 -56.6549 -2.1400
UNIT 84
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 24 -10.4636 -79.5251 -2.1400
UNIT 85
COM='13X1 WATER LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 25 -10.4636 -79.5251 -2.1400
UNIT 86
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 26 -10.4636 -79.5251 -2.1400
'
'  SUPPORT DISK LEVEL BASKET ARRAYS
'
UNIT 90
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 30 -10.4636 -33.6323 -0.6604
UNIT 91
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 31 -10.4636 -33.6323 -0.6604
UNIT 92
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 32 -10.4636 -56.6549 -0.6604
UNIT 93
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 33 -10.4636 -56.6549 -0.6604
UNIT 94
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 34 -10.4636 -79.5251 -0.6604
UNIT 95
COM='13X1 SUPPORT DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 35 -10.4636 -79.5251 -0.6604
UNIT 96
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 36 -10.4636 -79.5251 -0.6604
'
'  HEAT TRANSFER DISK LEVEL BASKET ARRAYS
'
UNIT 100
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 40 -10.4636 -33.6323 -0.6604
UNIT 101
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 41 -10.4636 -33.6323 -0.6604
UNIT 102
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 42 -10.4636 -56.6549 -0.6604
UNIT 103
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 43 -10.4636 -56.6549 -0.6604
UNIT 104
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 44 -10.4636 -79.5251 -0.6604
UNIT 105
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 45 -10.4636 -79.5251 -0.6604
UNIT 106
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 46 -10.4636 -79.5251 -0.6604
'
'  BASKET ARRAY IN TRANSFER CASK OVERPACK (LEVEL CONSTRUCTION)
'
UNIT 110
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - WATER LEVEL'
ARRAY 50 -33.6323 -79.5251 -2.1400
CYLINDER 3 1 88.1253      2P2.1400
HOLE 80      -69.0614 0.0 0.0
HOLE 82      -46.1912 0.0 0.0
HOLE 81       69.0614 0.0 0.0
HOLE 83       46.1912 0.0 0.0
CYLINDER  5 1  89.7128    2P2.1400
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
CYLINDER  0 1  90.805      2P2.1400
CYLINDER  9 1  92.71       2P2.1400
CYLINDER  7 1 101.6        2P2.1400
CYLINDER  8 1 106.68       2P2.1400
CYLINDER  9 1 109.855      2P2.1400
CUBOID   10 1 4P159.855    2P2.1400
UNIT 111
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - SUPPORT DISK LEVEL'
ARRAY 51 -33.6323 -79.5251 -0.6604
CYLINDER 5 1 87.6046      2P0.6604
HOLE 90      -69.0614 0.0 0.0
HOLE 92      -46.1912 0.0 0.0
HOLE 91       69.0614 0.0 0.0
HOLE 93       46.1912 0.0 0.0
CYLINDER  3 1  88.1253     2P0.6604
CYLINDER  5 1  89.7128     2P0.6604
CYLINDER  0 1  90.805      2P0.6604
CYLINDER  9 1  92.71       2P0.6604
CYLINDER  7 1 101.6        2P0.6604
CYLINDER  8 1 106.68       2P0.6604
CYLINDER  9 1 109.855      2P0.6604
CUBOID   10 1 4P159.855    2P0.6604
UNIT 112
COM='BASKET ARRAY IN TRANSFER CASK OVERPACK - HEAT TRANSFER DISK LEVEL'
ARRAY 52 -33.6323 -79.5251 -0.6604
CYLINDER 4 1 87.249       2P0.6604
HOLE 100     -69.0614 0.0 0.0
HOLE 102     -46.1912 0.0 0.0
HOLE 101      69.0614 0.0 0.0
HOLE 103      46.1912 0.0 0.0
CYLINDER  3 1  88.1253     2P0.6604
CYLINDER  5 1  89.7128     2P0.6604
CYLINDER  0 1  90.805      2P0.6604
CYLINDER  9 1  92.71       2P0.6604
CYLINDER  7 1 101.6        2P0.6604
CYLINDER  8 1 106.68       2P0.6604
CYLINDER  9 1 109.855      2P0.6604
CUBOID   10 1 4P159.855    2P0.6604
'
'  GLOBAL UNIT
'
GLOBAL UNIT 120
ARRAY 60 -159.855 -159.855 0.0
END GEOM
READ ARRAY
ARA=1 NUX=16 NUY=16 NUZ=1  FILL
1 1 1 1 1 1 1 1 3 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 4 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
END FILL
ARA=2 NUX=16 NUY=16 NUZ=1  FILL
5 5 5 5 5 5 5 5 7 6 6 6 6 6 6 6
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
7 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 8 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
END FILL
'
'  WATER LEVEL ARRAYS
'
ARA=20  NUX=1 NUY=5 NUZ=1
FILL
55
22
54
22
57
END FILL
ARA=21  NUX=1 NUY=5 NUZ=1
FILL
56
22
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
53
22
58
END FILL
ARA=22  NUX=1 NUY=9 NUZ=1
FILL
55
21
55
22
54
22
57
21
57
END FILL
ARA=23  NUX=1 NUY=9 NUZ=1
FILL
56
21
56
22
53
22
58
21
58
END FILL
ARA=24  NUX=1 NUY=13 NUZ=1
FILL
55
20
55
21
55
22
54
22
57
21
57
20
57
END FILL
ARA=25  NUX=1 NUY=13 NUZ=1
FILL
52
20
52
21
52
22
59
22
51
21
51
20
51
END FILL
ARA=26  NUX=1 NUY=13 NUZ=1
FILL
56
20
56
21
56
22
53
22
58
21
58
20
58
END FILL
'
'  SUPPOR DISK LEVEL ARRAYS
'
ARA=30  NUX=1 NUY=5 NUZ=1
FILL
65
32
64
32
67
END FILL
ARA=31  NUX=1 NUY=5 NUZ=1
FILL
66
32
63
32
68
END FILL
ARA=32  NUX=1 NUY=9 NUZ=1
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
FILL
65
31
65
32
64
32
67
31
67
END FILL
ARA=33  NUX=1 NUY=9 NUZ=1
FILL
66
31
66
32
63
32
68
31
68
END FILL
ARA=34  NUX=1 NUY=13 NUZ=1
FILL
65
30
65
31
65
32
64
32
67
31
67
30
67
END FILL
ARA=35  NUX=1 NUY=13 NUZ=1
FILL
62
30
62
31
62
32
69
32
61
31
61
30
61
END FILL
ARA=36  NUX=1 NUY=13 NUZ=1
FILL
66
30
66
31
66
32
63
32
68
31
68
30
68
END FILL
'
' HEAT TRANSFER DISK LEVEL ARRAYS
'
ARA=40  NUX=1 NUY=5 NUZ=1
FILL
75
42
74
42
77
END FILL
ARA=41  NUX=1 NUY=5 NUZ=1
FILL
76
42
73
42
78
END FILL
ARA=42  NUX=1 NUY=9 NUZ=1
FILL
75
41
75
42
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
74
42
77
41
77
END FILL
ARA=43  NUX=1 NUY=9 NUZ=1
FILL
76
41
76
42
73
42
78
41
78
END FILL
ARA=44  NUX=1 NUY=13 NUZ=1
FILL
75
40
75
41
75
42
74
42
77
41
77
40
77
END FILL
ARA=45  NUX=1 NUY=13 NUZ=1
FILL
72
40
72
41
72
42
79
42
71
41
71
40
71
END FILL
ARA=46  NUX=1 NUY=13 NUZ=1
FILL
76
40
76
41
76
42
73
42
78
41
78
40
78
END FILL
'
'  MAJOR ARRAYS
'
ARA=50 NUX=5 NUY=1 NUZ=1
FILL
84 23 85 23 86
END FILL
ARA=51 NUX=5 NUY=1 NUZ=1
FILL
94 33 95 33 96
END FILL
ARA=52 NUX=5 NUY=1 NUZ=1
FILL
104 43 105 43 106
END FILL
'
'  GLOBAL ARRAY
'
ARA=60 NUX=1 NUY=1 NUZ=4
FILL
112
110
111
110
END FILL
END ARRAY

READ BOUNDS ZFC=PER YXF=REFLECT END BOUNDS

END DATA
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
 CCCCCCCCCCC     SSSSSSSSSSS      AAAAAAAAA      SSSSSSSSSSS     22222222222    5555555555555
CCCCCCCCCCCCC   SSSSSSSSSSSSS    AAAAAAAAAAA    SSSSSSSSSSSSS   2222222222222   5555555555555
CC         CC   SS         SS   AA         AA   SS         SS   22         22   55
CC              SS              AA         AA   SS                         22   55
CC              SS              AA         AA   SS                         22   55
CC              SSSSSSSSSSSS    AAAAAAAAAAAAA   SSSSSSSSSSSS             22     555555555555
CC               SSSSSSSSSSSS   AAAAAAAAAAAAA    SSSSSSSSSSSS          22       5555555555555
CC                         SS   AA         AA              SS        22                    55
CC                         SS   AA         AA              SS      22                      55
CC         CC   SS         SS   AA         AA   SS         SS    22             55         55
CCCCCCCCCCCCC   SSSSSSSSSSSSS   AA         AA   SSSSSSSSSSSSS   2222222222222   5555555555555
 CCCCCCCCCCC     SSSSSSSSSSS    AA         AA    SSSSSSSSSSS    2222222222222    55555555555


 SSSSSSSSSSS     CCCCCCCCCCC      AAAAAAAAA     LL              EEEEEEEEEEEEE                   PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS   CCCCCCCCCCCCC    AAAAAAAAAAA    LL              EEEEEEEEEEEEE                   PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS   CC         CC   AA         AA   LL              EE                              PP         PP   CC         CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SSSSSSSSSSSS    CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPP    CC
           SS   CC              AA         AA   LL              EE                              PP              CC
           SS   CC              AA         AA   LL              EE                              PP              CC
SS         SS   CC         CC   AA         AA   LL              EE                              PP              CC         CC
SSSSSSSSSSSSS   CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLL    EEEEEEEEEEEEE                   PP              CCCCCCCCCCCCC
 SSSSSSSSSSS     CCCCCCCCCCC    AA         AA   LLLLLLLLLLLL    EEEEEEEEEEEEE                   PP               CCCCCCCCCCC


      11              11                    //        11        7777777777777               //   99999999999     66666666666
     111             111                   //        111        777777777777               //   9999999999999   6666666666666
    1111            1111                  //        1111        77         77             //    99         99   66
      11              11                 //           11                  77             //     99         99   66
      11              11                //            11                 77             //      99         99   66
      11              11               //             11                77             //       9999999999999   666666666666
      11              11              //              11                77            //         999999999999   6666666666666
      11              11             //               11               77            //                    99   66         66
      11              11            //                11               77           //                     99   66         66
      11              11           //                 11              77           //                      99   66         66
   11111111        11111111       //               11111111           77          //            9999999999999   6666666666666
   11111111        11111111      //                11111111           77         //             999999999999     66666666666


      11        5555555555555                   5555555555555    22222222222                          11         33333333333
     111        5555555555555                   5555555555555   2222222222222                        111        3333333333333
    1111        55                    :::       55              22         22         :::           1111        33         33
      11        55                    :::       55                         22         :::             11                   33
      11        55                    :::       55                         22         :::             11                   33
      11        555555555555                    555555555555             22                           11                  333
      11        5555555555555                   5555555555555          22                             11                  333
      11                   55         :::                  55        22               :::             11                   33
      11                   55         :::                  55      22                 :::             11                   33
      11        55         55         :::       55         55    22                   :::             11        33         33
   11111111     5555555555555                   5555555555555   2222222222222                      11111111     3333333333333
   11111111      55555555555                     55555555555    2222222222222                      11111111      33333333333
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA     LL             EEEEEEEEEEEEE                 PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA    LL             EEEEEEEEEEEEE                 PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS  CC         CC   AA         AA   LL             EE                            PP         PP   CC         CC
SS             CC              AA         AA   LL             EE                            PP         PP   CC
SS             CC              AA         AA   LL             EE                            PP         PP   CC
SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL             EEEEEEEEE     -------------   PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS  CC              AAAAAAAAAAAAA   LL             EEEEEEEEE     -------------   PPPPPPPPPPPP    CC
           SS  CC              AA         AA   LL             EE                            PP              CC
           SS  CC              AA         AA   LL             EE                            PP              CC
SS         SS  CC         CC   AA         AA   LL             EE                            PP              CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP              CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC    AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP               CCCCCCCCCCC
```

```
********************************************************************************
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                    PROGRAM VERIFICATION INFORMATION                  *****
*****                                                                      *****
*****                 CODE SYSTEM:   SCALE-PC VERSION:  4.3                *****
*****                                                                      *****
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                                                                      *****
*****                  PROGRAM:  CSAS                                      *****
*****                                                                      *****
*****            CREATION DATE:  03-08-96                                  *****
*****                                                                      *****
*****                   VOLUME:  ENG                                       *****
*****                                                                      *****
*****                  LIBRARY:  G:\scale43\exe                            *****
*****                                                                      *****
*****                                                                      *****
*****          PRODUCTION DOCE:  CSAS                                      *****
*****                                                                      *****
*****                  VERSION:  3.1                                       *****
*****                                                                      *****
*****                  JOBNAME:  SCALE-PC                                  *****
*****                                                                      *****
*****        DATE OF EXECUTION:  11/17/96                                  *****
*****                                                                      *****
*****        TIME OF EXECUTION:  15:52:13                                  *****
*****                                                                      *****
*****                                                                      *****
********************************************************************************
********************************************************************************
********************************************************************************
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP

    **** PROBLEM PARAMETERS ****

    LIB 27GROUPNDF4  LIBRARY
    MXX             11 MIXTURES
    MSC             20 COMPOSITION SPECIFICATIONS
    IZM              4 MATERIAL ZONES
    GE  LATTICECELL  GEOMETRY
    MORE             0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
    MSLN             0 FUEL SOLUTIONS

    **** PROBLEM COMPOSITION DESCRIPTION ****

    SC  UO2            STANDARD COMPOSITION
    MX               1 MIXTURE NO.
    VF          0.9500 VOLUME FRACTION
    ROTH       10.9600 THEORETICAL DENSITY
    NEL              2 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 92000      1.00 ATOM/MOLECULE
                                  92235     4.000 WT%
                                  92238    96.000 WT%
                  8016      2.00 ATOMS/MOLECULE
    END

    SC  ZIRCALLOY      STANDARD COMPOSITION
    MX               2 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        6.5600 THEORETICAL DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 40302      1.00 ATOM/MOLECULE
    END

    SC  H2O            STANDARD COMPOSITION
    MX               3 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        0.9982 THEORETICAL DENSITY
    NEL              2 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  1001      2.00 ATOMS/MOLECULE
                  8016      1.00 ATOM/MOLECULE
    END

    SC  AL             STANDARD COMPOSITION
    MX               4 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        2.7020 THEORETICAL DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 13027      1.00 ATOM/MOLECULE
    END

    SC  SS304          STANDARD COMPOSITION
    MX               5 MIXTURE NO.
    VF          1.0000 VOLUME FRACTION
    ROTH        7.9200 THEORETICAL DENSITY
    NEL              4 NO. ELEMENTS
    ICP              0 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                 24304    19.000 WT%
                 25055     2.000 WT%
                 26304    69.500 WT%
                 28304     9.500 WT%
    END

    SC  B-10           STANDARD COMPOSITION
    MX               6 MIXTURE NO.
    VF          0.0450 VOLUME FRACTION
    ROTH        2.6226 SPECIFIED DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  5010      1.00 ATOM/MOLECULE
    END

    SC  B-11           STANDARD COMPOSITION
    MX               6 MIXTURE NO.
    VF          0.2736 VOLUME FRACTION
    ROTH        2.6226 SPECIFIED DENSITY
    NEL              1 NO. ELEMENTS
    ICP              1 0/1 MIXTURE/COMPOUND
    TEMP         293.0 DEG KELVIN
                  5011      1.00 ATOM/MOLECULE
    END

    SC  C              STANDARD COMPOSITION
    MX               6 MIXTURE NO.
    VF          0.0927 VOLUME FRACTION
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
ROTH        2.6226 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              6012        1.00 ATOM/MOLECULE
END

SC  AL             STANDARD COMPOSITION
MX               6 MIXTURE NO.
VF          0.5737 VOLUME FRACTION
ROTH        2.6226 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
             13027        1.00 ATOM/MOLECULE
END

SC  PB             STANDARD COMPOSITION
MX               7 MIXTURE NO.
VF          1.0000 VOLUME FRACTION
ROTH       11.3440 THEORETICAL DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
             82000        1.00 ATOM/MOLECULE
END

SC  H              STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.0600 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              1001        1.00 ATOM/MOLECULE
END

SC  O              STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.4250 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              8016        1.00 ATOM/MOLECULE
END

SC  C              STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.2770 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              6012        1.00 ATOM/MOLECULE
END

SC  N              STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.0200 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              7014        1.00 ATOM/MOLECULE
END

SC  AL             STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.2140 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
             13027        1.00 ATOM/MOLECULE
END

SC  B-10           STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.0010 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              5010        1.00 ATOM/MOLECULE
END

SC  B-11           STANDARD COMPOSITION
MX               8 MIXTURE NO.
VF          0.0040 VOLUME FRACTION
ROTH        1.6291 SPECIFIED DENSITY
NEL              1 NO. ELEMENTS
ICP              1 0/1 MIXTURE/COMPOUND
TEMP         293.0 DEG KELVIN
              5011        1.00 ATOM/MOLECULE
END
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
SC  CARBONSTEEL  STANDARD COMPOSITION
MX             9 MIXTURE NO.
VF        1.0000 VOLUME FRACTION
ROTH      7.8212 THEORETICAL DENSITY
NEL            2 NO. ELEMENTS
ICP            0 0/1 MIXTURE/COMPOUND
TEMP       293.0 DEG KELVIN
           26000     99.000 WT%
            6012      1.000 WT%
END

SC  H2O          STANDARD COMPOSITION
MX            10 MIXTURE NO.
VF        1.0000 VOLUME FRACTION
ROTH      0.9982 THEORETICAL DENSITY
NEL            2 NO. ELEMENTS
ICP            1 0/1 MIXTURE/COMPOUND
TEMP       293.0 DEG KELVIN
            1001        2.00 ATOMS/MOLECULE
            8016        1.00 ATOM/MOLECULE
END

SC  H2O          STANDARD COMPOSITION
MX            11 MIXTURE NO.
VF        1.0000 VOLUME FRACTION
ROTH      0.9982 THEORETICAL DENSITY
NEL            2 NO. ELEMENTS
ICP            1 0/1 MIXTURE/COMPOUND
TEMP       293.0 DEG KELVIN
            1001        2.00 ATOMS/MOLECULE
            8016        1.00 ATOM/MOLECULE
END

**** PROBLEM GEOMETRY ****

CTP SQUAREPITCH  CELL TYPE
PITCH     1.1887 CM CENTER TO CENTER SPACING
FUELOD    0.7887 CM FUEL DIAMETER OR SLAB THICKNESS
MFUEL          1 MIXTURE NO. OF FUEL
MMOD           3 MIXTURE NO. OF MODERATOR
CLADOD    0.9271 CM CLAD OUTER DIAMETER
MCLAD          2 MIXTURE NO. OF CLAD
GAPOD     0.8052 CM GAP OUTER DIAMETER
MGAP          11 MIXTURE NO. OF GAP

ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

               ZONE  1 IS FUEL
               ZONE  2 IS GAP
               ZONE  3 IS CLAD
               ZONE  4 IS MOD
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
***                                                                                                   ***
***                TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP ***
***                                                                                                   ***

***                         ********** DATA LIBRARY INFORMATION **********                            ***
***      UNIT                                              VOLUME                                     ***
***     NUMBER                 DATA SET NAME                NAME       UNIT FUNCTION                  ***
***     ------                 -------------                ----       -------------                  ***
***
***       89     G:\scale43\DATALIB\FT89F001                           STANDARD COMPOSITION LIBRARY   ***
***       82     G:\scale43\DATALIB\FT82F001                           CROSS SECTION LIBRARY          ***
***       11     C:\svv\yankee\wrr5402\tf-mr-wg\FT11F001               SHORT CROSS SECTION LIBRARY    ***
***       90     C:\svv\yankee\wrr5402\tf-mr-wg\FT90F001               INPUT DATA DIRECT ACCESS       ***

***                            STANDARD COMPOSITION LIBRARY DATA                                      ***
***                            ---------------------------------                                      ***
***      UNIT NUMBER  :  89                                                                           ***
***      DATASET NAME :  G:\scale43\DATALIB\FT89F001                                                  ***
***      LIBRARY TITLE:  SCALE-4 STANDARD COMPOSITION LIBRARY                                         ***
***                        637 STANDARD COMPOSITIONS, 490 NUCLIDES                                    ***
***                        90 ELEMENTS WITH VARIABLE ISOTOPIC DISTRBUTIONS.                           ***
***      CREATION DATE:   6/30/95                                                                     ***

***                              CROSS SECTION LIBRARY DATA                                           ***
***                             ---------------------------                                           ***
***      UNIT NUMBER  :  82                                                                           ***
***      DATASET NAME :  G:\scale43\DATALIB\FT82F001                                                  ***
***      LIBRARY TITLE:  SCALE 4.2 - 27 GROUP NEUTRON GROUP LIBRARY                                   ***
***                         BASED ON ENDF-B VERSION 4 DATA                                            ***
***                            COMPILED FOR NRC      1/27/89                                          ***
***                               LAST UPDATED                                            08/12/94    ***
***                                  L.M.PETRIE   -    ORNL                                           ***

CONTROL MODULE CSAS25    IS COMPLETE.
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
             KK        KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO               VV          VV
             KK       KK   EEEEEEEEEEEEE  NNN        NN  OOOOOOOOOOOOO              VV          VV
             KK      KK    EE             NNNN       NN  OO         OO              VV          VV
             KK     KK     EE             NN NN      NN  OO         OO              VV          VV
             KK    KK      EE             NN  NN     NN  OO         OO              VV          VV
             KKKKKKKK      EEEEEEEEE      NN   NN    NN  OO         OO  ----------- VV          VV
             KKKKKKKK      EEEEEEEEE      NN    NN   NN  OO         OO  -----------  VV        VV
             KK    KK      EE             NN     NN  NN  OO         OO                VV      VV
             KK     KK     EE             NN      NN NN  OO         OO                 VV    VV
             KK      KK    EE             NN       NNNN  OO         OO                  VV  VV
             KK       KK   EEEEEEEEEEEEE  NN        NNN  OOOOOOOOOOOOO                   VVVV
             KK        KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO                     VV

 SSSSSSSSSSS   CCCCCCCCCCC     AAAAAAAAA    LL            EEEEEEEEEEEEE             PPPPPPPPPPPP    CCCCCCCCCCC
SSSSSSSSSSSSS CCCCCCCCCCCCC   AAAAAAAAAAA   LL            EEEEEEEEEEEEE             PPPPPPPPPPPPP  CCCCCCCCCCCCC
SS         SS CC         CC  AA         AA  LL            EE                        PP         PP  CC         CC
SS            CC             AA         AA  LL            EE                        PP         PP  CC
SS            CC             AA         AA  LL            EE                        PP         PP  CC
SSSSSSSSSSSS  CC             AAAAAAAAAAAAA  LL            EEEEEEEEE    -----------  PPPPPPPPPPPPP  CC
 SSSSSSSSSSSS CC             AAAAAAAAAAAAA  LL            EEEEEEEEE    -----------  PPPPPPPPPPPP   CC
           SS CC             AA         AA  LL            EE                        PP             CC
           SS CC             AA         AA  LL            EE                        PP             CC
SS         SS CC         CC  AA         AA  LL            EE                        PP             CC         CC
SSSSSSSSSSSSS CCCCCCCCCCCCC  AA         AA  LLLLLLLLLLLLL EEEEEEEEEEEEE             PP             CCCCCCCCCCCCC
 SSSSSSSSSSS   CCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL EEEEEEEEEEEEE             PP              CCCCCCCCCCC

     11           11             //       11        7777777777777       //  99999999999    666666666666
    111          111            //       111        777777777777       //  9999999999999  6666666666666
   1111         1111           //       1111        77         77     //   99         99  66
     11           11          //          11                  77     //    99         99  66
     11           11         //           11                 77     //     99         99  66
     11           11        //            11                77     //      9999999999999  666666666666
     11           11       //             11               77     //        999999999999  6666666666666
     11           11      //              11              77     //                  99  66         66
     11           11     //               11             77     //                   99  66         66
     11           11    //                11            77     //                    99  66         66
  11111111     11111111 //             11111111         77    //        9999999999999  6666666666666
  11111111     11111111 //             11111111         77   //         999999999999    66666666666

     11      5555555555555             5555555555555  22222222222             22222222222    99999999999
    111      5555555555555             5555555555555 2222222222222           2222222222222  9999999999999
   1111      55                 :::    55            22         22    :::    22         22  99         99
     11      55                 :::    55                       22    :::               22  99         99
     11      55                 :::    55                       22    :::               22  99         99
     11      555555555555              555555555555            22                      22   9999999999999
     11      5555555555555             5555555555555          22                      22     999999999999
     11                 55      :::               55        22        :::           22                 99
     11                 55      :::               55      22          :::         22                   99
     11      55         55      :::    55         55    22            :::       22                     99
  11111111   5555555555555             5555555555555 2222222222222           2222222222222  9999999999999
  11111111    55555555555               55555555555  2222222222222           2222222222222  999999999999
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL              EEEEEEEEEEEEE                    PPPPPPPPPPPP    CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL              EEEEEEEEEEEEE                    PPPPPPPPPPPPP  CCCCCCCCCCCCC
SS         SS  CC         CC   AA         AA  LL              EE                               PP         PP  CC         CC
SS             CC              AA         AA  LL              EE                               PP         PP  CC
SS             CC              AA         AA  LL              EE                               PP         PP  CC
SSSSSSSSSSSS   CC              AAAAAAAAAAAAA  LL              EEEEEEEEE       -------------    PPPPPPPPPPPPP  CC
 SSSSSSSSSSSS  CC              AAAAAAAAAAAAA  LL              EEEEEEEEE       -------------    PPPPPPPPPPPP   CC
           SS  CC              AA         AA  LL              EE                               PP             CC
           SS  CC              AA         AA  LL              EE                               PP             CC
SS         SS  CC         CC   AA         AA  LL              EE                               PP             CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                    PP             CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC    AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                    PP              CCCCCCCCCCC
```

```
*******************************************************************************
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                  PROGRAM VERIFICATION INFORMATION                   *****
*****                                                                     *****
*****                CODE SYSTEM:   SCALE-PC VERSION:  4.3                *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                                                                     *****
*****                 PROGRAM:  000009                                    *****
*****                                                                     *****
*****           CREATION DATE:  03-08-96                                  *****
*****                                                                     *****
*****                  VOLUME:  ENG                                       *****
*****                                                                     *****
*****                 LIBRARY:  G:\scale43\exe                            *****
*****                                                                     *****
*****                                                                     *****
*****         PRODUCTION CODE:   KENOVA                                   *****
*****                                                                     *****
*****                 VERSION:   3.1                                      *****
*****                                                                     *****
*****                 JOBNAME:  SCALE-PC                                  *****
*****                                                                     *****
*****       DATE OF EXECUTION:  11/17/96                                  *****
*****                                                                     *****
*****       TIME OF EXECUTION:  15:52:29                                  *****
*****                                                                     *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*******************************************************************************
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
*****************************************************************************************************************
***                                                                                                           ***
***                              TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP ***
***                                                                                                           ***
*****************************************************************************************************************
***                           ******        NUMERIC PARAMETERS        ******                                  ***
***                                                                                                           ***
***                                                                                                           ***
***          TME        MAXIMUM PROBLEM TIME (MIN)                          500.00                            ***
***                                                                                                           ***
***          TBA        TIME PER GENERATION (MIN)                             0.50                            ***
***                                                                                                           ***
***          GEN        NUMBER OF GENERATIONS                                 1003                            ***
***                                                                                                           ***
***          NPG        NUMBER PER GENERATION                                 1000                            ***
***                                                                                                           ***
***          NSK        NUMBER OF GENERATIONS TO BE SKIPPED                      3                            ***
***                                                                                                           ***
***          BEG        BEGINNING GENERATION NUMBER                              1                            ***
***                                                                                                           ***
***          RES        GENERATIONS BETWEEN CHECKPOINTS                          0                            ***
***                                                                                                           ***
***          X1D        NUMBER OF EXTRA 1-D CROSS SECTIONS                       1                            ***
***                                                                                                           ***
***          NBK        NEUTRON BANK SIZE                                     1025                            ***
***                                                                                                           ***
***          XNB        EXTRA POSITIONS IN NEUTRON BANK                          0                            ***
***                                                                                                           ***
***          NFB        FISSION BANK SIZE                                     1000                            ***
***                                                                                                           ***
***          XFB        EXTRA POSITIONS IN FISSION BANK                          0                            ***
***                                                                                                           ***
***          WTA        DEFAULT VALUE OF WEIGHT AVERAGE                     0.5000                            ***
***                                                                                                           ***
***          WTH        WEIGHT HIGH FOR SPLITTING                           3.0000                            ***
***                                                                                                           ***
***          WTL        WEIGHT LOW FOR RUSSIAN ROULETTE                     0.3333                            ***
***                                                                                                           ***
***          RND        STARTING RANDOM NUMBER                         BB827100001                            ***
***                                                                                                           ***
***          NB8        NUMBER OF D.A. BLOCKS ON UNIT  8                       200                            ***
***                                                                                                           ***
***          NL8        LENGTH OF D.A. BLOCKS ON UNIT  8                       512                            ***
***                                                                                                           ***
***          ADJ        MODE OF CALCULATION                                FORWARD                            ***
***                                                                                                           ***
***                     INPUT DATA WRITTEN ON RESTART UNIT                      NO                            ***
***                                                                                                           ***
***                     BINARY DATA INTERFACE                                  YES                            ***
***                                                                                                           ***
***                                                                                                           ***
*****************************************************************************************************************
*****************************************************************************************************************
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
*******************************************************************************************************
*******************************************************************************************************
***                                                                                                 ***
***                  TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP ***
***                                                                                                 ***
*******************************************************************************************************
***                  ******      LOGICAL PARAMETERS       ******                                    ***
***                                                                                                 ***
***  RUN  EXECUTE PROBLEM AFTER CHECKING DATA   YES     PLT  PLOT PICTURE MAP(S)                  NO ***
***                                                                                                 ***
***  FLX  COMPUTE FLUX                          NO      FDN  COMPUTE FISSION DENSITIES            NO ***
***                                                                                                 ***
***  SMU  COMPUTE AVG UNIT SELF-MULTIPLICATION  NO      NUB  COMPUTE NU-BAR & AVG FISSION GROUP  YES ***
***                                                                                                 ***
***  MKU  COMPUTE MATRIX K-EFF BY UNIT NUMBER   NO      MKP  COMPUTE MATRIX K-EFF BY UNIT LOCATION  NO ***
***                                                                                                 ***
***  CKU  COMPUTE COFACTOR K-EFF BY UNIT NUMBER  NO     CKP  COMPUTE COFACTOR K-EFF BY UNIT LOCATION  NO ***
***                                                                                                 ***
***  FMU  PRINT FISS PROD MATRIX BY UNIT NUMBER  NO     FMP  PRINT FISS PROD MATRIX BY UNIT LOCATION  NO ***
***                                                                                                 ***
***  MKH  COMPUTE MATRIX K-EFF BY HOLE NUMBER   NO      MKA  COMPUTE MATRIX K-EFF BY ARRAY NUMBER  NO ***
***                                                                                                 ***
***  CKH  COMPUTE COFACTOR K-EFF BY HOLE NUMBER  NO     CKA  COMPUTE COFACTOR K-EFF BY ARRAY NUMBER  NO ***
***                                                                                                 ***
***  FMH  PRINT FISS PROD MATRIX BY HOLE NUMBER  NO     FMA  PRINT FISS PROD MATRIX BY ARRAY NUMBER  NO ***
***                                                                                                 ***
***  HHL  COLLECT MATRIX BY HIGHEST HOLE LEVEL  NO      HAL  COLLECT MATRIX BY HIGHEST ARRAY LEVEL  NO ***
***                                                                                                 ***
***  AMX  PRINT ALL MIXED CROSS SECTIONS        NO      FAR  PRINT FIS. AND ABS. BY REGION        NO ***
***                                                                                                 ***
***  XS1  PRINT 1-D MIXTURE X-SECTIONS          NO      GAS  PRINT FAR BY GROUP                   NO ***
***                                                                                                 ***
***  XS2  PRINT 2-D MIXTURE X-SECTIONS          NO      PAX  PRINT XSEC-ALBEDO CORRELATION TABLES  NO ***
***                                                                                                 ***
***  XAP  PRINT MIXTURE ANGLES & PROBABILITIES  NO      PWT  PRINT WEIGHT AVERAGE ARRAY           NO ***
***                                                                                                 ***
***  PKI  PRINT FISSION SPECTRUM                NO      PGM  PRINT INPUT GEOMETRY                 NO ***
***                                                                                                 ***
***  P1D  PRINT EXTRA 1-D CROSS SECTIONS        NO      BUG  PRINT DEBUG INFORMATION              NO ***
***                                                                                                 ***
***                                                     TRK  PRINT TRACKING INFORMATION           NO ***
***                                                                                                 ***
***                                                                                                 ***
*******************************************************************************************************
*******************************************************************************************************
*******************************************************************************************************
                    PARAMETER INPUT COMPLETED

         ........      0 IO'S WERE USED READING THE PARAMETER DATA      ........

     *************** DATA READING COMPLETED ***************
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
****************************************************************************************************************
***                                                                                                          ***
***                              TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP ***
***                                                                                                          ***
****************************************************************************************************************
****************************************************************************************************************
***                                                                                                          ***
***       UNIT                                                    VOLUME                                     ***
***      NUMBER                DATA SET NAME                       NAME        UNIT FUNCTION                 ***
***      ------                -------------                       ----        -------------                 ***
***                                                                                                          ***
***    XSC  14    C:\svv\yankee\wrr5402\tf-mr-wg\FT14F001                      MIXED CROSS SECTIONS          ***
***                                                                                                          ***
***    ALB  79    G:\scale43\DATALIB\FT79F001                                  INPUT ALBEDOS                 ***
***                                                                                                          ***
***    WTS  80    G:\scale43\DATALIB\FT80F001                                  INPUT WEIGHTS                 ***
***                                                                                                          ***
***    SKT  16     UNKNOWN                                                     WRITE SCRATCH DATA            ***
***                                                                                                          ***
***    BIN  95    C:\svv\yankee\wrr5402\tf-mr-wg\FT95F001                      BINARY INPUT DATA             ***
***                                                                                                          ***
***    RST  95    C:\svv\yankee\wrr5402\tf-mr-wg\FT95F001                      READ RESTART DATA             ***
***                                                                                                          ***
***    LIB   4    C:\svv\yankee\wrr5402\tf-mr-wg\FT04F001                      INPUT AMPX WORKING LIBRARY    ***
***                                                                                                          ***
***          8    C:\svv\yankee\wrr5402\tf-mr-wg\FT08F001                      INPUT DATA DIRECT ACCESS      ***
***                                                                                                          ***
***          9     UNKNOWN                                                     SUPER GROUPED DIRECT ACCESS   ***
***                                                                                                          ***
***         10     UNKNOWN                                                     XSEC MIXING DIRECT ACCESS     ***
***                                                                                                          ***
****************************************************************************************************************

                        ........    0 IO'S WERE USED PREPARING INPUT DATA    ........

                         CROSS SECTIONS READ FROM THE AMPX WORKING LIBRARY ON UNIT     4
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
                              TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP
                                                      MIXING TABLE
                                              NUMBER OF SCATTERING ANGLES =  2
                                          CROSS SECTION MESSAGE THRESHOLD =3.0E-05

MIXTURE =     1         DENSITY(G/CC) =  10.412
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  1008016  4.64617E-02  1.18487E-01   8016    15.9904      OXYGEN-16      ENDF/B-IV MAT 1276                         UPDATED
08/12/94
  1092235  9.40641E-04  3.52606E-02  92235   235.0441      URANIUM-235    ENDF/B-IV MAT 1261                         UPDATED
08/12/94
  1092238  2.22902E-02  8.46253E-01  92238   238.0510      URANIUM-238    ENDF/B-IV MAT 1262                         UPDATED
08/12/94

MIXTURE =     2         DENSITY(G/CC) =  6.5600
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  2040302  4.33078E-02  1.00000E+00  40000    91.2196      ZIRCALLOY      ENDF/B-IV MAT 1284                         UPDATED
08/12/94

MIXTURE =     3         DENSITY(G/CC) = 0.99817
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  3001001  6.67692E-02  1.11927E-01   1001     1.0077      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                UPDATED
08/12/94
  3008016  3.33846E-02  8.88074E-01   8016    15.9904      OXYGEN-16      ENDF/B-IV MAT 1276                         UPDATED
08/12/94

MIXTURE =     4         DENSITY(G/CC) =  2.7020
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  4013027  6.03066E-02  1.00000E+00  13027    26.9818     AL-27 1193 218 GP 040375(5)                                UPDATED
08/12/94

MIXTURE =     5         DENSITY(G/CC) =  7.9200
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  5024304  1.74286E-02  1.90000E-01  24000    51.9957     CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'           UPDATED
08/12/94
  5025055  1.73633E-03  1.99999E-02  25055    54.9379      MANGANESE-55   ENDF/B-IV MAT 1197                         UPDATED
08/12/94
  5026304  5.93579E-02  6.95000E-01  26000    55.8447     FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'           UPDATED
08/12/94
  5028304  7.72070E-03  9.50001E-02  28000    58.6872     NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'           UPDATED
08/12/94

MIXTURE =     6         DENSITY(G/CC) =  2.5833
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  6005010  7.09799E-03  4.56855E-02   5010    10.0130     B-10 1273 218NGP 042375 P-3 293K                           UPDATED
08/12/94
  6005011  3.92499E-02  2.77771E-01   5011    11.0096      BORON-11       ENDF/B-IV MAT 1160                         UPDATED
08/12/94
  6006012  1.22006E-02  9.41116E-02   6000    12.0001      CARBON-12      ENDF/B-IV MAT 1274/THRM1065                UPDATED
08/12/94
  6013027  3.35812E-02  5.82432E-01  13027    26.9818     AL-27 1193 218 GP 040375(5)                                UPDATED
08/12/94

MIXTURE =     7         DENSITY(G/CC) =  11.344
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  7082000  3.29690E-02  1.00000E+00  82000   207.2100     PB   1288 218NGP 042375 P-3 293K                           UPDATED
08/12/94

MIXTURE =     8         DENSITY(G/CC) =  1.6307
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  8001001  5.84084E-02  5.99323E-02   1001     1.0077      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                UPDATED
08/12/94
  8005010  9.79802E-05  9.99025E-04   5010    10.0130     B-10 1273 218NGP 042375 P-3 293K                           UPDATED
08/12/94
  8005011  3.56450E-04  3.99615E-03   5011    11.0096      BORON-11       ENDF/B-IV MAT 1160                         UPDATED
08/12/94
  8006012  2.26463E-02  2.76729E-01   6000    12.0001      CARBON-12      ENDF/B-IV MAT 1274/THRM1065                UPDATED
08/12/94
  8007014  1.40121E-03  1.99805E-02   7014    14.0033      NITROGEN-14    ENDF/B-IV MAT 1275                         UPDATED
08/12/94
  8008016  2.60749E-02  4.24574E-01   8016    15.9904      OXYGEN-16      ENDF/B-IV MAT 1276                         UPDATED
08/12/94
  8013027  7.78110E-03  2.13789E-01  13027    26.9818     AL-27 1193 218 GP 040375(5)                                UPDATED
08/12/94

MIXTURE =     9         DENSITY(G/CC) =  7.8212
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
  9006012  3.92503E-03  1.00001E-02   6000    12.0001      CARBON-12      ENDF/B-IV MAT 1274/THRM1065                UPDATED
08/12/94
  9026000  8.34982E-02  9.90000E-01  26000    55.8447      IRON           ENDF/B-IV MAT 1192                         UPDATED
08/12/94

MIXTURE =    10         DENSITY(G/CC) = 0.99817
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
 10001001  6.67692E-02  1.11927E-01   1001     1.0077      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                UPDATED
08/12/94
 10008016  3.33846E-02  8.88074E-01   8016    15.9904      OXYGEN-16      ENDF/B-IV MAT 1276                         UPDATED
08/12/94

MIXTURE =    11         DENSITY(G/CC) = 0.99817
  NUCLIDE   ATOM-DENS.   WGT. FRAC.    ZA      AWT                 NUCLIDE TITLE
 11001001  6.67692E-02  1.11927E-01   1001     1.0077      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                UPDATED
08/12/94
 11008016  3.33846E-02  8.88074E-01   8016    15.9904      OXYGEN-16      ENDF/B-IV MAT 1276                         UPDATED
08/12/94
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

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*************************************************************************************************
***                                                                                           ***
***         TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP   ***
***                                                                                           ***
*************************************************************************************************
*************************************************************************************************
***                                                                                           ***
***                              ****** ADDITIONAL INFORMATION ******                         ***
***                                                                                           ***
***  NUMBER OF ENERGY GROUPS               27      USE LATTICE GEOMETRY                  YES  ***
***                                                                                           ***
***  NO. OF FISSION SPECTRUM SOURCE GROUP  1       GLOBAL ARRAY NUMBER                    60  ***
***                                                                                           ***
***  NO. OF SCATTERING ANGLES IN XSECS     2       NUMBER OF UNITS IN THE GLOBAL X DIR.    1  ***
***                                                                                           ***
***  ENTRIES/NEUTRON IN THE NEUTRON BANK  33       NUMBER OF UNITS IN THE GLOBAL Y DIR.    1  ***
***                                                                                           ***
***  ENTRIES/NEUTRON IN THE FISSION BANK  26       NUMBER OF UNITS IN THE GLOBAL Z DIR.    4  ***
***                                                                                           ***
***  NUMBER OF MIXTURES USED               11      USE A GLOBAL REFLECTOR                YES  ***
***                                                                                           ***
***  NUMBER OF BIAS ID'S USED               1      USE NESTED HOLES                      YES  ***
***                                                                                           ***
***  NUMBER OF DIFFERENTIAL ALBEDOS USED    0      NUMBER OF HOLES                        48  ***
***                                                                                           ***
***  TOTAL INPUT GEOMETRY REGIONS         133      MAXIMUM HOLE NESTING LEVEL              3  ***
***                                                                                           ***
***  NUMBER OF GEOMETRY REGIONS USED      133      USE NESTED ARRAYS                     YES  ***
***                                                                                           ***
***  LARGEST GEOMETRY UNIT NUMBER         120      NUMBER OF ARRAYS USED                  27  ***
***                                                                                           ***
***  LARGEST ARRAY NUMBER                  60      MAXIMUM ARRAY NESTING LEVEL             4  ***
***                                                                                           ***
***                                                                                           ***
***  +X BOUNDARY CONDITION            REFLECT      -X BOUNDARY CONDITION             REFLECT  ***
***                                                                                           ***
***  +Y BOUNDARY CONDITION            REFLECT      -Y BOUNDARY CONDITION             REFLECT  ***
***                                                                                           ***
***  +Z BOUNDARY CONDITION                PER      -Z BOUNDARY CONDITION                 PER  ***
***                                                                                           ***
*************************************************************************************************
```

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
KENO MESSAGE NUMBER K5-132		WARNING....ONLY	960 INDEPENDENT	FISSION POINTS WERE	GENERATED	
1	8.38679E-01	1.08833E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	9.42980E-01	1.48167E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY	932 INDEPENDENT	FISSION POINTS WERE	GENERATED	
3	8.79994E-01	1.86667E-01	8.79994E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	8.82794E-01	2.27000E-01	8.81394E-01	1.40035E-03	0.00000E+00	0.00000E+00
5	8.34080E-01	2.66333E-01	8.65623E-01	1.57920E-02	0.00000E+00	0.00000E+00
6	8.72462E-01	3.07500E-01	8.67333E-01	1.12968E-02	0.00000E+00	0.00000E+00
7	8.52487E-01	3.56000E-01	8.64363E-01	9.24043E-03	0.00000E+00	0.00000E+00
8	8.86952E-01	4.00000E-01	8.68128E-01	8.43192E-03	0.00000E+00	0.00000E+00
9	9.00160E-01	4.40333E-01	8.72704E-01	8.46893E-03	0.00000E+00	0.00000E+00
10	9.27940E-01	4.77833E-01	8.79609E-01	1.00729E-02	0.00000E+00	0.00000E+00
11	8.82204E-01	5.19000E-01	8.79897E-01	8.88814E-03	0.00000E+00	0.00000E+00
12	9.06370E-01	5.60167E-01	8.82544E-01	8.37898E-03	0.00000E+00	0.00000E+00
13	9.02590E-01	5.99500E-01	8.84367E-01	7.79507E-03	0.00000E+00	0.00000E+00
14	8.60403E-01	6.38833E-01	8.82370E-01	7.39080E-03	0.00000E+00	0.00000E+00
15	8.63454E-01	6.82833E-01	8.80914E-01	6.95252E-03	0.00000E+00	0.00000E+00
16	8.77766E-01	7.22167E-01	8.80690E-01	6.44070E-03	0.00000E+00	0.00000E+00
17	8.84876E-01	7.62500E-01	8.80969E-01	6.00246E-03	0.00000E+00	0.00000E+00
18	8.73653E-01	8.01833E-01	8.80511E-01	5.63338E-03	0.00000E+00	0.00000E+00
19	8.76214E-01	8.40333E-01	8.80259E-01	5.29767E-03	0.00000E+00	0.00000E+00
20	8.83080E-01	8.78667E-01	8.80415E-01	4.99715E-03	0.00000E+00	0.00000E+00
21	8.86274E-01	9.18167E-01	8.80724E-01	4.73688E-03	0.00000E+00	0.00000E+00
22	8.81537E-01	9.56500E-01	8.80764E-01	4.49398E-03	0.00000E+00	0.00000E+00
23	8.49911E-01	9.97667E-01	8.79295E-01	4.52007E-03	0.00000E+00	0.00000E+00
24	8.97669E-01	1.03617E+00	8.80130E-01	4.38990E-03	0.00000E+00	0.00000E+00
25	8.52765E-01	1.07550E+00	8.78941E-01	4.36017E-03	0.00000E+00	0.00000E+00
26	9.06153E-01	1.11500E+00	8.80074E-01	4.32579E-03	0.00000E+00	0.00000E+00
27	8.73814E-01	1.15433E+00	8.79824E-01	4.15670E-03	0.00000E+00	0.00000E+00
28	8.85887E-01	1.19367E+00	8.80057E-01	4.00044E-03	0.00000E+00	0.00000E+00
29	8.88861E-01	1.23300E+00	8.80383E-01	3.86321E-03	0.00000E+00	0.00000E+00
30	9.03642E-01	1.27233E+00	8.81214E-01	3.81423E-03	0.00000E+00	0.00000E+00
31	9.16851E-01	1.31267E+00	8.82443E-01	3.88009E-03	0.00000E+00	0.00000E+00
32	8.58351E-01	1.35300E+00	8.81640E-01	3.83358E-03	0.00000E+00	0.00000E+00
33	8.87792E-01	1.39133E+00	8.81838E-01	3.71316E-03	0.00000E+00	0.00000E+00
34	8.76488E-01	1.43067E+00	8.81671E-01	3.59914E-03	0.00000E+00	0.00000E+00
35	8.81292E-01	1.46917E+00	8.81660E-01	3.48839E-03	0.00000E+00	0.00000E+00
36	8.48341E-01	1.50850E+00	8.80680E-01	3.52326E-03	0.00000E+00	0.00000E+00
37	8.68676E-01	1.54783E+00	8.80337E-01	3.43826E-03	0.00000E+00	0.00000E+00
38	8.83753E-01	1.58733E+00	8.80431E-01	3.34274E-03	0.00000E+00	0.00000E+00
39	8.71009E-01	1.62667E+00	8.80177E-01	3.26110E-03	0.00000E+00	0.00000E+00
40	8.74951E-01	1.66600E+00	8.80039E-01	3.17710E-03	0.00000E+00	0.00000E+00
41	8.93585E-01	1.70450E+00	8.80387E-01	3.11399E-03	0.00000E+00	0.00000E+00
42	8.90604E-01	1.74383E+00	8.80642E-01	3.04587E-03	0.00000E+00	0.00000E+00
43	8.84406E-01	1.78967E+00	8.80734E-01	2.97207E-03	0.00000E+00	0.00000E+00
44	9.19408E-01	1.82900E+00	8.81655E-01	3.04310E-03	0.00000E+00	0.00000E+00
45	8.67636E-01	1.87200E+00	8.81329E-01	2.98932E-03	0.00000E+00	0.00000E+00
46	8.64888E-01	1.91583E+00	8.80955E-01	2.94440E-03	0.00000E+00	0.00000E+00
47	8.74001E-01	1.95533E+00	8.80800E-01	2.88237E-03	0.00000E+00	0.00000E+00
48	8.70232E-01	1.99467E+00	8.80571E-01	2.82836E-03	0.00000E+00	0.00000E+00
49	9.08330E-01	2.03500E+00	8.81161E-01	2.82985E-03	0.00000E+00	0.00000E+00
50	8.93306E-01	2.07433E+00	8.81414E-01	2.78180E-03	0.00000E+00	0.00000E+00
.						
.						
.						
950	8.61184E-01	3.76597E+01	8.83707E-01	7.49771E-04	0.00000E+00	0.00000E+00
951	9.38198E-01	3.76998E+01	8.83765E-01	7.51178E-04	0.00000E+00	0.00000E+00
952	8.70550E-01	3.77402E+01	8.83751E-01	7.50516E-04	0.00000E+00	0.00000E+00
953	8.62074E-01	3.77805E+01	8.83728E-01	7.50073E-04	0.00000E+00	0.00000E+00
954	8.87262E-01	3.78198E+01	8.83732E-01	7.49294E-04	0.00000E+00	0.00000E+00
955	8.75056E-01	3.78592E+01	8.83723E-01	7.48562E-04	0.00000E+00	0.00000E+00
956	8.85677E-01	3.79003E+01	8.83725E-01	7.47780E-04	0.00000E+00	0.00000E+00
957	8.60378E-01	3.79397E+01	8.83700E-01	7.47396E-04	0.00000E+00	0.00000E+00
958	9.04548E-01	3.79790E+01	8.83722E-01	7.46933E-04	0.00000E+00	0.00000E+00
959	9.11408E-01	3.80193E+01	8.83751E-01	7.46712E-04	0.00000E+00	0.00000E+00
960	8.77433E-01	3.80597E+01	8.83745E-01	7.45962E-04	0.00000E+00	0.00000E+00
961	9.30274E-01	3.80982E+01	8.83793E-01	7.46761E-04	0.00000E+00	0.00000E+00
962	8.70589E-01	3.81383E+01	8.83779E-01	7.46110E-04	0.00000E+00	0.00000E+00
963	8.76762E-01	3.81787E+01	8.83772E-01	7.45369E-04	0.00000E+00	0.00000E+00
964	9.30255E-01	3.82190E+01	8.83820E-01	7.46160E-04	0.00000E+00	0.00000E+00
965	8.86082E-01	3.82602E+01	8.83823E-01	7.45388E-04	0.00000E+00	0.00000E+00
966	8.37636E-01	3.83003E+01	8.83775E-01	7.46154E-04	0.00000E+00	0.00000E+00
967	9.13884E-01	3.83398E+01	8.83806E-01	7.46033E-04	0.00000E+00	0.00000E+00
968	9.01212E-01	3.83782E+01	8.83824E-01	7.45479E-04	0.00000E+00	0.00000E+00
969	8.98383E-01	3.84185E+01	8.83839E-01	7.44859E-04	0.00000E+00	0.00000E+00
970	9.02978E-01	3.84578E+01	8.83859E-01	7.44352E-04	0.00000E+00	0.00000E+00
971	9.18267E-01	3.84982E+01	8.83894E-01	7.44431E-04	0.00000E+00	0.00000E+00
972	8.78049E-01	3.85375E+01	8.83888E-01	7.43688E-04	0.00000E+00	0.00000E+00
973	8.52884E-01	3.85797E+01	8.83856E-01	7.43607E-04	0.00000E+00	0.00000E+00
974	8.45918E-01	3.86190E+01	8.83817E-01	7.43866E-04	0.00000E+00	0.00000E+00
975	8.58468E-01	3.86583E+01	8.83791E-01	7.43558E-04	0.00000E+00	0.00000E+00
976	9.44680E-01	3.86968E+01	8.83854E-01	7.45420E-04	0.00000E+00	0.00000E+00
977	9.16211E-01	3.87362E+01	8.83887E-01	7.45394E-04	0.00000E+00	0.00000E+00
978	8.71239E-01	3.87755E+01	8.83874E-01	7.44743E-04	0.00000E+00	0.00000E+00
979	8.98959E-01	3.88167E+01	8.83889E-01	7.44141E-04	0.00000E+00	0.00000E+00
980	9.29580E-01	3.88578E+01	8.83936E-01	7.44846E-04	0.00000E+00	0.00000E+00
981	8.87870E-01	3.88973E+01	8.83940E-01	7.44096E-04	0.00000E+00	0.00000E+00
982	9.04001E-01	3.89367E+01	8.83961E-01	7.43618E-04	0.00000E+00	0.00000E+00
983	8.56109E-01	3.89768E+01	8.83932E-01	7.43402E-04	0.00000E+00	0.00000E+00
984	8.79591E-01	3.90163E+01	8.83928E-01	7.42657E-04	0.00000E+00	0.00000E+00
985	9.29226E-01	3.90557E+01	8.83974E-01	7.43331E-04	0.00000E+00	0.00000E+00
986	8.77684E-01	3.90950E+01	8.83968E-01	7.42603E-04	0.00000E+00	0.00000E+00

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

987	8.91019E-01	3.91353E+01	8.83975E-01	7.41883E-04	0.00000E+00	0.00000E+00
988	8.83327E-01	3.91747E+01	8.83974E-01	7.41131E-04	0.00000E+00	0.00000E+00
989	8.90881E-01	3.92130E+01	8.83981E-01	7.40412E-04	0.00000E+00	0.00000E+00
990	8.95827E-01	3.92533E+01	8.83993E-01	7.39760E-04	0.00000E+00	0.00000E+00
991	8.83975E-01	3.92937E+01	8.83993E-01	7.39012E-04	0.00000E+00	0.00000E+00
992	8.88243E-01	3.93338E+01	8.83997E-01	7.38277E-04	0.00000E+00	0.00000E+00
993	8.61167E-01	3.93742E+01	8.83974E-01	7.37891E-04	0.00000E+00	0.00000E+00
994	8.94656E-01	3.94145E+01	8.83985E-01	7.37226E-04	0.00000E+00	0.00000E+00
995	8.47387E-01	3.94547E+01	8.83948E-01	7.37405E-04	0.00000E+00	0.00000E+00
996	9.31154E-01	3.94950E+01	8.83996E-01	7.38192E-04	0.00000E+00	0.00000E+00
997	8.82171E-01	3.95343E+01	8.83994E-01	7.37452E-04	0.00000E+00	0.00000E+00
998	8.57257E-01	3.95755E+01	8.83967E-01	7.37200E-04	0.00000E+00	0.00000E+00
999	8.41131E-01	3.96150E+01	8.83924E-01	7.37712E-04	0.00000E+00	0.00000E+00
1000	9.17187E-01	3.96552E+01	8.83957E-01	7.37726E-04	0.00000E+00	0.00000E+00
1001	9.33352E-01	3.96937E+01	8.84007E-01	7.38644E-04	0.00000E+00	0.00000E+00
1002	8.90597E-01	3.97358E+01	8.84013E-01	7.37934E-04	0.00000E+00	0.00000E+00
1003	8.92086E-01	3.97742E+01	8.84021E-01	7.37241E-04	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123 EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP

```
LIFETIME =  3.45256E-05 + OR -  6.86456E-08             GENERATION TIME =  2.47901E-05 + OR -  3.68122E-08
NU BAR   =  2.44276E+00 + OR -  6.93264E-05        AVERAGE FISSION GROUP =  2.16172E+01 + OR -  3.98797E-03
                     ENERGY(EV) OF THE AVERAGE LETHARGY CAUSING FISSION =  3.02159E-01 + OR -  9.59208E-04
```

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.88403	+ OR - 0.00074	0.88329 TO 0.88476	0.88255 TO 0.88550	0.88181 TO 0.88624	1000000
4	0.88403	+ OR - 0.00074	0.88329 TO 0.88477	0.88255 TO 0.88550	0.88181 TO 0.88624	999000
5	0.88408	+ OR - 0.00074	0.88334 TO 0.88481	0.88260 TO 0.88555	0.88186 TO 0.88629	998000
6	0.88409	+ OR - 0.00074	0.88335 TO 0.88483	0.88261 TO 0.88557	0.88187 TO 0.88630	997000
7	0.88412	+ OR - 0.00074	0.88338 TO 0.88486	0.88264 TO 0.88560	0.88190 TO 0.88634	996000
8	0.88412	+ OR - 0.00074	0.88338 TO 0.88486	0.88264 TO 0.88560	0.88190 TO 0.88633	995000
9	0.88410	+ OR - 0.00074	0.88336 TO 0.88484	0.88262 TO 0.88558	0.88188 TO 0.88632	994000
10	0.88406	+ OR - 0.00074	0.88332 TO 0.88480	0.88258 TO 0.88554	0.88184 TO 0.88627	993000
11	0.88406	+ OR - 0.00074	0.88332 TO 0.88480	0.88258 TO 0.88554	0.88184 TO 0.88628	992000
12	0.88404	+ OR - 0.00074	0.88330 TO 0.88478	0.88256 TO 0.88552	0.88182 TO 0.88626	991000
17	0.88407	+ OR - 0.00074	0.88332 TO 0.88481	0.88258 TO 0.88555	0.88184 TO 0.88630	986000
22	0.88409	+ OR - 0.00075	0.88334 TO 0.88483	0.88259 TO 0.88558	0.88185 TO 0.88633	981000
27	0.88413	+ OR - 0.00075	0.88338 TO 0.88488	0.88263 TO 0.88563	0.88188 TO 0.88637	976000
32	0.88410	+ OR - 0.00075	0.88334 TO 0.88485	0.88259 TO 0.88560	0.88184 TO 0.88635	971000
37	0.88415	+ OR - 0.00075	0.88340 TO 0.88491	0.88265 TO 0.88566	0.88189 TO 0.88642	966000
42	0.88416	+ OR - 0.00076	0.88340 TO 0.88492	0.88265 TO 0.88568	0.88189 TO 0.88643	961000
47	0.88417	+ OR - 0.00076	0.88341 TO 0.88493	0.88265 TO 0.88569	0.88189 TO 0.88645	956000
52	0.88411	+ OR - 0.00076	0.88334 TO 0.88487	0.88258 TO 0.88563	0.88182 TO 0.88639	951000
57	0.88413	+ OR - 0.00076	0.88336 TO 0.88489	0.88260 TO 0.88565	0.88183 TO 0.88642	946000
62	0.88417	+ OR - 0.00077	0.88341 TO 0.88494	0.88264 TO 0.88571	0.88187 TO 0.88647	941000
67	0.88417	+ OR - 0.00077	0.88341 TO 0.88494	0.88264 TO 0.88571	0.88187 TO 0.88647	936000
72	0.88421	+ OR - 0.00077	0.88344 TO 0.88498	0.88267 TO 0.88575	0.88190 TO 0.88652	931000
77	0.88422	+ OR - 0.00077	0.88345 TO 0.88499	0.88267 TO 0.88577	0.88190 TO 0.88654	926000
82	0.88424	+ OR - 0.00077	0.88346 TO 0.88501	0.88269 TO 0.88578	0.88191 TO 0.88656	921000
87	0.88421	+ OR - 0.00078	0.88343 TO 0.88499	0.88265 TO 0.88576	0.88188 TO 0.88654	916000
92	0.88414	+ OR - 0.00078	0.88336 TO 0.88492	0.88258 TO 0.88570	0.88179 TO 0.88648	911000

Figure 6.7-2 CSAS Input/Output Summary for Transfer Cask - Accident Conditions (Continued)

```
TRANSFER CASK CRITICALITY: MOST REACTIVE CONFIGURATION - WATER IN FUEL CLAD GAP

                                   FREQUENCY FOR GENERATIONS    4 TO 1003
0.8068 TO 0.8099     *
0.8099 TO 0.8130
0.8130 TO 0.8160
0.8160 TO 0.8191     **
0.8191 TO 0.8222     *
0.8222 TO 0.8253     *
0.8253 TO 0.8283     ***
0.8283 TO 0.8314     ***
0.8314 TO 0.8345     *******
0.8345 TO 0.8376     ***
0.8376 TO 0.8406     ***********
0.8406 TO 0.8437     *********
0.8437 TO 0.8468     ************
0.8468 TO 0.8499     *****************
0.8499 TO 0.8529     *********************
0.8529 TO 0.8560     ******************????
0.8560 TO 0.8591     ***************************
0.8591 TO 0.8621     ********************************
0.8621 TO 0.8652     *************************************
0.8652 TO 0.8683     ************************************
0.8683 TO 0.8714     **************************************************
0.8714 TO 0.8744     ******************************************
0.8744 TO 0.8775     *************************************************
0.8775 TO 0.8806     ********************************************
0.8806 TO 0.8837     ***********************************************
0.8837 TO 0.8867     **************************************************************
0.8867 TO 0.8898     *******************************************
0.8898 TO 0.8929     ********************************************************
0.8929 TO 0.8960     **********************************************
0.8960 TO 0.8990     *******************************************
0.8990 TO 0.9021     *************************************
0.9021 TO 0.9052     ******************************
0.9052 TO 0.9082     *******************************
0.9082 TO 0.9113     *****************************
0.9113 TO 0.9144     ****************************
0.9144 TO 0.9175     ****************************
0.9175 TO 0.9205     *******************
0.9205 TO 0.9236     **********
0.9236 TO 0.9267     ******
0.9267 TO 0.9298     *******
0.9298 TO 0.9328     ******
0.9328 TO 0.9359     *******
0.9359 TO 0.9390     *****
0.9390 TO 0.9421     **
0.9421 TO 0.9451     ****
0.9451 TO 0.9482
0.9482 TO 0.9513
0.9513 TO 0.9543     ***
0.9543 TO 0.9574
0.9574 TO 0.9605     *
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions

```
      PRIMARY MODULE ACCESS AND INPUT RECORD ( SCALE DRIVER - 95/03/29 - 09:06:37 )
MODULE CSAS25   WILL BE CALLED
  WRR EC455-5302 YANKEE Storage CASK KENO-Va MODEL Base Case
  '
  '   File: storage.in
  '
  '   THIS IS A BASE CASE MODEL OF THE NAC-MPC BASKET
  '   LOADED WITH 36 UNITED NUCLEAR TYPE A ASSEMBLIES
  '           INSERTED INTO THE STORAGE CASK
  '
  '   The normal condition is dry (0.0001) everywhere
  '
  '
  '        material     volume
  '         number      fraction
  '        --------     --------
  '            3         0.0001      inside canister
  '            7         0.0001      canister/VCC gap
  '           10         0.0001      external to VCC
  '
  '
  '            PRODUCED FOR THE YANKEE ROWE
  '               STC LICENSE AMENDMENT
  '
  27GROUPNDF4 LATTICECELL
  UO2          1             0.95     293.0 92235 4.0 92238 96.0 END
  ZIRCALLOY    2             1.0      293.0                      END
  H2O          3             0.0001   293.0                      END
  AL           4             1.0      293.0                      END
  SS304        5             1.0      293.0                      END
  B-10         6  DEN=2.6226 0.0450   293.0                      END
  B-11         6  DEN=2.6226 0.2736   293.0                      END
  C            6  DEN=2.6226 0.0927   293.0                      END
  AL           6  DEN=2.6226 0.5737   293.0                      END
  H2O          7             0.0001   293.0                      END
  CARBONSTEEL  8             1.0      293.0                      END
  REG-CONCRETE 9  DEN=2.243  1.0      293.0                      END
  H2O         10             0.0001   293.0                      END
  END COMP
  SQUAREPITCH  1.1887 0.7887 1 3 0.9271 2 0.8052 0 END
  WRR EC455-5302 YANKEE Storage CASK KENO-Va MODEL Base Case
  READ PARAM RUN=yes PLT=YES GEN=1003 NPG=1000 tme=500 END PARAM
  READ GEOM
  '
  '  WATER LEVEL UNIT CELLS
  '
  UNIT  1
  COM='FUEL PIN CELL - BETWEEN DISKS'
  CYLINDER  1 1  0.3943    2P2.1654
  CYLINDER  0 1  0.4026    2P2.1654
  CYLINDER  2 1  0.4635    2P2.1654
  CUBOID    3 1  4P0.5944  2P2.1654
  UNIT  2
  COM='WATER CELL - BETWEEN DISKS'
  CUBOID    3 1  4P0.5944  2P2.1654
  UNIT  3
  COM='DISPLACEMENT CELL - BETWEEN DISKS'
  CYLINDER  2 1  0.4635    2P2.1654
  CUBOID    3 1  4P0.5944  2P2.1654
  UNIT  4
  COM='INSTRUMENT TUBE CELL - BETWEEN DISKS'
  CYLINDER  3 1  0.4998    2P2.1654
  CYLINDER  5 1  0.5442    2P2.1654
  CUBOID    3 1  4P0.5944  2P2.1654
  '
  '  DISK LEVEL UNIT CELLS (BOTH SS AND AL)
  '
  UNIT  5
  COM='FUEL PIN CELL - WITH SS DISK'
  CYLINDER  1 1  0.3943   2P0.635
  CYLINDER  0 1  0.4026   2P0.635
  CYLINDER  2 1  0.4635   2P0.635
  CUBOID    3 1  4P0.5944 2P0.635
  UNIT  6
  COM='WATER CELL - WITH SS DISK'
  CUBOID    3 1  4P0.5944 2P0.635
  UNIT  7
  COM='DISPLACEMENT CELL - WITH SS DISK'
  CYLINDER  2 1  0.4635   2P0.635
  CUBOID    3 1  4P0.5944 2P0.635
  UNIT  8
  COM='INSTRUMENT TUBE CELL - WITH SS DISK'
  CYLINDER  3 1  0.4998   2P0.635
  CYLINDER  5 1  0.5442   2P0.635
  CUBOID    3 1  4P0.5944 2P0.635
  '
  '  WATER LEVEL BORAL SHEETS
  '
  UNIT 14
  COM='X-X BORAL SHEET BETWEEN DISKS'
  CUBOID 6 1 2P9.144 2P0.0318 2P2.1654
  CUBOID 4 1 2P9.144 2P0.0953 2P2.1654
  UNIT 15
  COM='Y-Y BORAL SHEET BETWEEN DISKS'
  CUBOID 6 1 2P0.0318 2P9.144 2P2.1654
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
CUBOID 4 1 2P0.0953 2P9.144 2P2.1654
'
'  DISK LEVEL BORAL SHEETS (AL AND SS)
'
UNIT 16
COM='X-X BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P9.144 2P0.0318 2P0.635
CUBOID 4 1 2P9.144 2P0.0953 2P0.635
UNIT 17
COM='Y-Y BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P0.0318 2P9.144 2P0.635
CUBOID 4 1 2P0.0953 2P9.144 2P0.635
'
' WATER LEVEL WEB MATERIAL
'
UNIT 20
COM='WATER LEVEL WEB MATERIAL (SMALL) X-X'
CUBOID    3 1 2P10.4826 2P0.9525 2P2.1654
UNIT 21
COM='WATER LEVEL WEB MATERIAL (MEDIUM) X-X'
CUBOID    3 1 2P10.4826 2P1.0287 2P2.1654
UNIT 22
COM='WATER LEVEL WEB MATERIAL (LARGE) X-X'
CUBOID    3 1 2P10.4826 2P1.1112 2P2.1654
UNIT 23
COM='WATER LEVEL WEB MATERIAL (LONG) Y-Y'
CUBOID    3 1 2P1.1112 2P79.5630 2P2.1654
'
'  SUPPORT DISK WEB MATERIAL
'
UNIT 30
COM='SUPPORT DISK WEB MATERIAL (SMALL) X-X'
CUBOID    5 1 2P10.4826 2P0.9525 2P0.635
UNIT 31
COM='SUPPORT DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    5 1 2P10.4826 2P1.0287 2P0.635
UNIT 32
COM='SUPPORT DISK WEB MATERIAL (LARGE) X-X'
CUBOID    5 1 2P10.4826 2P1.1112 2P0.635
UNIT 33
COM='SUPPORT DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    5 1 2P1.1112 2P79.5630 2P0.635
'
'  HEAT TRANSFER DISK WEB MATERIAL
'
UNIT 40
COM='HEAT TRANSFER DISK WEB MATERIAL (SMALL) X-X'
CUBOID    4 1 2P10.4445 2P0.9906 2P0.635
UNIT 41
COM='HEAT TRANSFER DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    4 1 2P10.4445 2P1.0668 2P0.635
UNIT 42
COM='HEAT TRANSFER DISK WEB MATERIAL (LARGE) X-X'
CUBOID    4 1 2P10.4445 2P1.1493 2P0.635
UNIT 43
COM='HEAT TRANSFER DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    4 1 2P1.1493 2P79.5249 2P0.635
'
'  WATER LEVEL ASSEMBLY ARRAYS
'
UNIT 50
COM='WATER LEVEL ASSEMBLY CELL'
ARRAY  1  -9.5104 -9.5104 -2.1654
CUBOID 3 1 4P9.906                          2P2.1654
CUBOID 5 1 4P10.028                         2P2.1654
CUBOID 3 1 4P10.2187                        2P2.1654
HOLE  14    0.0       10.1234  0.0
HOLE  14    0.0      -10.1234  0.0
HOLE  15    10.1234   0.0      0.0
HOLE  15    -10.1234  0.0      0.0
CUBOID 5 1 4P10.267                         2P2.1654
CUBOID 3 1 4P10.4826                        2P2.1654
UNIT 51
COM='WATER LEVEL CENTRAL HOLE'
CUBOID 3 1 4P10.4826                        2P2.1654

'
'  SUPPORT DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 60
COM='SUPPORT DISK ASSEMBLY CELL'
ARRAY  2  -9.5104 -9.5104 -0.635
CUBOID 3 1 4P9.906                          2P0.635
CUBOID 5 1 4P10.028                         2P0.635
CUBOID 3 1 4P10.2187                        2P0.635
HOLE  16    0.0       10.1234  0.0
HOLE  16    0.0      -10.1234  0.0
HOLE  17    10.1234   0.0      0.0
HOLE  17    -10.1234  0.0      0.0
CUBOID 5 1 4P10.267                         2P0.635
CUBOID 3 1 4P10.4826                        2P0.635
UNIT 61
COM='SUPPORT DISK CENTRAL HOLE'
CUBOID 3 1 4P10.4826                        2P0.635

'
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
'   HEAT TRANSFER DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 70
COM='HEAT TRANSFER ASSEMBLY CELL'
ARRAY  2   -9.5104 -9.5104 -0.635
CUBOID 3 1 4P9.906                          2P0.635
CUBOID 5 1 4P10.028                         2P0.635
CUBOID 3 1 4P10.2187                        2P0.635
HOLE  16    0.0        10.1234  0.0
HOLE  16    0.0       -10.1234 0.0
HOLE  17    10.1234  0.0       0.0
HOLE  17    -10.1234 0.0       0.0
CUBOID 5 1 4P10.267                         2P0.635
CUBOID 3 1 4P10.4445                        2P0.635
UNIT 71
COM='HEAT TRANSFER CENTRAL HOLE'
CUBOID 3 1 4P10.4445                        2P0.635

'
'  WATER LEVEL BASKET ARRAYS
'
UNIT 80
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY)'
ARRAY 20 -10.4826 -33.6702 -2.1654
UNIT 81
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY)'
ARRAY 21 -10.4826 -56.6928 -2.1654
UNIT 82
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY)'
ARRAY 22 -10.4826 -79.5630 -2.1654
UNIT 83
COM='13X1 WATER LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 23 -10.4826 -79.5630 -2.1654
'
'  SUPPORT DISK LEVEL BASKET ARRAYS
'
UNIT 90
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY)'
ARRAY 30 -10.4826 -33.6702 -0.635
UNIT 91
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY)'
ARRAY 31 -10.4826 -56.6928 -0.635
UNIT 92
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY)'
ARRAY 32 -10.4826 -79.5630 -0.635
UNIT 93
COM='13X1 SUPPORT DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 33 -10.4826 -79.5630 -0.635
'
'  HEAT TRANSFER DISK LEVEL BASKET ARRAYS
'
UNIT 100
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY)'
ARRAY 40 -10.4445 -33.6321 -0.635
UNIT 101
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY)'
ARRAY 41 -10.4445 -56.6547 -0.635
UNIT 102
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY)'
ARRAY 42 -10.4445 -79.5249 -0.635
UNIT 103
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 43 -10.4445 -79.5249 -0.635
'
'  BASKET ARRAY IN STORAGE CASK OVERPACK (LEVEL CONSTRUCTION)
'
UNIT 110
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - WATER LEVEL'
ARRAY 50 -33.6702 -79.5630 -2.1654
CYLINDER 3 1 88.1253      2P2.1654
HOLE 80      -69.0804 0.0 0.0
HOLE 81      -46.2102 0.0 0.0
HOLE 80       69.0804 0.0 0.0
HOLE 81       46.2102 0.0 0.0
CYLINDER  5 1  89.7128     2P2.1654
CYLINDER  7 1 100.33       2P2.1654
CYLINDER  8 1 109.22       2P2.1654
CYLINDER  9 1 162.56       2P2.1654
CUBOID   10 1 4P228.60     2P2.1654
UNIT 111
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - SUPPORT DISK LEVEL'
ARRAY 51 -33.6702 -79.5630 -0.635
CYLINDER 5 1 87.6046      2P0.635
HOLE 90      -69.0804 0.0 0.0
HOLE 91      -46.2102 0.0 0.0
HOLE 90       69.0804 0.0 0.0
HOLE 91       46.2102 0.0 0.0
CYLINDER  3 1  88.1253     2P0.635
CYLINDER  5 1  89.7128     2P0.635
CYLINDER  7 1 100.33       2P0.635
CYLINDER  8 1 109.22       2P0.635
CYLINDER  9 1 162.56       2P0.635
CUBOID   10 1 4P228.60     2P0.635
UNIT 112
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - HEAT TRANSFER DISK LEVEL'
ARRAY 52 -33.6321 -79.5249 -0.635
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
CYLINDER 4 1 87.249        2P0.635
HOLE 100     -69.0804 0.0 0.0
HOLE 101     -46.2102 0.0 0.0
HOLE 100      69.0804 0.0 0.0
HOLE 101      46.2102 0.0 0.0
CYLINDER  3 1  88.1253     2P0.635
CYLINDER  5 1  89.7128     2P0.635
CYLINDER  7 1 100.33       2P0.635
CYLINDER  8 1 109.22       2P0.635
CYLINDER  9 1 162.56       2P0.635
CUBOID   10 1 4P228.60     2P0.635
'
'  GLOBAL UNIT
'
GLOBAL UNIT 120
ARRAY 60 -228.60  -228.60  0.0
END GEOM
READ ARRAY
ARA=1 NUX=16 NUY=16 NUZ=1  FILL
1 1 1 1 1 1 1 3 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 4 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
END FILL
ARA=2 NUX=16 NUY=16 NUZ=1  FILL
5 5 5 5 5 5 5 7 6 6 6 6 6 6 6 6
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
7 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 8 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
END FILL
'
'  WATER LEVEL ARRAYS
'
ARA=20  NUX=1 NUY=5 NUZ=1
FILL
50
22
50
22
50
END FILL
ARA=21  NUX=1 NUY=9 NUZ=1
FILL
50
21
50
22
50
22
50
21
50
END FILL
ARA=22  NUX=1 NUY=13 NUZ=1
FILL
50
20
50
21
50
22
50
22
50
21
50
20
50
END FILL
ARA=23  NUX=1 NUY=13 NUZ=1
FILL
50
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
20
50
21
50
22
51
22
50
21
50
20
50
END FILL
'
'  SUPPOR DISK LEVEL ARRAYS
'
ARA=30  NUX=1 NUY=5 NUZ=1
FILL
60
32
60
32
60
END FILL
ARA=31  NUX=1 NUY=9 NUZ=1
FILL
60
31
60
32
60
32
60
31
60
END FILL
ARA=32  NUX=1 NUY=13 NUZ=1
FILL
60
30
60
31
60
32
60
32
60
31
60
30
60
END FILL
ARA=33  NUX=1 NUY=13 NUZ=1
FILL
60
30
60
31
60
32
61
32
60
31
60
30
60
END FILL
'
'  HEAT TRANSFER DISK LEVEL ARRAYS
'
ARA=40  NUX=1 NUY=5 NUZ=1
FILL
70
42
70
42
70
END FILL
ARA=41  NUX=1 NUY=9 NUZ=1
FILL
70
41
70
42
70
42
70
41
70
END FILL
ARA=42  NUX=1 NUY=13 NUZ=1
FILL
70
40
70
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
41
70
42
70
42
70
41
70
40
70
END FILL
ARA=43  NUX=1 NUY=13 NUZ=1
FILL
70
40
70
41
70
42
71
42
70
41
70
40
70
END FILL
'
'  MAJOR ARRAYS
'
ARA=50 NUX=5 NUY=1 NUZ=1
FILL
82 23 83 23 82
END FILL
ARA=51 NUX=5 NUY=1 NUZ=1
FILL
92 33 93 33 92
END FILL
ARA=52 NUX=5 NUY=1 NUZ=1
FILL
102 43 103 43 102
END FILL
'
'  GLOBAL ARRAY
'
ARA=60 NUX=1 NUY=1 NUZ=4
FILL
112
110
111
110
END FILL
END ARRAY

READ BOUNDS ZFC=PER YXF=REFLECT END BOUNDS

READ PLOT
SCR=YES PIC=MAT LPI=10
clr=0 255 255 255
    1   0   0   0
    2   0 238   0
    3 135 206 250
    4 205 205   0
    5 238   0   0
    6 160  32 240
    7 238 118  33
    8 255 165   0
    9 150 150 150
   10  60 179 113  end color
'
' WHOLE BASKET HORIZONTAL SLICES
'
TTL='BASKET X-Y CROSS SECTION AT Z= 0.635 HEAT TRANSFER DISK LEVEL'
XUL=  -175 YUL=  175  ZUL= 0.635
XLR=   175 YLR= -175  ZLR= 0.635
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y CROSS SECTION AT Z= 3.44 WATER LEVEL'
XUL=  -175 YUL=  175  ZUL= 3.44
XLR=   175 YLR= -175  ZLR= 3.44
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y CROSS SECTION AT Z= 6.236 SS DISK LEVEL'
XUL=  -175 YUL=  175  ZUL= 6.236
XLR=   175 YLR= -175  ZLR= 6.236
UAX=1.0 VDN=-1.0 NAX=1500 END
'
' HEAT TRANSFER DISK LEVEL BASKET QUADRANTS
'
TTL='BASKET X-Y QUADRANTD I HEAT TRANSFER DISK'
XUL=   0.    YUL= 80      ZUL= 0.635
XLR=  80.0   YLR=  0.0    ZLR= 0.635
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT II HEAT TRANSFER DISK'
XUL=   0.0 YUL= -0.0    ZUL= 0.635
XLR=  80   YLR= -80     ZLR= 0.635
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT III HEAT TRANSFER DISK'
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
XUL= -80.0  YUL=  -0.0  ZUL= 0.635
XLR=  -0.0  YLR= -80.0  ZLR= 0.635
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT IV HEAT TRANSFER DISK'
XUL= -80.0  YUL= 80.0   ZUL= 0.635
XLR=  -0.0  YLR=  0.0   ZLR= 0.635
UAX=1.0 VDN=-1.0 NAX=1500 END
'
' WATER LEVEL BASKET QUADRANTS
'
TTL='BASKET X-Y QUADRANT I WATER LEVEL'
XUL=   0.   YUL=  80     ZUL= 3.44
XLR=  80.0  YLR=   0.0   ZLR= 3.44
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT II WATER LEVEL'
XUL=   0.0  YUL=  -0.0   ZUL= 3.44
XLR=  80    YLR= -80     ZLR= 3.44
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT III WATER LEVEL'
XUL= -80.0  YUL=  -0.0   ZUL= 3.44
XLR=  -0.0  YLR= -80.0   ZLR= 3.44
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT IV WATER LEVEL'
XUL= -80.0  YUL= 80.0    ZUL= 3.44
XLR=  -0.0  YLR=  0.0    ZLR= 3.44
UAX=1.0 VDN=-1.0 NAX=1500 END
'
' SUPPORT DISK LEVEL BASKET QUADRANTS
'
TTL='BASKET X-Y QUADRANT I WATER LEVEL'
XUL=   0.   YUL=  80     ZUL= 6.236
XLR=  80.0  YLR=   0.0   ZLR= 6.236
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT II WATER LEVEL'
XUL=   0.0  YUL=  -0.0   ZUL= 6.236
XLR=  80    YLR= -80     ZLR= 6.236
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT III WATER LEVEL'
XUL= -80.0  YUL=  -0.0   ZUL= 6.236
XLR=  -0.0  YLR= -80.0   ZLR= 6.236
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='BASKET X-Y QUADRANT IV WATER LEVEL'
XUL= -80.0  YUL= 80.0    ZUL= 6.236
XLR=  -0.0  YLR=  0.0    ZLR= 6.236
UAX=1.0 VDN=-1.0 NAX=1500 END
'
'  VERTICAL SLICES
'
TTL='BASKET X-Z CROSS SECTION ALUMINUM LEVEL (MIDDLE OF FUEL PIN)'
XUL= -90  YUL=0.4   ZUL= 1.27
XLR=  90  YLR=0.4   ZLR= -.1
UAX=1.0 WDN=-1.0 NAX=1500 END
TTL='BASKET X-Z CROSS SECTION WATER LEVEL (MIDDLE OF FUEL PIN)'
XUL= -90  YUL=0.4   ZUL= 4.318
XLR=  90  YLR=0.4   ZLR= 1.27
UAX=1.0 WDN=-1.0 NAX=1500 END
TTL='BASKET X-Z CROSS SECTION SS LEVEL (MIDDLE OF FUEL PIN)'
XUL= -90  YUL=0.4   ZUL= 6.858
XLR=  90  YLR=0.4   ZLR= 5.588
UAX=1.0 WDN=-1.0 NAX=1500 END
TTL='BASKET X-Z CROSS SECTION ENTIRE MODEL (MIDDLE OF FUEL PIN)'
XUL= -90  YUL=0.4   ZUL= 12
XLR=  90  YLR=0.4   ZLR= 0
UAX=1.0 WDN=-1.0 NAX=1500 END
END PLOT
END DATA
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
 CCCCCCCCCCC     SSSSSSSSSSS      AAAAAAAAA      SSSSSSSSSSS     22222222222    5555555555555
CCCCCCCCCCCCC   SSSSSSSSSSSSS    AAAAAAAAAAA    SSSSSSSSSSSSS   2222222222222   5555555555555
CC         CC   SS         SS   AA         AA   SS         SS   22         22   55
CC              SS              AA         AA   SS                         22   55
CC              SS              AA         AA   SS                         22   55
CC              SSSSSSSSSSSS    AAAAAAAAAAAAA   SSSSSSSSSSSS              22    555555555555
CC               SSSSSSSSSSSS   AAAAAAAAAAAAA    SSSSSSSSSSSS           22      5555555555555
CC                         SS   AA         AA              SS         22                   55
CC                         SS   AA         AA              SS       22                     55
CC         CC   SS         SS   AA         AA   SS         SS     22            55         55
CCCCCCCCCCCCC   SSSSSSSSSSSSS   AA         AA   SSSSSSSSSSSSS   2222222222222   5555555555555
 CCCCCCCCCCC     SSSSSSSSSSS    AA         AA    SSSSSSSSSSS    2222222222222    55555555555

 SSSSSSSSSSS     CCCCCCCCCCC      AAAAAAAAA     LL              EEEEEEEEEEEEE                   PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS   CCCCCCCCCCCCC    AAAAAAAAAAA    LL              EEEEEEEEEEEEE                   PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS   CC         CC   AA         AA   LL              EE                              PP         PP   CC         CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SS              CC              AA         AA   LL              EE                              PP         PP   CC
SSSSSSSSSSSS    CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------   PPPPPPPPPPPP    CC
           SS   CC              AA         AA   LL              EE                              PP              CC
           SS   CC              AA         AA   LL              EE                              PP              CC
SS         SS   CC         CC   AA         AA   LL              EE                              PP              CC         CC
SSSSSSSSSSSSS   CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP              CCCCCCCCCCCCC
 SSSSSSSSSSS     CCCCCCCCCCC    AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP               CCCCCCCCCCC

     11          22222222222               //      0000000      7777777777777              //    99999999999     666666666666
    111         2222222222222             //      000000000     777777777777              //    9999999999999   6666666666666
   1111         22         22            //      00       00    77        77             //     99         99   66
     11                    22           //      00         00            77             //      99         99   66
     11                    22          //       00         00           77             //       99         99   66
     11                   22          //        00         00          77             //        9999999999999   666666666666
     11                 22           //         00         00          77            //          999999999999   6666666666666
     11               22            //          00         00         77            //                     99   66         66
     11             22             //           00         00         77           //                      99   66         66
     11           22              //             00       00         77           //                       99   66         66
  11111111      2222222222222    //               000000000          77          //             9999999999999   6666666666666
  11111111      2222222222222   //                 0000000           77         //              999999999999     66666666666

   0000000      666666666666                         11         88888888888                     5555555555555      0000000
  000000000     6666666666666                       111        8888888888888                    5555555555555     000000000
 00       00    66                   :::           1111        88         88         :::        55               00       00
00         00   66                   :::             11        88         88         :::        55              00         00
00         00   66                   :::             11        88         88         :::        55              00         00
00         00   666666666666                         11         88888888888                     555555555555    00         00
00         00   6666666666666                        11         88888888888                     5555555555555   00         00
00         00   66         66        :::             11        88         88         :::                   55   00         00
00         00   66         66        :::             11        88         88         :::                   55   00         00
 00       00    66         66        :::             11        88         88         :::        55         55    00       00
  000000000     6666666666666                     11111111     8888888888888                    5555555555555     000000000
   0000000       66666666666                      11111111      88888888888                      55555555555       0000000
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
 SSSSSSSSSSS    CCCCCCCCCCC     AAAAAAAAA    LL              EEEEEEEEEEEEE                    PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC   AAAAAAAAAAA   LL              EEEEEEEEEEEEE                    PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS  CC         CC  AA         AA  LL              EE                               PP         PP   CC         CC
SS             CC             AA         AA  LL              EE                               PP         PP   CC
SS             CC             AA         AA  LL              EE                               PP         PP   CC
SSSSSSSSSSSS   CC             AAAAAAAAAAAAA  LL              EEEEEEEEE      -------------     PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS  CC             AAAAAAAAAAAAA  LL              EEEEEEEEE      -------------     PPPPPPPPPPPP    CC
           SS  CC             AA         AA  LL              EE                               PP              CC
           SS  CC             AA         AA  LL              EE                               PP              CC
SS         SS  CC         CC  AA         AA  LL              EE                               PP              CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC  AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                    PP              CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL   EEEEEEEEEEEEE                    PP               CCCCCCCCCCC
```

```
********************************************************************************
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                     PROGRAM VERIFICATION INFORMATION                 *****
*****                                                                      *****
*****                  CODE SYSTEM:   SCALE-PC VERSION:  4.3               *****
*****                                                                      *****
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                                                                      *****
*****                 PROGRAM:  CSAS                                       *****
*****                                                                      *****
*****           CREATION DATE:  03-08-96                                   *****
*****                                                                      *****
*****                 VOLUME:   ENG                                        *****
*****                                                                      *****
*****                 LIBRARY:  G:\scale43\exe                             *****
*****                                                                      *****
*****                                                                      *****
*****         PRODUCTION CODE:  CSAS                                       *****
*****                                                                      *****
*****                 VERSION:  3.1                                        *****
*****                                                                      *****
*****                 JOBNAME:  SCALE-PC                                   *****
*****                                                                      *****
*****       DATE OF EXECUTION:  12/07/96                                   *****
*****                                                                      *****
*****       TIME OF EXECUTION:  06:18:50                                   *****
*****                                                                      *****
*****                                                                      *****
********************************************************************************
********************************************************************************
********************************************************************************
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

    **** PROBLEM PARAMETERS ****

    LIB 27GROUPNDF4  LIBRARY
    MXX           10 MIXTURES
    MSC           13 COMPOSITION SPECIFICATIONS
    IZM            4 MATERIAL ZONES
    GE  LATTICECELL  GEOMETRY
    MORE           0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
    MSLN           0 FUEL SOLUTIONS

    **** PROBLEM COMPOSITION DESCRIPTION ****

    SC  UO2          STANDARD COMPOSITION
    MX             1 MIXTURE NO.
    VF        0.9500 VOLUME FRACTION
    ROTH     10.9600 THEORETICAL DENSITY
    NEL            2 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
               92000      1.00 ATOM/MOLECULE
                               92235     4.000 WT%
                               92238    96.000 WT%
                8016      2.00 ATOMS/MOLECULE
    END

    SC  ZIRCALLOY    STANDARD COMPOSITION
    MX             2 MIXTURE NO.
    VF        1.0000 VOLUME FRACTION
    ROTH      6.5600 THEORETICAL DENSITY
    NEL            1 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
               40302      1.00 ATOM/MOLECULE
    END

    SC  H2O          STANDARD COMPOSITION
    MX             3 MIXTURE NO.
    VF        0.0001 VOLUME FRACTION
    ROTH      0.9982 THEORETICAL DENSITY
    NEL            2 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND.
    TEMP       293.0 DEG KELVIN
                1001      2.00 ATOMS/MOLECULE
                8016      1.00 ATOM/MOLECULE
    END

    SC  AL           STANDARD COMPOSITION
    MX             4 MIXTURE NO.
    VF        1.0000 VOLUME FRACTION
    ROTH      2.7020 THEORETICAL DENSITY
    NEL            1 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
               13027      1.00 ATOM/MOLECULE
    END

    SC  SS304        STANDARD COMPOSITION
    MX             5 MIXTURE NO.
    VF        1.0000 VOLUME FRACTION
    ROTH      7.9200 THEORETICAL DENSITY
    NEL            4 NO. ELEMENTS
    ICP            0 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
               24304    19.000 WT%
               25055     2.000 WT%
               26304    69.500 WT%
               28304     9.500 WT%
    END

    SC  B-10         STANDARD COMPOSITION
    MX             6 MIXTURE NO.
    VF        0.0450 VOLUME FRACTION
    ROTH      2.6226 SPECIFIED DENSITY
    NEL            1 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
                5010      1.00 ATOM/MOLECULE
    END

    SC  B-11         STANDARD COMPOSITION
    MX             6 MIXTURE NO.
    VF        0.2736 VOLUME FRACTION
    ROTH      2.6226 SPECIFIED DENSITY
    NEL            1 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
                5011      1.00 ATOM/MOLECULE
    END

    SC  C            STANDARD COMPOSITION
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
MX              6 MIXTURE NO.
VF         0.0927 VOLUME FRACTION
ROTH       2.6226 SPECIFIED DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             6012        1.00 ATOM/MOLECULE
END

SC  AL            STANDARD COMPOSITION
MX              6 MIXTURE NO.
VF         0.5737 VOLUME FRACTION
ROTH       2.6226 SPECIFIED DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            13027        1.00 ATOM/MOLECULE
END

SC  H2O           STANDARD COMPOSITION
MX              7 MIXTURE NO.
VF         0.0001 VOLUME FRACTION
ROTH       0.9982 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             1001        2.00 ATOMS/MOLECULE
             8016        1.00 ATOM/MOLECULE
END

SC  CARBONSTEEL   STANDARD COMPOSITION
MX              8 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       7.8212 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             0 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            26000     99.000 WT%
             6012      1.000 WT%
END

SC  REG-CONCRETE STANDARD COMPOSITION
MX              9 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       2.2430 SPECIFIED DENSITY
NEL             7 NO. ELEMENTS
ICP             0 0/1 MIXTURE/COMPOUND.
TEMP        293.0 DEG KELVIN
            26000      1.400 WT%
             1001      1.000 WT%
            13027      3.400 WT%
            20000      4.400 WT%
             8016     53.200 WT%
            14000     33.700 WT%
            11023      2.900 WT%
END

SC  H2O           STANDARD COMPOSITION
MX             10 MIXTURE NO.
VF         0.0001 VOLUME FRACTION
ROTH       0.9982 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             1001        2.00 ATOMS/MOLECULE
             8016        1.00 ATOM/MOLECULE
END

**** PROBLEM GEOMETRY ****

CTP SQUAREPITCH   CELL TYPE
PITCH      1.1887 CM CENTER TO CENTER SPACING
FUELOD     0.7887 CM FUEL DIAMETER OR SLAB THICKNESS
MFUEL           1 MIXTURE NO. OF FUEL
MMOD            3 MIXTURE NO. OF MODERATOR
CLADOD     0.9271 CM CLAD OUTER DIAMETER
MCLAD           2 MIXTURE NO. OF CLAD
GAPOD      0.8052 CM GAP OUTER DIAMETER
MGAP            0 MIXTURE NO. OF GAP

ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

               ZONE  1 IS FUEL
               ZONE  2 IS GAP
               ZONE  3 IS CLAD
               ZONE  4 IS MOD
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

********** DATA LIBRARY INFORMATION **********

UNIT                                          VOLUME
NUMBER          DATA SET NAME                 NAME      UNIT FUNCTION
------          -------------                 ----      -------------

  89    G:\scale43\DATALIB\FT89F001                     STANDARD COMPOSITION LIBRARY

  82    G:\scale43\DATALIB\FT82F001                     CROSS SECTION LIBRARY

  11    C:\svv\wrr5302\storage\FT11F001                 SHORT CROSS SECTION LIBRARY

  90    C:\svv\wrr5302\storage\FT90F001                 INPUT DATA DIRECT ACCESS


                 STANDARD COMPOSITION LIBRARY DATA
                 ---------------------------------

UNIT NUMBER   :  89

DATASET NAME  :  G:\scale43\DATALIB\FT89F001

LIBRARY TITLE:   SCALE-4 STANDARD COMPOSITION LIBRARY
                 637 STANDARD COMPOSITIONS, 490 NUCLIDES
                 90 ELEMENTS WITH VARIABLE ISOTOPIC DISTRBUTIONS.

CREATION DATE:    6/30/95


                    CROSS SECTION LIBRARY DATA
                    ---------------------------

UNIT NUMBER   :  82

DATASET NAME  :  G:\scale43\DATALIB\FT82F001

LIBRARY TITLE:   SCALE 4.2 - 27 GROUP NEUTRON GROUP LIBRARY
                     BASED ON ENDF-B VERSION 4 DATA
                         COMPILED FOR NRC     1/27/89
                             LAST UPDATED                          08/12/94
                                 L.M.PETRIE   -   ORNL

CONTROL MODULE CSAS25    IS COMPLETE.
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
KK        KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO                   VV        VV
KK       KK   EEEEEEEEEEEEE  NNN        NN  OOOOOOOOOOOOO                  VV        VV
KK      KK    EE             NNNN       NN  OO         OO                  VV        VV
KK     KK     EE             NN NN      NN  OO         OO                  VV        VV
KK    KK      EE             NN  NN     NN  OO         OO                  VV        VV
KKKKKKKK      EEEEEEEEE      NN   NN    NN  OO         OO  -------------   VV        VV
KKKKKKKK      EEEEEEEEE      NN    NN   NN  OO         OO  -------------    VV      VV
KK    KK      EE             NN     NN  NN  OO         OO                    VV    VV
KK     KK     EE             NN      NN NN  OO         OO                     VV  VV
KK      KK    EE             NN       NNNN  OO         OO                      VV VV
KK       KK   EEEEEEEEEEEEE  NN        NNN  OOOOOOOOOOOOO                       VVV
KK        KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO                         V

 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL             EEEEEEEEEEEEE                   PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL             EEEEEEEEEEEEE                   PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS  CC         CC   AA         AA  LL             EE                              PP         PP   CC         CC
SS             CC              AA         AA  LL             EE                              PP         PP   CC
SS             CC              AA         AA  LL             EE                              PP         PP   CC
SSSSSSSSSSSS   CC              AAAAAAAAAAAAA  LL             EEEEEEEEE      -------------    PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS  CC              AAAAAAAAAAAAA  LL             EEEEEEEEE      -------------    PPPPPPPPPPPP    CC
           SS  CC              AA         AA  LL             EE                              PP              CC
           SS  CC              AA         AA  LL             EE                              PP              CC
SS         SS  CC         CC   AA         AA  LL             EE                              PP              CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL  EEEEEEEEEEEEE                   PP              CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC    AA         AA  LLLLLLLLLLLLL  EEEEEEEEEEEEE                   PP               CCCCCCCCCCC

     11         22222222222              //     0000000     7777777777777              //   99999999999     666666666666
    111        2222222222222            //     000000000    777777777777              //   9999999999999   6666666666666
   1111        22         22           //     00       00   77        77             //    99         99   66
     11                   22          //     00         00           77             //     99         99   66
     11                   22         //      00         00          77             //      99         99   66
     11                  22         //       00         00         77             //       9999999999999   666666666666
     11                22          //        00         00         77            //         999999999999   6666666666666
     11              22           //         00         00        77            //                    99   66         66
     11            22            //          00         00        77           //                     99   66         66
     11          22             //            00       00        77           //                      99   66         66
  11111111     2222222222222   //             000000000          77          //          9999999999999   6666666666666
  11111111     2222222222222  //               0000000           77         //           999999999999     66666666666

   0000000     666666666666                     11         99999999999                   0000000       7777777777777
  000000000    6666666666666                   111        9999999999999                 000000000      777777777777
 00       00   66                 :::         1111        99         99     :::        00       00     77        77
00         00  66                 :::           11        99         99     :::       00         00            77
00         00  66                 :::           11        99         99     :::       00         00           77
00         00  666666666666                     11        9999999999999               00         00          77
00         00  6666666666666                    11         999999999999               00         00          77
00         00  66         66      :::           11                   99     :::       00         00         77
00         00  66         66      :::           11                   99     :::       00         00         77
 00       00   66         66      :::           11                   99     :::        00       00         77
  000000000    6666666666666                 11111111     9999999999999                 000000000         77
   0000000     66666666666                   11111111     999999999999                   0000000          77
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
 SSSSSSSSSSS     CCCCCCCCCCC      AAAAAAAAA     LL              EEEEEEEEEEEEE                         PPPPPPPPPPPP     CCCCCCCCCCC
SSSSSSSSSSSSS   CCCCCCCCCCCCC    AAAAAAAAAAA    LL              EEEEEEEEEEEEE                         PPPPPPPPPPPPP   CCCCCCCCCCCCC
SS         SS   CC         CC   AA         AA   LL              EE                                    PP         PP   CC         CC
SS              CC              AA         AA   LL              EE                                    PP         PP   CC
SS              CC              AA         AA   LL              EE                                    PP         PP   CC
SSSSSSSSSSSS    CC              AAAAAAAAAAAAA   LL              EEEEEEEEE        -------------        PPPPPPPPPPPPP   CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL              EEEEEEEEE        -------------        PPPPPPPPPPPP    CC
           SS   CC              AA         AA   LL              EE                                    PP              CC
           SS   CC              AA         AA   LL              EE                                    PP              CC
SS         SS   CC         CC   AA         AA   LL              EE                                    PP              CC         CC
SSSSSSSSSSSSS   CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                         PP              CCCCCCCCCCCCC
 SSSSSSSSSSS     CCCCCCCCCCC    AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                         PP               CCCCCCCCCCC
```

```
*******************************************************************************
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                    PROGRAM VERIFICATION INFORMATION                 *****
*****                                                                     *****
*****                   CODE SYSTEM:  SCALE-PC VERSION:  4.3              *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*****                                                                     *****
*****                                                                     *****
*****                  PROGRAM:  000009                                   *****
*****                                                                     *****
*****            CREATION DATE:  03-08-96                                 *****
*****                                                                     *****
*****                   VOLUME:  ENG                                      *****
*****                                                                     *****
*****                  LIBRARY:  G:\scale43\exe                           *****
*****                                                                     *****
*****                                                                     *****
*****          PRODUCTION CODE:  KENOVA                                   *****
*****                                                                     *****
*****                  VERSION:  3.1                                      *****
*****                                                                     *****
*****                  JOBNAME:  SCALE-PC                                 *****
*****                                                                     *****
*****        DATE OF EXECUTION:  12/07/96                                 *****
*****                                                                     *****
*****        TIME OF EXECUTION:  06:19:07                                 *****
*****                                                                     *****
*****                                                                     *****
*******************************************************************************
*******************************************************************************
*******************************************************************************
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

****** NUMERIC PARAMETERS ******

TME   MAXIMUM PROBLEM TIME (MIN)               500.00
TBA   TIME PER GENERATION (MIN)                  0.50
GEN   NUMBER OF GENERATIONS                      1003
NPG   NUMBER PER GENERATION                      1000
NSK   NUMBER OF GENERATIONS TO BE SKIPPED           3
BEG   BEGINNING GENERATION NUMBER                   1
RES   GENERATIONS BETWEEN CHECKPOINTS               0
X1D   NUMBER OF EXTRA 1-D CROSS SECTIONS            1
NBK   NEUTRON BANK SIZE                          1025
XNB   EXTRA POSITIONS IN NEUTRON BANK               0
NFB   FISSION BANK SIZE                          1000
XFB   EXTRA POSITIONS IN FISSION BANK               0
WTA   DEFAULT VALUE OF WEIGHT AVERAGE          0.5000
WTH   WEIGHT HIGH FOR SPLITTING                3.0000
WTL   WEIGHT LOW FOR RUSSIAN ROULETTE          0.3333
RND   STARTING RANDOM NUMBER              BB827100001
NB8   NUMBER OF D.A. BLOCKS ON UNIT  8            200
NL8   LENGTH OF D.A. BLOCKS ON UNIT  8            512
ADJ   MODE OF CALCULATION                     FORWARD
      INPUT DATA WRITTEN ON RESTART UNIT           NO
      BINARY DATA INTERFACE                       YES
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
*****************************************************************************************************
*****************************************************************************************************
***                                                                                               ***
***                        WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE             ***
***                                                                                               ***
*****************************************************************************************************
***                         ******     LOGICAL PARAMETERS     ******                              ***
***                                                                                               ***
***  RUN  EXECUTE PROBLEM AFTER CHECKING DATA    YES      PLT  PLOT PICTURE MAP(S)            YES ***
***                                                                                               ***
***  FLX  COMPUTE FLUX                            NO      FDN  COMPUTE FISSION DENSITIES        NO ***
***                                                                                               ***
***  SMU  COMPUTE AVG UNIT SELF-MULTIPLICATION    NO      NUB  COMPUTE NU-BAR & AVG FISSION GROUP  YES ***
***                                                                                               ***
***  MKU  COMPUTE MATRIX K-EFF BY UNIT NUMBER     NO      MKP  COMPUTE MATRIX K-EFF BY UNIT LOCATION  NO ***
***                                                                                               ***
***  CKU  COMPUTE COFACTOR K-EFF BY UNIT NUMBER   NO      CKP  COMPUTE COFACTOR K-EFF BY UNIT LOCATION  NO ***
***                                                                                               ***
***  FMU  PRINT FISS PROD MATRIX BY UNIT NUMBER   NO      FMP  PRINT FISS PROD MATRIX BY UNIT LOCATION  NO ***
***                                                                                               ***
***  MKH  COMPUTE MATRIX K-EFF BY HOLE NUMBER     NO      MKA  COMPUTE MATRIX K-EFF BY ARRAY NUMBER  NO ***
***                                                                                               ***
***  CKH  COMPUTE COFACTOR K-EFF BY HOLE NUMBER   NO      CKA  COMPUTE COFACTOR K-EFF BY ARRAY NUMBER  NO ***
***                                                                                               ***
***  FMH  PRINT FISS PROD MATRIX BY HOLE NUMBER   NO      FMA  PRINT FISS PROD MATRIX BY ARRAY NUMBER  NO ***
***                                                                                               ***
***  HHL  COLLECT MATRIX BY HIGHEST HOLE LEVEL    NO      HAL  COLLECT MATRIX BY HIGHEST ARRAY LEVEL  NO ***
***                                                                                               ***
***  AMX  PRINT ALL MIXED CROSS SECTIONS          NO      FAR  PRINT FIS. AND ABS. BY REGION    NO ***
***                                                                                               ***
***  XS1  PRINT 1-D MIXTURE X-SECTIONS            NO      GAS  PRINT FAR BY GROUP               NO ***
***                                                                                               ***
***  XS2  PRINT 2-D MIXTURE X-SECTIONS            NO      PAX  PRINT XSEC-ALBEDO CORRELATION TABLES  NO ***
***                                                                                               ***
***  XAP  PRINT MIXTURE ANGLES & PROBABILITIES    NO      PWT  PRINT WEIGHT AVERAGE ARRAY       NO ***
***                                                                                               ***
***  PKI  PRINT FISSION SPECTRUM                  NO      PGM  PRINT INPUT GEOMETRY             NO ***
***                                                                                               ***
***  P1D  PRINT EXTRA 1-D CROSS SECTIONS          NO      BUG  PRINT DEBUG INFORMATION          NO ***
***                                                                                               ***
***                                                       TRK  PRINT TRACKING INFORMATION       NO ***
***                                                                                               ***
***                                                                                               ***
*****************************************************************************************************
*****************************************************************************************************
*****************************************************************************************************
                              PARAMETER INPUT COMPLETED

                   ........    0 IO'S WERE USED READING THE PARAMETER DATA     ........

                   *************** DATA READING COMPLETED ***************
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
*****************************************************************************************************
***                                                                                               ***
***                      WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE               ***
***                                                                                               ***
*****************************************************************************************************
*****************************************************************************************************
***                                                                                               ***
***       UNIT                                          VOLUME                                    ***
***      NUMBER              DATA SET NAME               NAME      UNIT FUNCTION                  ***
***      ------              -------------               ----      -------------                  ***
***                                                                                               ***
***    XSC  14   C:\svv\wrr5302\storage\FT14F001                   MIXED CROSS SECTIONS           ***
***                                                                                               ***
***    ALB  79   G:\scale43\DATALIB\FT79F001                       INPUT ALBEDOS                  ***
***                                                                                               ***
***    WTS  80   G:\scale43\DATALIB\FT80F001                       INPUT WEIGHTS                  ***
***                                                                                               ***
***    SKT  16    UNKNOWN                                          WRITE SCRATCH DATA             ***
***                                                                                               ***
***    BIN  95   C:\svv\wrr5302\storage\FT95F001                   BINARY INPUT DATA              ***
***                                                                                               ***
***    RST  95   C:\svv\wrr5302\storage\FT95F001                   READ RESTART DATA              ***
***                                                                                               ***
***    LIB   4   C:\svv\wrr5302\storage\FT04F001                   INPUT AMPX WORKING LIBRARY     ***
***                                                                                               ***
***          8   C:\svv\wrr5302\storage\FT08F001                   INPUT DATA DIRECT ACCESS       ***
***                                                                                               ***
***          9    UNKNOWN                                          SUPER GROUPED DIRECT ACCESS    ***
***                                                                                               ***
***         10    UNKNOWN                                          XSEC MIXING DIRECT ACCESS      ***
***                                                                                               ***
*****************************************************************************************************

                ........   0 IO'S WERE USED PREPARING INPUT DATA   ........

                CROSS SECTIONS READ FROM THE AMPX WORKING LIBRARY ON UNIT    4
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
                        WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

                                          MIXING TABLE

                                  NUMBER OF SCATTERING ANGLES =  2
                              CROSS SECTION MESSAGE THRESHOLD =3.0E-05

MIXTURE =      1          DENSITY(G/CC) =  10.412
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   1008016  4.64617E-02  1.18487E-01    8016     15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                       UPDATED
08/12/94
   1092235  9.40641E-04  3.52606E-02   92235    235.0441     URANIUM-235    ENDF/B-IV MAT 1261                       UPDATED
08/12/94
   1092238  2.22902E-02  8.46253E-01   92238    238.0510     URANIUM-238    ENDF/B-IV MAT 1262                       UPDATED
08/12/94

MIXTURE =      2          DENSITY(G/CC) =  6.5600
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   2040302  4.33078E-02  1.00000E+00   40000     91.2196     ZIRCALLOY      ENDF/B-IV MAT 1284                       UPDATED
08/12/94

MIXTURE =      3          DENSITY(G/CC) = 0.99817E-04
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   3001001  6.67692E-06  1.11927E-01    1001      1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002              UPDATED
08/12/94
   3008016  3.33846E-06  8.88074E-01    8016     15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                       UPDATED
08/12/94

MIXTURE =      4          DENSITY(G/CC) =  2.7020
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   4013027  6.03066E-02  1.00000E+00   13027     26.9818    AL-27 1193 218 GP 040375(5)                              UPDATED
08/12/94

MIXTURE =      5          DENSITY(G/CC) =  7.9200
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   5024304  1.74286E-02  1.90000E-01   24000     51.9957    CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'         UPDATED
08/12/94
   5025055  1.73633E-03  1.99999E-02   25055     54.9379     MANGANESE-55   ENDF/B-IV MAT 1197                       UPDATED
08/12/94
   5026304  5.93579E-02  6.95000E-01   26000     55.8447    FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'         UPDATED
08/12/94
   5028304  7.72070E-03  9.50001E-02   28000     58.6872    NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'         UPDATED
08/12/94

MIXTURE =      6          DENSITY(G/CC) =  2.5833
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   6005010  7.09799E-03  4.56855E-02    5010     10.0130    B-10 1273 218NGP 042375 P-3 293K                         UPDATED
08/12/94
   6005011  3.92499E-02  2.77771E-01    5011     11.0096     BORON-11       ENDF/B-IV MAT 1160                       UPDATED
08/12/94
   6006012  1.22006E-02  9.41116E-02    6000     12.0001     CARBON-12      ENDF/B-IV MAT 1274/THRM1065              UPDATED
08/12/94
   6013027  3.35812E-02  5.82432E-01   13027     26.9818    AL-27 1193 218 GP 040375(5)                              UPDATED
08/12/94

MIXTURE =      7          DENSITY(G/CC) = 0.99817E-04
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   7001001  6.67692E-06  1.11927E-01    1001      1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002              UPDATED
08/12/94
   7008016  3.33846E-06  8.88074E-01    8016     15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                       UPDATED
08/12/94

MIXTURE =      8          DENSITY(G/CC) =  7.8212
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   8006012  3.92503E-03  1.00001E-02    6000     12.0001     CARBON-12      ENDF/B-IV MAT 1274/THRM1065              UPDATED
08/12/94
   8026000  8.34982E-02  9.90000E-01   26000     55.8447     IRON           ENDF/B-IV MAT 1192                       UPDATED
08/12/94

MIXTURE =      9          DENSITY(G/CC) =  2.2430
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
   9001001  1.34031E-02  9.99867E-03    1001      1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002              UPDATED
08/12/94
   9008016  4.49394E-02  5.31997E-01    8016     15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                       UPDATED
08/12/94
   9011023  1.70392E-03  2.90003E-02   11023     22.9895     SODIUM-23      ENDF/B-IV MAT 1156                       UPDATED
08/12/94
   9013027  1.70211E-03  3.40003E-02   13027     26.9818    AL-27 1193 218 GP 040375(5)                              UPDATED
08/12/94
   9014000  1.62080E-02  3.37003E-01   14000     28.0853     SILICON        ENDF/B-IV MAT 1194                       UPDATED
08/12/94
   9020000  1.48287E-03  4.40004E-02   20000     40.0803    CALCIUM ENDF/B-IV MAT 1195                               UPDATED
08/12/94
   9026000  3.38630E-04  1.40001E-02   26000     55.8447     IRON           ENDF/B-IV MAT 1192                       UPDATED
08/12/94

MIXTURE =     10          DENSITY(G/CC) = 0.99817E-04
   NUCLIDE   ATOM-DENS.   WGT. FRAC.      ZA        AWT                NUCLIDE TITLE
  10001001  6.67692E-06  1.11927E-01    1001      1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002              UPDATED
08/12/94
  10008016  3.33846E-06  8.88074E-01    8016     15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                       UPDATED
08/12/94
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

```
***********************************************************************************************
***                                                                                         ***
***        WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE                       ***
***                                                                                         ***
***********************************************************************************************
***********************************************************************************************
***                                                                                         ***
***                        ****** ADDITIONAL INFORMATION ******                             ***
***                                                                                         ***
*** NUMBER OF ENERGY GROUPS              27    USE LATTICE GEOMETRY                    YES  ***
***                                                                                         ***
*** NO. OF FISSION SPECTRUM SOURCE GROUP  1    GLOBAL ARRAY NUMBER                      60  ***
***                                                                                         ***
*** NO. OF SCATTERING ANGLES IN XSECS     2    NUMBER OF UNITS IN THE GLOBAL X DIR.      1  ***
***                                                                                         ***
*** ENTRIES/NEUTRON IN THE NEUTRON BANK  32    NUMBER OF UNITS IN THE GLOBAL Y DIR.      1  ***
***                                                                                         ***
*** ENTRIES/NEUTRON IN THE FISSION BANK  25    NUMBER OF UNITS IN THE GLOBAL Z DIR.      4  ***
***                                                                                         ***
*** NUMBER OF MIXTURES USED              10    USE A GLOBAL REFLECTOR                  YES  ***
***                                                                                         ***
*** NUMBER OF BIAS ID'S USED              1    USE NESTED HOLES                        YES  ***
***                                                                                         ***
*** NUMBER OF DIFFERENTIAL ALBEDOS USED   0    NUMBER OF HOLES                          24  ***
***                                                                                         ***
*** TOTAL INPUT GEOMETRY REGIONS         97    MAXIMUM HOLE NESTING LEVEL                2  ***
***                                                                                         ***
*** NUMBER OF GEOMETRY REGIONS USED      97    USE NESTED ARRAYS                       YES  ***
***                                                                                         ***
*** LARGEST GEOMETRY UNIT NUMBER        120    NUMBER OF ARRAYS USED                    18  ***
***                                                                                         ***
*** LARGEST ARRAY NUMBER                 60    MAXIMUM ARRAY NESTING LEVEL               4  ***
***                                                                                         ***
***                                                                                         ***
*** +X BOUNDARY CONDITION           REFLECT    -X BOUNDARY CONDITION               REFLECT  ***
***                                                                                         ***
*** +Y BOUNDARY CONDITION           REFLECT    -Y BOUNDARY CONDITION               REFLECT  ***
***                                                                                         ***
*** +Z BOUNDARY CONDITION               PER    -Z BOUNDARY CONDITION                   PER  ***
***                                                                                         ***
***********************************************************************************************
```

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 475 INDEPENDENT FISSION POINTS WERE GENERATED				
1	4.11868E-01	6.25517E+00	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 477 INDEPENDENT FISSION POINTS WERE GENERATED				
2	4.19477E-01	6.55817E+00	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY 511 INDEPENDENT FISSION POINTS WERE GENERATED				
3	4.40874E-01	6.86483E+00	4.40874E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	4.31155E-01	7.17333E+00	4.36014E-01	4.85970E-03	0.00000E+00	0.00000E+00
5	4.38865E-01	7.49550E+00	4.36965E-01	2.96232E-03	0.00000E+00	0.00000E+00
6	4.17054E-01	7.80133E+00	4.31987E-01	5.40036E-03	0.00000E+00	0.00000E+00
7	4.24368E-01	8.11900E+00	4.30463E-01	4.45201E-03	0.00000E+00	0.00000E+00
8	4.17726E-01	8.43017E+00	4.28340E-01	4.20951E-03	0.00000E+00	0.00000E+00
9	4.26347E-01	8.74600E+00	4.28056E-01	3.56907E-03	0.00000E+00	0.00000E+00
10	4.31943E-01	9.06183E+00	4.28542E-01	3.12887E-03	0.00000E+00	0.00000E+00
11	4.34519E-01	9.37583E+00	4.29206E-01	2.83822E-03	0.00000E+00	0.00000E+00
12	4.34790E-01	9.69900E+00	4.29764E-01	2.59928E-03	0.00000E+00	0.00000E+00
13	4.36472E-01	1.00185E+01	4.30374E-01	2.42892E-03	0.00000E+00	0.00000E+00
14	4.35529E-01	1.03362E+01	4.30804E-01	2.25852E-03	0.00000E+00	0.00000E+00
15	4.38165E-01	1.06510E+01	4.31370E-01	2.15332E-03	0.00000E+00	0.00000E+00
16	4.41168E-01	1.09660E+01	4.32070E-01	2.11286E-03	0.00000E+00	0.00000E+00
17	4.50614E-01	1.12882E+01	4.33306E-01	2.32321E-03	0.00000E+00	0.00000E+00
18	4.42851E-01	1.16077E+01	4.33903E-01	2.25356E-03	0.00000E+00	0.00000E+00
19	4.31047E-01	1.19188E+01	4.33735E-01	2.12351E-03	0.00000E+00	0.00000E+00
20	4.43283E-01	1.22375E+01	4.34265E-01	2.07115E-03	0.00000E+00	0.00000E+00
21	4.31275E-01	1.25487E+01	4.34108E-01	1.96543E-03	0.00000E+00	0.00000E+00
22	4.22313E-01	1.28553E+01	4.33518E-01	1.95561E-03	0.00000E+00	0.00000E+00
23	4.16142E-01	1.31638E+01	4.32690E-01	2.03588E-03	0.00000E+00	0.00000E+00
24	4.38541E-01	1.34760E+01	4.32956E-01	1.95927E-03	0.00000E+00	0.00000E+00
25	4.22596E-01	1.37863E+01	4.32506E-01	1.92557E-03	0.00000E+00	0.00000E+00
26	4.43309E-01	1.40985E+01	4.32956E-01	1.89775E-03	0.00000E+00	0.00000E+00
27	4.29567E-01	1.44117E+01	4.32821E-01	1.82530E-03	0.00000E+00	0.00000E+00
28	4.32907E-01	1.47247E+01	4.32824E-01	1.75369E-03	0.00000E+00	0.00000E+00
29	4.30161E-01	1.50332E+01	4.32725E-01	1.69037E-03	0.00000E+00	0.00000E+00
30	4.45822E-01	1.53545E+01	4.33193E-01	1.69471E-03	0.00000E+00	0.00000E+00
31	4.58676E-01	1.56703E+01	4.34072E-01	1.85638E-03	0.00000E+00	0.00000E+00
32	4.43808E-01	1.59733E+01	4.34396E-01	1.82256E-03	0.00000E+00	0.00000E+00
33	4.41420E-01	1.62827E+01	4.34623E-01	1.77729E-03	0.00000E+00	0.00000E+00
34	4.38101E-01	1.65940E+01	4.34732E-01	1.72428E-03	0.00000E+00	0.00000E+00
35	4.20226E-01	1.68997E+01	4.34292E-01	1.72806E-03	0.00000E+00	0.00000E+00
36	4.30418E-01	1.72110E+01	4.34178E-01	1.68033E-03	0.00000E+00	0.00000E+00
37	4.40334E-01	1.75222E+01	4.34354E-01	1.64107E-03	0.00000E+00	0.00000E+00
38	4.29066E-01	1.78343E+01	4.34207E-01	1.60158E-03	0.00000E+00	0.00000E+00
39	4.26009E-01	1.81373E+01	4.33985E-01	1.57337E-03	0.00000E+00	0.00000E+00
40	4.30454E-01	1.84458E+01	4.33893E-01	1.53423E-03	0.00000E+00	0.00000E+00
41	4.28514E-01	1.87580E+01	4.33755E-01	1.50072E-03	0.00000E+00	0.00000E+00
42	4.34513E-01	1.90683E+01	4.33774E-01	1.46284E-03	0.00000E+00	0.00000E+00
43	4.30687E-01	1.93823E+01	4.33698E-01	1.42870E-03	0.00000E+00	0.00000E+00
44	4.14305E-01	1.96882E+01	4.33237E-01	1.46874E-03	0.00000E+00	0.00000E+00
45	4.18237E-01	2.00003E+01	4.32888E-01	1.47599E-03	0.00000E+00	0.00000E+00
46	4.29721E-01	2.03215E+01	4.32816E-01	1.44385E-03	0.00000E+00	0.00000E+00
47	4.32701E-01	2.06292E+01	4.32813E-01	1.41140E-03	0.00000E+00	0.00000E+00
48	4.18180E-01	2.09312E+01	4.32495E-01	1.41656E-03	0.00000E+00	0.00000E+00
49	4.33377E-01	2.12488E+01	4.32514E-01	1.38622E-03	0.00000E+00	0.00000E+00
50	4.35003E-01	2.15565E+01	4.32566E-01	1.35802E-03	0.00000E+00	0.00000E+00
.						
.						
.						
950	4.23082E-01	3.02703E+02	4.30921E-01	3.02884E-04	0.00000E+00	0.00000E+00
951	4.23632E-01	3.03085E+02	4.30913E-01	3.02662E-04	0.00000E+00	0.00000E+00
952	4.39814E-01	3.03453E+02	4.30922E-01	3.02489E-04	0.00000E+00	0.00000E+00
953	4.33060E-01	3.03762E+02	4.30925E-01	3.02179E-04	0.00000E+00	0.00000E+00
954	4.38819E-01	3.04109E+02	4.30933E-01	3.01975E-04	0.00000E+00	0.00000E+00
955	4.25373E-01	3.04472E+02	4.30927E-01	3.01715E-04	0.00000E+00	0.00000E+00
956	4.39266E-01	3.04828E+02	4.30936E-01	3.01525E-04	0.00000E+00	0.00000E+00
957	4.32237E-01	3.05156E+02	4.30937E-01	3.01212E-04	0.00000E+00	0.00000E+00
958	4.11043E-01	3.05477E+02	4.30916E-01	3.01616E-04	0.00000E+00	0.00000E+00
959	4.11484E-01	3.05803E+02	4.30896E-01	3.01984E-04	0.00000E+00	0.00000E+00
960	4.43532E-01	3.06125E+02	4.30909E-01	3.01957E-04	0.00000E+00	0.00000E+00
961	4.28865E-01	3.06449E+02	4.30907E-01	3.01649E-04	0.00000E+00	0.00000E+00
962	4.37268E-01	3.06771E+02	4.30914E-01	3.01408E-04	0.00000E+00	0.00000E+00
963	4.30274E-01	3.07099E+02	4.30913E-01	3.01094E-04	0.00000E+00	0.00000E+00
964	4.24956E-01	3.07414E+02	4.30907E-01	3.00845E-04	0.00000E+00	0.00000E+00
965	4.26253E-01	3.07715E+02	4.30902E-01	3.00571E-04	0.00000E+00	0.00000E+00
966	4.48713E-01	3.08029E+02	4.30921E-01	3.00827E-04	0.00000E+00	0.00000E+00
967	4.26241E-01	3.08331E+02	4.30916E-01	3.00554E-04	0.00000E+00	0.00000E+00
968	4.21349E-01	3.08625E+02	4.30906E-01	3.00406E-04	0.00000E+00	0.00000E+00
969	4.23477E-01	3.08963E+02	4.30898E-01	3.00194E-04	0.00000E+00	0.00000E+00
970	4.22261E-01	3.09289E+02	4.30889E-01	3.00016E-04	0.00000E+00	0.00000E+00
971	4.21615E-01	3.09630E+02	4.30880E-01	2.99859E-04	0.00000E+00	0.00000E+00
972	4.34719E-01	3.10055E+02	4.30884E-01	2.99576E-04	0.00000E+00	0.00000E+00
973	4.34609E-01	3.10379E+02	4.30888E-01	2.99292E-04	0.00000E+00	0.00000E+00
974	4.15198E-01	3.10694E+02	4.30871E-01	2.99419E-04	0.00000E+00	0.00000E+00
975	4.30697E-01	3.11024E+02	4.30871E-01	2.99112E-04	0.00000E+00	0.00000E+00
976	4.40992E-01	3.11341E+02	4.30882E-01	2.98985E-04	0.00000E+00	0.00000E+00
977	4.26609E-01	3.11709E+02	4.30877E-01	2.98710E-04	0.00000E+00	0.00000E+00
978	4.40731E-01	3.12052E+02	4.30887E-01	2.98575E-04	0.00000E+00	0.00000E+00
979	4.29475E-01	3.12365E+02	4.30886E-01	2.98273E-04	0.00000E+00	0.00000E+00
980	4.21792E-01	3.12669E+02	4.30877E-01	2.98113E-04	0.00000E+00	0.00000E+00
981	4.38641E-01	3.13015E+02	4.30884E-01	2.97913E-04	0.00000E+00	0.00000E+00
982	4.24572E-01	3.13313E+02	4.30878E-01	2.97679E-04	0.00000E+00	0.00000E+00
983	4.47810E-01	3.13628E+02	4.30895E-01	2.97876E-04	0.00000E+00	0.00000E+00
984	4.39955E-01	3.13948E+02	4.30905E-01	2.97715E-04	0.00000E+00	0.00000E+00
985	4.32729E-01	3.14266E+02	4.30906E-01	2.97418E-04	0.00000E+00	0.00000E+00

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

986	4.12678E-01	3.14578E+02	4.30888E-01	2.97693E-04	0.00000E+00	0.00000E+00
987	4.42827E-01	3.14927E+02	4.30900E-01	2.97637E-04	0.00000E+00	0.00000E+00
988	4.33477E-01	3.15251E+02	4.30903E-01	2.97347E-04	0.00000E+00	0.00000E+00
989	4.31513E-01	3.15611E+02	4.30903E-01	2.97046E-04	0.00000E+00	0.00000E+00
990	4.18927E-01	3.15916E+02	4.30891E-01	2.96993E-04	0.00000E+00	0.00000E+00
991	4.26421E-01	3.16219E+02	4.30887E-01	2.96727E-04	0.00000E+00	0.00000E+00
992	4.31255E-01	3.16526E+02	4.30887E-01	2.96427E-04	0.00000E+00	0.00000E+00
993	4.50152E-01	3.16845E+02	4.30906E-01	2.96765E-04	0.00000E+00	0.00000E+00
994	4.31645E-01	3.17155E+02	4.30907E-01	2.96467E-04	0.00000E+00	0.00000E+00
995	4.26160E-01	3.17469E+02	4.30902E-01	2.96206E-04	0.00000E+00	0.00000E+00
996	4.22311E-01	3.17781E+02	4.30894E-01	2.96035E-04	0.00000E+00	0.00000E+00
997	4.19499E-01	3.18098E+02	4.30882E-01	2.95959E-04	0.00000E+00	0.00000E+00
998	4.37252E-01	3.18400E+02	4.30889E-01	2.95730E-04	0.00000E+00	0.00000E+00
999	4.24955E-01	3.18710E+02	4.30883E-01	2.95494E-04	0.00000E+00	0.00000E+00
1000	4.26402E-01	3.19030E+02	4.30878E-01	2.95231E-04	0.00000E+00	0.00000E+00
1001	4.37645E-01	3.19351E+02	4.30885E-01	2.95014E-04	0.00000E+00	0.00000E+00
1002	4.38846E-01	3.19670E+02	4.30893E-01	2.94826E-04	0.00000E+00	0.00000E+00
1003	4.31258E-01	3.19986E+02	4.30893E-01	2.94531E-04	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123   EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

```
LIFETIME =  2.46949E-04 + OR -  1.25870E-06            GENERATION TIME =  1.80874E-06 + OR -  7.97475E-09
NU BAR   =  2.55392E+00 + OR -  2.02013E-04        AVERAGE FISSION GROUP =  6.60224E+00 + OR -  2.87354E-03
                  ENERGY(EV) OF THE AVERAGE LETHARGY CAUSING FISSION =  8.67901E+04 + OR -  2.67219E+02
```

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.43088	+ OR - 0.00029	0.43059 TO 0.43118	0.43029 TO 0.43147	0.43000 TO 0.43177	1000000
4	0.43088	+ OR - 0.00029	0.43059 TO 0.43118	0.43029 TO 0.43147	0.43000 TO 0.43177	999000
5	0.43088	+ OR - 0.00030	0.43058 TO 0.43117	0.43028 TO 0.43147	0.42999 TO 0.43176	998000
6	0.43089	+ OR - 0.00030	0.43059 TO 0.43118	0.43030 TO 0.43148	0.43000 TO 0.43177	997000
7	0.43090	+ OR - 0.00030	0.43060 TO 0.43119	0.43030 TO 0.43149	0.43001 TO 0.43178	996000
8	0.43091	+ OR - 0.00030	0.43061 TO 0.43120	0.43032 TO 0.43150	0.43002 TO 0.43179	995000
9	0.43091	+ OR - 0.00030	0.43062 TO 0.43121	0.43032 TO 0.43150	0.43003 TO 0.43180	994000
10	0.43091	+ OR - 0.00030	0.43062 TO 0.43121	0.43032 TO 0.43150	0.43002 TO 0.43180	993000
11	0.43091	+ OR - 0.00030	0.43061 TO 0.43120	0.43032 TO 0.43150	0.43002 TO 0.43180	992000
12	0.43090	+ OR - 0.00030	0.43061 TO 0.43120	0.43031 TO 0.43150	0.43002 TO 0.43179	991000
17	0.43086	+ OR - 0.00030	0.43056 TO 0.43115	0.43026 TO 0.43145	0.42997 TO 0.43175	986000
22	0.43084	+ OR - 0.00030	0.43054 TO 0.43114	0.43024 TO 0.43144	0.42995 TO 0.43173	981000
27	0.43084	+ OR - 0.00030	0.43055 TO 0.43114	0.43025 TO 0.43144	0.42995 TO 0.43174	976000
32	0.43079	+ OR - 0.00030	0.43049 TO 0.43108	0.43019 TO 0.43138	0.42989 TO 0.43168	971000
37	0.43077	+ OR - 0.00030	0.43047 TO 0.43107	0.43017 TO 0.43137	0.42987 TO 0.43166	966000
42	0.43077	+ OR - 0.00030	0.43047 TO 0.43107	0.43017 TO 0.43137	0.42987 TO 0.43167	961000
47	0.43080	+ OR - 0.00030	0.43050 TO 0.43110	0.43020 TO 0.43140	0.42990 TO 0.43171	956000
52	0.43081	+ OR - 0.00030	0.43051 TO 0.43111	0.43020 TO 0.43141	0.42990 TO 0.43171	951000
57	0.43083	+ OR - 0.00030	0.43053 TO 0.43114	0.43023 TO 0.43144	0.42993 TO 0.43174	946000
62	0.43084	+ OR - 0.00030	0.43053 TO 0.43114	0.43023 TO 0.43145	0.42992 TO 0.43175	941000
67	0.43085	+ OR - 0.00031	0.43055 TO 0.43116	0.43024 TO 0.43146	0.42994 TO 0.43177	936000
72	0.43088	+ OR - 0.00031	0.43058 TO 0.43119	0.43027 TO 0.43150	0.42996 TO 0.43180	931000
77	0.43087	+ OR - 0.00031	0.43056 TO 0.43118	0.43025 TO 0.43148	0.42994 TO 0.43179	926000
82	0.43088	+ OR - 0.00031	0.43057 TO 0.43119	0.43026 TO 0.43150	0.42995 TO 0.43181	921000
87	0.43090	+ OR - 0.00031	0.43059 TO 0.43122	0.43028 TO 0.43153	0.42997 TO 0.43184	916000
92	0.43096	+ OR - 0.00031	0.43065 TO 0.43127	0.43034 TO 0.43158	0.43003 TO 0.43189	911000

Figure 6.7-3 CSAS Input/Output Summary for Storage Cask - Normal Conditions (Continued)

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WRR EC455-5302 YANKEE STORAGE CASK KENO-VA MODEL BASE CASE

                                  FREQUENCY FOR GENERATIONS     4 TO 1003
0.3976 TO 0.3985     *
0.3985 TO 0.3994
0.3994 TO 0.4003
0.4003 TO 0.4013
0.4013 TO 0.4022
0.4022 TO 0.4031
0.4031 TO 0.4040
0.4040 TO 0.4050
0.4050 TO 0.4059
0.4059 TO 0.4068     *
0.4068 TO 0.4077     ***
0.4077 TO 0.4087     *
0.4087 TO 0.4096     *
0.4096 TO 0.4105     *
0.4105 TO 0.4115     *****
0.4115 TO 0.4124     ******
0.4124 TO 0.4133     ******
0.4133 TO 0.4142     *****
0.4142 TO 0.4152     ***********
0.4152 TO 0.4161     ***********
0.4161 TO 0.4170     ************
0.4170 TO 0.4179     **********************
0.4179 TO 0.4189     ******************
0.4189 TO 0.4198     **************
0.4198 TO 0.4207     ***********************
0.4207 TO 0.4216     ****************************
0.4216 TO 0.4226     *****************************
0.4226 TO 0.4235     *************************************
0.4235 TO 0.4244     **************************
0.4244 TO 0.4253     ******************
0.4253 TO 0.4263     ************************************
0.4263 TO 0.4272     **********************************
0.4272 TO 0.4281     ****************************************
0.4281 TO 0.4290     ******************************
0.4290 TO 0.4300     ************************************
0.4300 TO 0.4309     *********************************************
0.4309 TO 0.4318     ************************************
0.4318 TO 0.4327     ****************************************
0.4327 TO 0.4337     *************************************************
0.4337 TO 0.4346     ***********************************
0.4346 TO 0.4355     ******************************
0.4355 TO 0.4364     ****************************
0.4364 TO 0.4374     *****************************
0.4374 TO 0.4383     ***********************************
0.4383 TO 0.4392     *************************
0.4392 TO 0.4401     *******************************
0.4401 TO 0.4411     **************************
0.4411 TO 0.4420     *************************
0.4420 TO 0.4429     *****************
0.4429 TO 0.4438     *************
0.4438 TO 0.4448     *********
0.4448 TO 0.4457     *******************
0.4457 TO 0.4466     ****
0.4466 TO 0.4475     *****
0.4475 TO 0.4485     *********
0.4485 TO 0.4494     *********
0.4494 TO 0.4503     *******
0.4503 TO 0.4513     *****
0.4513 TO 0.4522     *
0.4522 TO 0.4531     *****
0.4531 TO 0.4540     ***
0.4540 TO 0.4550
0.4550 TO 0.4559     *
0.4559 TO 0.4568     *
0.4568 TO 0.4577     *
0.4577 TO 0.4587     *
0.4587 TO 0.4596     *
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions

```
      PRIMARY MODULE ACCESS AND INPUT RECORD ( SCALE DRIVER - 95/03/29 - 09:06:37 )
MODULE CSAS25    WILL BE CALLED
  WRR EC455-5302 STORAGE CASK CRITICALITY: water in fuel/clad gap
  '
  '      File st-mr-wg.in
  '
  '      THIS IS A MODEL OF THE YNPS NAC-MPC BASKET IN THE STORAGE CASK
  '              LOADED WITH 36 UNITED NUCLEAR TYPE A ASSEMBLIES
  '
  '           PRODUCED FOR THE YANKEE ROWE
  '              STC LICENSE AMENDMENT
  '
  '       material      volume
  '        number      fraction
  '       --------     --------
  '           3         1.0000     inside canister
  '           7         1.0000     canister/VCC gap
  '          10         1.0000     external to VCC
  '          11         1.0000     fuel/clad gap
  '
  '
  '           PRODUCED FOR THE YANKEE ROWE
  '              STC LICENSE AMENDMENT
  '
  27GROUPNDF4 LATTICECELL
  UO2          1              0.95    293.0 92235 4.0 92238 96.0 END
  ZIRCALLOY    2              1.0     293.0                      END
  H2O          3              1.0     293.0                      END
  AL           4              1.0     293.0                      END
  SS304        5              1.0     293.0                      END
  B-10         6  DEN=2.6226 0.0450   293.0                      END
  B-11         6  DEN=2.6226 0.2736   293.0                      END
  C            6  DEN=2.6226 0.0927   293.0                      END
  AL           6  DEN=2.6226 0.5737   293.0                      END
  H2O          7              1.0     293.0                      END
  CARBONSTEEL  8              1.0     293.0                      END
  REG-CONCRETE 9  DEN=2.243   1.0     293.0                      END
  H2O         10              1.0     293.0                      END
  H2O         11              1.0     293.0                      END
  END COMP
  SQUAREPITCH  1.1887 0.7887 1 3 0.9271 2 0.8052 11 END
  WRR EC455-5302 STORAGE CASK CRITICALITY: water in fuel/clad gap
  READ PARAM RUN=yes PLT=no  GEN=1003 NPG=1000 TME=500 END PARAM
  READ GEOM
  '
  '  WATER LEVEL UNIT CELLS
  '
  UNIT  1
  COM='FUEL PIN CELL - BETWEEN DISKS'
  CYLINDER  1 1  0.3943    2P2.1400
  CYLINDER 11 1  0.4026    2P2.1400
  CYLINDER  2 1  0.4635    2P2.1400
  CUBOID    3 1  4P0.5944  2P2.1400
  UNIT  2
  COM='WATER CELL - BETWEEN DISKS'
  CUBOID    3 1  4P0.5944  2P2.1400
  UNIT  3
  COM='DISPLACEMENT CELL - BETWEEN DISKS'
  CYLINDER  2 1  0.4635    2P2.1400
  CUBOID    3 1  4P0.5944  2P2.1400
  UNIT  4
  COM='INSTRUMENT TUBE CELL - BETWEEN DISKS'
  CYLINDER  3 1  0.4998    2P2.1400
  CYLINDER  5 1  0.5442    2P2.1400
  CUBOID    3 1  4P0.5944  2P2.1400
  '
  '  DISK LEVEL UNIT CELLS (BOTH SS AND AL)
  '
  UNIT  5
  COM='FUEL PIN CELL - WITH SS DISK'
  CYLINDER  1 1  0.3943   2P0.6604
  CYLINDER 11 1  0.4026   2P0.6604
  CYLINDER  2 1  0.4635   2P0.6604
  CUBOID    3 1  4P0.5944 2P0.6604
  UNIT  6
  COM='WATER CELL - WITH SS DISK'
  CUBOID    3 1  4P0.5944 2P0.6604
  UNIT  7
  COM='DISPLACEMENT CELL - WITH SS DISK'
  CYLINDER  2 1  0.4635   2P0.6604
  CUBOID    3 1  4P0.5944 2P0.6604
  UNIT  8
  COM='INSTRUMENT TUBE CELL - WITH SS DISK'
  CYLINDER  3 1  0.4998   2P0.6604
  CYLINDER  5 1  0.5442   2P0.6604
  CUBOID    3 1  4P0.5944 2P0.6604
  '
  '  WATER LEVEL BORAL SHEETS
  '
  UNIT 14
  COM='X-X BORAL SHEET BETWEEN DISKS'
  CUBOID 6 1 2P9.144 2P0.0318 2P2.1400
  CUBOID 4 1 2P9.144 2P0.0953 2P2.1400
  UNIT 15
  COM='Y-Y BORAL SHEET BETWEEN DISKS'
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
CUBOID 6 1 2P0.0318 2P9.144 2P2.1400
CUBOID 4 1 2P0.0953 2P9.144 2P2.1400
'
'  DISK LEVEL BORAL SHEETS (AL AND SS)
'
UNIT 16
COM='X-X BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P9.144 2P0.0318 2P0.6604
CUBOID 4 1 2P9.144 2P0.0953 2P0.6604
UNIT 17
COM='Y-Y BORAL SHEET WITH SS DISK'
CUBOID 6 1 2P0.0318 2P9.144 2P0.6604
CUBOID 4 1 2P0.0953 2P9.144 2P0.6604
'
' WATER LEVEL WEB MATERIAL
'
UNIT 20
COM='WATER LEVEL WEB MATERIAL (SMALL) X-X'
CUBOID    3 1 2P10.4635 2P0.9716 2P2.1400
UNIT 21
COM='WATER LEVEL WEB MATERIAL (MEDIUM) X-X'
CUBOID    3 1 2P10.4635 2P1.0478 2P2.1400
UNIT 22
COM='WATER LEVEL WEB MATERIAL (LARGE) X-X'
CUBOID    3 1 2P10.4635 2P1.1208 2P2.1400
UNIT 23
COM='WATER LEVEL WEB MATERIAL (LONG) Y-Y'
CUBOID    3 1 2P1.1208 2P79.5249 2P2.1400
'
'  SUPPORT DISK WEB MATERIAL
'
UNIT 30
COM='SUPPORT DISK WEB MATERIAL (SMALL) X-X'
CUBOID    5 1 2P10.4635 2P0.9716 2P0.6604
UNIT 31
COM='SUPPORT DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    5 1 2P10.4635 2P1.0478 2P0.6604
UNIT 32
COM='SUPPORT DISK WEB MATERIAL (LARGE) X-X'
CUBOID    5 1 2P10.4635 2P1.1208 2P0.6604
UNIT 33
COM='SUPPORT DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    5 1 2P1.1208 2P79.5249 2P0.6604
'
'  HEAT TRANSFER DISK WEB MATERIAL
'
UNIT 40
COM='HEAT TRANSFER DISK WEB MATERIAL (SMALL) X-X'
CUBOID    4 1 2P10.4635 2P0.9716 2P0.6604
UNIT 41
COM='HEAT TRANSFER DISK WEB MATERIAL (MEDIUM) X-X'
CUBOID    4 1 2P10.4635 2P1.0478 2P0.6604
UNIT 42
COM='HEAT TRANSFER DISK WEB MATERIAL (LARGE) X-X'
CUBOID    4 1 2P10.4635 2P1.1208 2P0.6604
UNIT 43
COM='HEAT TRANSFER DISK WEB MATERIAL (LONG) Y-Y'
CUBOID    4 1 2P1.1208 2P79.5249 2P0.6604
'
'  WATER LEVEL ASSEMBLY ARRAYS
'
UNIT 50
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL'
ARRAY  1  -9.5104 -9.5104 -2.1400
CUBOID 3 1 4P9.9441                              2P2.1400
CUBOID 5 1 4P10.0661                             2P2.1400
CUBOID 3 1 4P10.25681                            2P2.1400
HOLE  14   0.0       10.1615  0.0
HOLE  14   0.0       -10.1615 0.0
HOLE  15   10.1615   0.0      0.0
HOLE  15   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                             2P2.1400
UNIT 51
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.0       -0.1584      0.0
UNIT 52
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.0       0.1584       0.0
UNIT 53
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   -0.1584   0.0            0.0
UNIT 54
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.1584    0.0          0.0
UNIT 55
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.1584    0.1584       0.0
UNIT 56
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X +Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   -0.1584   0.1584         0.0
UNIT 57
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL +X -Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   0.1584    -0.1584        0.0
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
UNIT 58
COM='FUEL TUBE AND ASSEMBLY - WATER LEVEL -X -Y'
CUBOID 3 1 4P10.4635                             2P2.1400
HOLE  50   -0.1584   -0.1584       0.0
UNIT 59
COM='WATER LEVEL CENTRAL HOLE'
CUBOID 3 1 4P10.4636                             2P2.1400
'
'   SUPPORT DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 60
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                              2P0.6604
CUBOID 5 1 4P10.0661                             2P0.6604
CUBOID 3 1 4P10.25681                            2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0      -10.1615  0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                             2P0.6604
UNIT 61
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   0.0       -0.1584       0.0
UNIT 62
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   0.0       0.1584        0.0
UNIT 63
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   -0.1584   0.0            0.0
UNIT 64
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   0.1584   0.0            0.0
UNIT 65
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   0.1584   0.1584        0.0
UNIT 66
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X +Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   -0.1584   0.1584        0.0
UNIT 67
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   0.1584   -0.1584        0.0
UNIT 68
COM='FUEL TUBE AND ASSEMBLY - SUPPORT DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  60   -0.1584   -0.1584        0.0
UNIT 69
COM='SUPPORT DISK CENTRAL HOLE'
CUBOID 3 1 4P10.4636   2P0.6604
'
'   HEAT TRANSFER DISK LEVEL ASSEMBLY ARRAYS
'
UNIT 70
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL'
ARRAY  2  -9.5104 -9.5104 -0.6604
CUBOID 3 1 4P9.9441                              2P0.6604
CUBOID 5 1 4P10.0661                             2P0.6604
CUBOID 3 1 4P10.25681                            2P0.6604
HOLE  16   0.0       10.1615  0.0
HOLE  16   0.0      -10.1615  0.0
HOLE  17   10.1615  0.0       0.0
HOLE  17   -10.1615 0.0       0.0
CUBOID 5 1 4P10.3051                             2P0.6604
UNIT 71
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   0.0       -0.1584       0.0
UNIT 72
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   0.0       0.1584        0.0
UNIT 73
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   -0.1584   0.0            0.0
UNIT 74
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   0.1584   0.0            0.0
UNIT 75
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X +Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   0.1584   0.1584        0.0
UNIT 76
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   -0.1584   0.1584        0.0
UNIT 77
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL +X -Y'
CUBOID 3 1 4P10.4635                             2P0.6604
HOLE  70   0.1584   -0.1584        0.0
UNIT 78
COM='FUEL TUBE AND ASSEMBLY - HEAT TRANSFER DISK LEVEL -X -Y'
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
CUBOID 3 1 4P10.4635                         2P0.6604
HOLE  70   -0.1584   -0.1584      0.0
UNIT 79
COM='HEAT TRANSFER CENTRAL HOLE'
CUBOID 3 1 4P10.4636                         2P0.6604
'
'  WATER LEVEL BASKET ARRAYS
'
UNIT 80
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 20 -10.4636 -33.6323 -2.1400
UNIT 81
COM='5X1 WATER LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 21 -10.4636 -33.6323 -2.1400
UNIT 82
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 22 -10.4636 -56.6549 -2.1400
UNIT 83
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 23 -10.4636 -56.6549 -2.1400
UNIT 84
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 24 -10.4636 -79.5251 -2.1400
UNIT 85
COM='13X1 WATER LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 25 -10.4636 -79.5251 -2.1400
UNIT 86
COM='13X1 WATER LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 26 -10.4636 -79.5251 -2.1400
'
'  SUPPORT DISK LEVEL BASKET ARRAYS
'
UNIT 90
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 30 -10.4636 -33.6323 -0.6604
UNIT 91
COM='5X1 SUPPORT DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 31 -10.4636 -33.6323 -0.6604
UNIT 92
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 32 -10.4636 -56.6549 -0.6604
UNIT 93
COM='9X1 WATER LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 33 -10.4636 -56.6549 -0.6604
UNIT 94
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 34 -10.4636 -79.5251 -0.6604
UNIT 95
COM='13X1 SUPPORT DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 35 -10.4636 -79.5251 -0.6604
UNIT 96
COM='13X1 SUPPORT DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 36 -10.4636 -79.5251 -0.6604
'
'  HEAT TRANSFER DISK LEVEL BASKET ARRAYS
'
UNIT 100
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY -X)'
ARRAY 40 -10.4636 -33.6323 -0.6604
UNIT 101
COM='5X1 HEAT TRANSFER DISK LEVEL ARRAY (SMALL ARRAY +X)'
ARRAY 41 -10.4636 -33.6323 -0.6604
UNIT 102
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY -X)'
ARRAY 42 -10.4636 -56.6549 -0.6604
UNIT 103
COM='9X1 HEAT TRANSFER DISK LEVEL ARRAY (MEDIUM ARRAY +X)'
ARRAY 43 -10.4636 -56.6549 -0.6604
UNIT 104
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY -X)'
ARRAY 44 -10.4636 -79.5251 -0.6604
UNIT 105
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (MIDDLE LARGE ARRAY)'
ARRAY 45 -10.4636 -79.5251 -0.6604
UNIT 106
COM='13X1 HEAT TRANSFER DISK LEVEL ARRAY (LARGE ARRAY +X)'
ARRAY 46 -10.4636 -79.5251 -0.6604
'
'  BASKET ARRAY IN STORAGE CASK OVERPACK (LEVEL CONSTRUCTION)
'
UNIT 110
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - WATER LEVEL'
ARRAY 50 -33.6323 -79.5251 -2.1400
CYLINDER 3 1 88.1253      2P2.1400
HOLE 80      -69.0614 0.0 0.0
HOLE 82      -46.1912 0.0 0.0
HOLE 81       69.0614 0.0 0.0
HOLE 83       46.1912 0.0 0.0
CYLINDER  5 1  89.7128     2P2.1400
CYLINDER  7 1 100.33       2P2.1400
CYLINDER  8 1 109.22       2P2.1400
CYLINDER  9 1 162.56       2P2.1400
CUBOID   10 1 4P228.60     2P2.1400
UNIT 111
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - SUPPORT DISK LEVEL'
ARRAY 51 -33.6323 -79.5251 -0.6604
CYLINDER 5 1 87.6046      2P0.6604
HOLE 90      -69.0614 0.0 0.0
HOLE 92      -46.1912 0.0 0.0
HOLE 91       69.0614 0.0 0.0
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
HOLE 93       46.1912 0.0 0.0
CYLINDER  3 1  88.1253    2P0.6604
CYLINDER  5 1  89.7128    2P0.6604
CYLINDER  7 1 100.33      2P0.6604
CYLINDER  8 1 109.22      2P0.6604
CYLINDER  9 1 162.56      2P0.6604
CUBOID   10 1 4P228.60    2P0.6604
UNIT 112
COM='BASKET ARRAY IN STORAGE CASK OVERPACK - HEAT TRANSFER DISK LEVEL'
ARRAY 52 -33.6323 -79.5251 -0.6604
CYLINDER 4 1 87.249       2P0.6604
HOLE 100     -69.0614 0.0 0.0
HOLE 102     -46.1912 0.0 0.0
HOLE 101      69.0614 0.0 0.0
HOLE 103      46.1912 0.0 0.0
CYLINDER  3 1  88.1253    2P0.6604
CYLINDER  5 1  89.7128    2P0.6604
CYLINDER  7 1 100.33      2P0.6604
CYLINDER  8 1 109.22      2P0.6604
CYLINDER  9 1 162.56      2P0.6604
CUBOID   10 1 4P228.60    2P0.6604
'
'  GLOBAL UNIT
'
GLOBAL UNIT 120
ARRAY 60 -228.60 -228.60 0.0
END GEOM
READ ARRAY
ARA=1 NUX=16 NUY=16 NUZ=1  FILL
1 1 1 1 1 1 1 3 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 4 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
END FILL
ARA=2 NUX=16 NUY=16 NUZ=1  FILL
5 5 5 5 5 5 5 7 6 6 6 6 6 6 6 6
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
7 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 8 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
END FILL
'
'  WATER LEVEL ARRAYS
'
ARA=20  NUX=1 NUY=5 NUZ=1
FILL
55
22
54
22
57
END FILL
ARA=21  NUX=1 NUY=5 NUZ=1
FILL
56
22
53
22
58
END FILL
ARA=22  NUX=1 NUY=9 NUZ=1
FILL
55
21
55
22
54
22
57
21
57
END FILL
ARA=23  NUX=1 NUY=9 NUZ=1
FILL
56
21
56
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
22
53
22
58
21
58
END FILL
ARA=24  NUX=1 NUY=13 NUZ=1
FILL
55
20
55
21
55
22
54
22
57
21
57
20
57
END FILL
ARA=25  NUX=1 NUY=13 NUZ=1
FILL
52
20
52
21
52
22
59
22
51
21
51
20
51
END FILL
ARA=26  NUX=1 NUY=13 NUZ=1
FILL
56
20
56
21
56
22
53
22
58
21
58
20
58
END FILL
'
'  SUPPOR DISK LEVEL ARRAYS
'
ARA=30  NUX=1 NUY=5 NUZ=1
FILL
65
32
64
32
67
END FILL
ARA=31  NUX=1 NUY=5 NUZ=1
FILL
66
32
63
32
68
END FILL
ARA=32  NUX=1 NUY=9 NUZ=1
FILL
65
31
65
32
64
32
67
31
67
END FILL
ARA=33  NUX=1 NUY=9 NUZ=1
FILL
66
31
66
32
63
32
68
31
68
END FILL
ARA=34  NUX=1 NUY=13 NUZ=1
FILL
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
65
30
65
31
65
32
64
32
67
31
67
30
67
END FILL
ARA=35  NUX=1 NUY=13 NUZ=1
FILL
62
30
62
31
62
32
69
32
61
31
61
30
61
END FILL
ARA=36  NUX=1 NUY=13 NUZ=1
FILL
66
30
66
31
66
32
63
32
68
31
68
30
68
END FILL
'
'  HEAT TRANSFER DISK LEVEL ARRAYS
'
ARA=40  NUX=1 NUY=5 NUZ=1
FILL
75
42
74
42
77
END FILL
ARA=41  NUX=1 NUY=5 NUZ=1
FILL
76
42
73
42
78
END FILL
ARA=42  NUX=1 NUY=9 NUZ=1
FILL
75
41
75
42
74
42
77
41
77
END FILL
ARA=43  NUX=1 NUY=9 NUZ=1
FILL
76
41
76
42
73
42
78
41
78
END FILL
ARA=44  NUX=1 NUY=13 NUZ=1
FILL
75
40
75
41
75
42
74
42
77
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
41
77
40
77
END FILL
ARA=45  NUX=1 NUY=13 NUZ=1
FILL
72
40
72
41
72
42
79
42
71
41
71
40
71
END FILL
ARA=46  NUX=1 NUY=13 NUZ=1
FILL
76
40
76
41
76
42
73
42
78
41
78
40
78
END FILL
'
'  MAJOR ARRAYS
'
ARA=50 NUX=5 NUY=1 NUZ=1
FILL
84 23 85 23 86
END FILL
ARA=51 NUX=5 NUY=1 NUZ=1
FILL
94 33 95 33 96
END FILL
ARA=52 NUX=5 NUY=1 NUZ=1
FILL
104 43 105 43 106
END FILL
'
'  GLOBAL ARRAY
'
ARA=60 NUX=1 NUY=1 NUZ=4
FILL
112
110
111
110
END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=REFLECT END BOUNDS
END DATA
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
  CCCCCCCCCCC    SSSSSSSSSSS      AAAAAAAAA     SSSSSSSSSSS    22222222222   5555555555555
 CCCCCCCCCCCCC  SSSSSSSSSSSSS    AAAAAAAAAAA   SSSSSSSSSSSSS  2222222222222  5555555555555
 CC         CC  SS         SS   AA         AA  SS         SS  22         22  55
 CC             SS              AA         AA  SS                        22  55
 CC             SS              AA         AA  SS                        22  55
 CC             SSSSSSSSSSSS    AAAAAAAAAAAAA  SSSSSSSSSSSS            22    555555555555
 CC              SSSSSSSSSSSS   AAAAAAAAAAAAA   SSSSSSSSSSSS         22      5555555555555
 CC                        SS   AA         AA             SS       22                   55
 CC                        SS   AA         AA             SS     22                     55
 CC         CC  SS         SS   AA         AA  SS         SS   22            55         55
 CCCCCCCCCCCCC  SSSSSSSSSSSSS   AA         AA  SSSSSSSSSSSSS  2222222222222  5555555555555
  CCCCCCCCCCC    SSSSSSSSSSS    AA         AA   SSSSSSSSSSS   2222222222222   55555555555


  SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL             EEEEEEEEEEEEE                 PPPPPPPPPPPP    CCCCCCCCCCC
 SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL             EEEEEEEEEEEEE                 PPPPPPPPPPPPP  CCCCCCCCCCCCC
 SS         SS  CC         CC   AA         AA  LL             EE                            PP         PP  CC         CC
 SS             CC              AA         AA  LL             EE                            PP         PP  CC
 SS             CC              AA         AA  LL             EE                            PP         PP  CC
 SSSSSSSSSSSS   CC              AAAAAAAAAAAAA  LL             EEEEEEEEE      -------------  PPPPPPPPPPPPP  CC
  SSSSSSSSSSSS  CC              AAAAAAAAAAAAA  LL             EEEEEEEEE      -------------  PPPPPPPPPPPP   CC
            SS  CC              AA         AA  LL             EE                            PP             CC
            SS  CC              AA         AA  LL             EE                            PP             CC
 SS         SS  CC         CC   AA         AA  LL             EE                            PP             CC         CC
 SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA  LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP             CCCCCCCCCCCCC
  SSSSSSSSSSS    CCCCCCCCCCC    AA         AA  LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP              CCCCCCCCCCC


      11         22222222222             //     0000000      99999999999             //     99999999999     666666666666
     111        2222222222222           //     000000000    9999999999999           //     9999999999999   6666666666666
    1111        22         22          //     00       00   99         99          //      99         99   66
      11                   22         //     00         00  99         99         //       99         99   66
      11                   22        //      00         00  99         99        //        99         99   66
      11                 22         //       00         00  9999999999999       //         9999999999999   666666666666
      11               22          //        00         00   999999999999      //           999999999999   6666666666666
      11             22           //         00         00             99     //                      99   66         66
      11           22            //          00         00             99    //                       99   66         66
      11         22             //            00       00              99   //                        99   66         66
   11111111     2222222222222  //              000000000    9999999999999  //              9999999999999   6666666666666
   11111111     2222222222222 //                0000000     999999999999  //               999999999999     66666666666


   0000000      7777777777777                     11         33333333333                   22222222222       0000000
  000000000     777777777777                     111        3333333333333                 2222222222222     000000000
 00       00    77         77        :::        1111        33         33       :::       22         22    00       00
00         00             77         :::          11                   33       :::                  22   00         00
00         00            77          :::          11                   33       :::                  22   00         00
00         00           77                        11                  333                          22     00         00
00         00           77                        11                  333                        22       00         00
00         00           77           :::          11                   33       :::            22         00         00
00         00           77           :::          11                   33       :::          22           00         00
 00       00            77           :::          11        33         33       :::        22              00       00
  000000000             77                     11111111     3333333333333                2222222222222      000000000
   0000000              77                     11111111      33333333333                 2222222222222       0000000
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA     LL              EEEEEEEEEEEEE                   PPPPPPPPPPPP    CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA    LL              EEEEEEEEEEEEE                   PPPPPPPPPPPPP  CCCCCCCCCCCCC
SS         SS  CC         CC   AA         AA   LL              EE                              PP         PP  CC         CC
SS             CC              AA         AA   LL              EE                              PP         PP  CC
SS             CC              AA         AA   LL              EE                              PP         PP  CC
SSSSSSSSSSSS   CC              AAAAAAAAAAAAA   LL              EEEEEEEEE     -------------     PPPPPPPPPPPPP  CC
 SSSSSSSSSSSS  CC              AAAAAAAAAAAAA   LL              EEEEEEEEE     -------------     PPPPPPPPPPPP   CC
           SS  CC              AA         AA   LL              EE                              PP             CC
           SS  CC              AA         AA   LL              EE                              PP             CC
SS         SS  CC         CC   AA         AA   LL              EE                              PP             CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP             CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC    AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                   PP              CCCCCCCCCCC
```

```
********************************************************************************
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                    PROGRAM VERIFICATION INFORMATION                  *****
*****                                                                      *****
*****                  CODE SYSTEM:  SCALE-PC VERSION:  4.3                *****
*****                                                                      *****
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                                                                      *****
*****                PROGRAM:  CSAS                                        *****
*****                                                                      *****
*****          CREATION DATE:  03-08-96                                    *****
*****                                                                      *****
*****                 VOLUME:  ENG                                         *****
*****                                                                      *****
*****                LIBRARY:  G:\scale43\exe                              *****
*****                                                                      *****
*****                                                                      *****
*****        PRODUCTION CODE:  CSAS                                        *****
*****                                                                      *****
*****                VERSION:  3.1                                         *****
*****                                                                      *****
*****                JOBNAME:  SCALE-PC                                    *****
*****                                                                      *****
*****      DATE OF EXECUTION:  12/09/96                                    *****
*****                                                                      *****
*****      TIME OF EXECUTION:  07:13:20                                    *****
*****                                                                      *****
*****                                                                      *****
********************************************************************************
********************************************************************************
********************************************************************************
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
**** PROBLEM PARAMETERS ****

LIB 27GROUPNDF4  LIBRARY
MXX           11 MIXTURES
MSC           14 COMPOSITION SPECIFICATIONS
IZM            4 MATERIAL ZONES
GE  LATTICECELL  GEOMETRY
MORE           0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
MSLN           0 FUEL SOLUTIONS

**** PROBLEM COMPOSITION DESCRIPTION ****

SC  UO2           STANDARD COMPOSITION
MX              1 MIXTURE NO.
VF         0.9500 VOLUME FRACTION
ROTH      10.9600 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            92000       1.00 ATOM/MOLECULE
                           92235      4.000 WT%
                           92238     96.000 WT%
             8016       2.00 ATOMS/MOLECULE
END

SC  ZIRCALLOY     STANDARD COMPOSITION
MX              2 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       6.5600 THEORETICAL DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            40302       1.00 ATOM/MOLECULE
END

SC  H2O           STANDARD COMPOSITION
MX              3 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       0.9982 THEORETICAL DENSITY
NEL             2 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             1001       2.00 ATOMS/MOLECULE
             8016       1.00 ATOM/MOLECULE
END

SC  AL            STANDARD COMPOSITION
MX              4 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       2.7020 THEORETICAL DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            13027       1.00 ATOM/MOLECULE
END

SC  SS304         STANDARD COMPOSITION
MX              5 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       7.9200 THEORETICAL DENSITY
NEL             4 NO. ELEMENTS
ICP             0 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
            24304     19.000 WT%
            25055      2.000 WT%
            26304     69.500 WT%
            28304      9.500 WT%
END

SC  B-10          STANDARD COMPOSITION
MX              6 MIXTURE NO.
VF         0.0450 VOLUME FRACTION
ROTH       2.6226 SPECIFIED DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             5010       1.00 ATOM/MOLECULE
END

SC  B-11          STANDARD COMPOSITION
MX              6 MIXTURE NO.
VF         0.2736 VOLUME FRACTION
ROTH       2.6226 SPECIFIED DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             5011       1.00 ATOM/MOLECULE
END

SC  C             STANDARD COMPOSITION
MX              6 MIXTURE NO.
VF         0.0927 VOLUME FRACTION
ROTH       2.6226 SPECIFIED DENSITY
NEL             1 NO. ELEMENTS
ICP             1 0/1 MIXTURE/COMPOUND
TEMP        293.0 DEG KELVIN
             6012       1.00 ATOM/MOLECULE
END
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
SC  AL            STANDARD COMPOSITION
MX             6  MIXTURE NO.
VF        0.5737  VOLUME FRACTION
ROTH      2.6226  SPECIFIED DENSITY
NEL            1  NO. ELEMENTS
ICP            1  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
           13027       1.00 ATOM/MOLECULE
END

SC  H2O           STANDARD COMPOSITION
MX             7  MIXTURE NO.
VF        1.0000  VOLUME FRACTION
ROTH      0.9982  THEORETICAL DENSITY
NEL            2  NO. ELEMENTS
ICP            1  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
            1001       2.00 ATOMS/MOLECULE
            8016       1.00 ATOM/MOLECULE
END

SC  CARBONSTEEL   STANDARD COMPOSITION
MX             8  MIXTURE NO.
VF        1.0000  VOLUME FRACTION
ROTH      7.8212  THEORETICAL DENSITY
NEL            2  NO. ELEMENTS
ICP            0  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
           26000     99.000 WT%
            6012      1.000 WT%
END

SC  REG-CONCRETE  STANDARD COMPOSITION
MX             9  MIXTURE NO.
VF        1.0000  VOLUME FRACTION
ROTH      2.2430  SPECIFIED DENSITY
NEL            7  NO. ELEMENTS
ICP            0  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
           26000      1.400 WT%
            1001      1.000 WT%
           13027      3.400 WT%
           20000      4.400 WT%
            8016     53.200 WT%
           14000     33.700 WT%
           11023      2.900 WT%
END

SC  H2O           STANDARD COMPOSITION
MX            10  MIXTURE NO.
VF        1.0000  VOLUME FRACTION
ROTH      0.9982  THEORETICAL DENSITY
NEL            2  NO. ELEMENTS
ICP            1  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
            1001       2.00 ATOMS/MOLECULE
            8016       1.00 ATOM/MOLECULE
END

SC  H2O           STANDARD COMPOSITION
MX            11  MIXTURE NO.
VF        1.0000  VOLUME FRACTION
ROTH      0.9982  THEORETICAL DENSITY
NEL            2  NO. ELEMENTS
ICP            1  0/1 MIXTURE/COMPOUND
TEMP       293.0  DEG KELVIN
            1001       2.00 ATOMS/MOLECULE
            8016       1.00 ATOM/MOLECULE
END

**** PROBLEM GEOMETRY ****

CTP SQUAREPITCH   CELL TYPE
PITCH     1.1887  CM CENTER TO CENTER SPACING
FUELOD    0.7887  CM FUEL DIAMETER OR SLAB THICKNESS
MFUEL          1  MIXTURE NO. OF FUEL
MMOD           3  MIXTURE NO. OF MODERATOR
CLADOD    0.9271  CM CLAD OUTER DIAMETER
MCLAD          2  MIXTURE NO. OF CLAD
GAPOD     0.8052  CM GAP OUTER DIAMETER
MGAP          11  MIXTURE NO. OF GAP

ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

               ZONE  1 IS FUEL
               ZONE  2 IS GAP
               ZONE  3 IS CLAD
               ZONE  4 IS MOD
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP

********** DATA LIBRARY INFORMATION **********

UNIT                                        VOLUME
NUMBER         DATA SET NAME                NAME     UNIT FUNCTION
------         -------------                ----     -------------

  89    G:\scale43\DATALIB\FT89F001                  STANDARD COMPOSITION LIBRARY

  82    G:\scale43\DATALIB\FT82F001                  CROSS SECTION LIBRARY

  11    C:\svv\st-mr-wg\FT11F001                     SHORT CROSS SECTION LIBRARY

  90    C:\svv\st-mr-wg\FT90F001                     INPUT DATA DIRECT ACCESS


                    STANDARD COMPOSITION LIBRARY DATA
                    ---------------------------------

UNIT NUMBER  :  89

DATASET NAME :  G:\scale43\DATALIB\FT89F001

LIBRARY TITLE:  SCALE-4 STANDARD COMPOSITION LIBRARY
                637 STANDARD COMPOSITIONS, 490 NUCLIDES
                90 ELEMENTS WITH VARIABLE ISOTOPIC DISTRBUTIONS.

CREATION DATE:   6/30/95


                    CROSS SECTION LIBRARY DATA
                    --------------------------

UNIT NUMBER  :  82

DATASET NAME :  G:\scale43\DATALIB\FT82F001

LIBRARY TITLE:  SCALE 4.2 - 27 GROUP NEUTRON GROUP LIBRARY
                   BASED ON ENDF-B VERSION 4 DATA
                      COMPILED FOR NRC      1/27/89
                         LAST UPDATED                              08/12/94
                            L.M.PETRIE   -    ORNL

CONTROL MODULE CSAS25    IS COMPLETE.
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
KK         KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO                  VV         VV
KK        KK   EEEEEEEEEEEEE  NNN        NN  OOOOOOOOOOOOO                 VV         VV
KK       KK    EE             NNNN       NN  OO         OO                 VV         VV
KK      KK     EE             NN NN      NN  OO         OO                 VV         VV
KK     KK      EE             NN  NN     NN  OO         OO                 VV         VV
KKKKKKKK       EEEEEEEEE      NN   NN    NN  OO         OO  -------------  VV         VV
KKKKKKKK       EEEEEEEEE      NN    NN   NN  OO         OO  -------------   VV       VV
KK     KK      EE             NN     NN  NN  OO         OO                   VV     VV
KK      KK     EE             NN      NN NN  OO         OO                    VV   VV
KK       KK    EE             NN       NNNN  OO         OO                     VV VV
KK        KK   EEEEEEEEEEEEE  NN        NNN  OOOOOOOOOOOOO                      VVV
KK         KK  EEEEEEEEEEEEE  NN         NN   OOOOOOOOOOO                        V

 SSSSSSSSSSS    CCCCCCCCCCC      AAAAAAAAA    LL             EEEEEEEEEEEEE                 PPPPPPPPPPPP    CCCCCCCCCCC
SSSSSSSSSSSSS  CCCCCCCCCCCCC    AAAAAAAAAAA   LL             EEEEEEEEEEEEE                 PPPPPPPPPPPPP  CCCCCCCCCCCCC
SS         SS  CC         CC  AA         AA   LL             EE                            PP         PP  CC         CC
SS             CC             AA         AA   LL             EE                            PP         PP  CC
SS             CC             AA         AA   LL             EE                            PP         PP  CC
SSSSSSSSSSSS   CC             AAAAAAAAAAAAA   LL             EEEEEEEEE      -------------  PPPPPPPPPPPPP  CC
 SSSSSSSSSSSS  CC             AAAAAAAAAAAAA   LL             EEEEEEEEE      -------------  PPPPPPPPPPPP   CC
           SS  CC             AA         AA   LL             EE                            PP             CC
           SS  CC             AA         AA   LL             EE                            PP             CC
SS         SS  CC         CC  AA         AA   LL             EE                            PP             CC         CC
SSSSSSSSSSSSS  CCCCCCCCCCCCC  AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP             CCCCCCCCCCCCC
 SSSSSSSSSSS    CCCCCCCCCCC   AA         AA   LLLLLLLLLLLLL  EEEEEEEEEEEEE                 PP              CCCCCCCCCCC

    11         22222222222            //     0000000     99999999999            //   99999999999   666666666666
   111        2222222222222          //     000000000   9999999999999          //   9999999999999  6666666666666
  1111        22         22         //     00       00  99         99         //    99         99  66
    11                   22        //     00         00 99         99        //     99         99  66
    11                   22       //      00         00 99         99       //      99         99  66
    11                  22       //       00         00 9999999999999      //       9999999999999  666666666666
    11                22        //        00         00  999999999999     //         999999999999  6666666666666
    11              22         //         00         00            99    //                    99  66         66
    11            22          //          00         00            99   //                     99  66         66
    11          22           //            00       00             99  //                      99  66         66
 11111111     2222222222222 //              000000000   9999999999999 //            9999999999999  6666666666666
 11111111     2222222222222 //               0000000    999999999999 //             999999999999    66666666666

   0000000    7777777777777                     11       33333333333                 33333333333   7777777777777
  000000000   777777777777                     111      3333333333333               3333333333333  777777777777
 00       00  77         77      :::          1111      33         33      :::      33         33  77         77
00         00           77       :::            11                 33      :::                 33            77
00         00          77        :::            11                 33      :::                 33           77
00         00         77                        11               333                         333           77
00         00         77                        11               333                         333           77
00         00        77          :::            11                 33      :::                 33         77
00         00        77          :::            11                 33      :::                 33         77
 00       00         77          :::            11      33         33      :::      33         33         77
  000000000          77                      11111111   3333333333333               3333333333333         77
   0000000           77                      11111111    33333333333                 33333333333          77
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
  SSSSSSSSSSS     CCCCCCCCCCC       AAAAAAAAA     LL              EEEEEEEEEEEEE                     PPPPPPPPPPPP     CCCCCCCCCCC
 SSSSSSSSSSSSS   CCCCCCCCCCCCC     AAAAAAAAAAA    LL              EEEEEEEEEEEEE                     PPPPPPPPPPPPP   CCCCCCCCCCCCC
 SS         SS   CC         CC    AA         AA   LL              EE                                PP         PP   CC         CC
 SS              CC               AA         AA   LL              EE                                PP         PP   CC
 SS              CC               AA         AA   LL              EE                                PP         PP   CC
 SSSSSSSSSSSS    CC               AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------     PPPPPPPPPPPPP   CC
  SSSSSSSSSSSS   CC               AAAAAAAAAAAAA   LL              EEEEEEEEE       -------------     PPPPPPPPPPPP    CC
           SS    CC               AA         AA   LL              EE                                PP              CC
           SS    CC               AA         AA   LL              EE                                PP              CC
 SS        SS    CC         CC    AA         AA   LL              EE                                PP              CC         CC
 SSSSSSSSSSSSS   CCCCCCCCCCCCC    AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                     PP              CCCCCCCCCCCCC
  SSSSSSSSSSS     CCCCCCCCCCC     AA         AA   LLLLLLLLLLLLL   EEEEEEEEEEEEE                     PP               CCCCCCCCCCC
```

```
********************************************************************************
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                    PROGRAM VERIFICATION INFORMATION                  *****
*****                                                                      *****
*****                  CODE SYSTEM:  SCALE-PC VERSION:  4.3                *****
*****                                                                      *****
********************************************************************************
********************************************************************************
*****                                                                      *****
*****                                                                      *****
*****                 PROGRAM:  000009                                     *****
*****                                                                      *****
*****           CREATION DATE:  03-08-96                                   *****
*****                                                                      *****
*****                  VOLUME:  ENG                                        *****
*****                                                                      *****
*****                 LIBRARY:  G:\scale43\exe                             *****
*****                                                                      *****
*****                                                                      *****
*****         PRODUCTION CODE:  KENOVA                                     *****
*****                                                                      *****
*****                 VERSION:  3.1                                        *****
*****                                                                      *****
*****                 JOBNAME:  SCALE-PC                                   *****
*****                                                                      *****
*****       DATE OF EXECUTION:  12/09/96                                   *****
*****                                                                      *****
*****       TIME OF EXECUTION:  07:13:37                                   *****
*****                                                                      *****
*****                                                                      *****
********************************************************************************
********************************************************************************
********************************************************************************
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
*********************************************************************************************************************
***                                                                                                               ***
***                        WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP                        ***
***                                                                                                               ***
*********************************************************************************************************************
***                               ******     NUMERIC PARAMETERS      ******                                       ***
***                                                                                                               ***
***                                                                                                               ***
***              TME      MAXIMUM PROBLEM TIME (MIN)                            500.00                            ***
***                                                                                                               ***
***              TBA      TIME PER GENERATION (MIN)                               0.50                            ***
***                                                                                                               ***
***              GEN      NUMBER OF GENERATIONS                                   1003                            ***
***                                                                                                               ***
***              NPG      NUMBER PER GENERATION                                   1000                            ***
***                                                                                                               ***
***              NSK      NUMBER OF GENERATIONS TO BE SKIPPED                        3                            ***
***                                                                                                               ***
***              BEG      BEGINNING GENERATION NUMBER                                1                            ***
***                                                                                                               ***
***              RES      GENERATIONS BETWEEN CHECKPOINTS                            0                            ***
***                                                                                                               ***
***              X1D      NUMBER OF EXTRA 1-D CROSS SECTIONS                         1                            ***
***                                                                                                               ***
***              NBK      NEUTRON BANK SIZE                                       1025                            ***
***                                                                                                               ***
***              XNB      EXTRA POSITIONS IN NEUTRON BANK                            0                            ***
***                                                                                                               ***
***              NFB      FISSION BANK SIZE                                       1000                            ***
***                                                                                                               ***
***              XFB      EXTRA POSITIONS IN FISSION BANK                            0                            ***
***                                                                                                               ***
***              WTA      DEFAULT VALUE OF WEIGHT AVERAGE                       0.5000                            ***
***                                                                                                               ***
***              WTH      WEIGHT HIGH FOR SPLITTING                             3.0000                            ***
***                                                                                                               ***
***              WTL      WEIGHT LOW FOR RUSSIAN ROULETTE                       0.3333                            ***
***                                                                                                               ***
***              RND      STARTING RANDOM NUMBER                          BB827100001                             ***
***                                                                                                               ***
***              NB8      NUMBER OF D.A. BLOCKS ON UNIT  8                         200                            ***
***                                                                                                               ***
***              NL8      LENGTH OF D.A. BLOCKS ON UNIT  8                         512                            ***
***                                                                                                               ***
***              ADJ      MODE OF CALCULATION                                  FORWARD                            ***
***                                                                                                               ***
***                       INPUT DATA WRITTEN ON RESTART UNIT                        NO                            ***
***                                                                                                               ***
***                       BINARY DATA INTERFACE                                    YES                            ***
***                                                                                                               ***
***                                                                                                               ***
*********************************************************************************************************************
*********************************************************************************************************************
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
***********************************************************************************************************************
***********************************************************************************************************************
***                                                                                                                 ***
***                          WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP                        ***
***                                                                                                                 ***
***********************************************************************************************************************
***                        ******      LOGICAL PARAMETERS       ******                                               ***
***                                                                                                                 ***
***  RUN  EXECUTE PROBLEM AFTER CHECKING DATA   YES        PLT  PLOT PICTURE MAP(S)                          NO ***
***                                                                                                                 ***
***  FLX  COMPUTE FLUX                           NO        FDN  COMPUTE FISSION DENSITIES                    NO ***
***                                                                                                                 ***
***  SMU  COMPUTE AVG UNIT SELF-MULTIPLICATION   NO        NUB  COMPUTE NU-BAR & AVG FISSION GROUP          YES ***
***                                                                                                                 ***
***  MKU  COMPUTE MATRIX K-EFF BY UNIT NUMBER    NO        MKP  COMPUTE MATRIX K-EFF BY UNIT LOCATION        NO ***
***                                                                                                                 ***
***  CKU  COMPUTE COFACTOR K-EFF BY UNIT NUMBER  NO        CKP  COMPUTE COFACTOR K-EFF BY UNIT LOCATION      NO ***
***                                                                                                                 ***
***  FMU  PRINT FISS PROD MATRIX BY UNIT NUMBER  NO        FMP  PRINT FISS PROD MATRIX BY UNIT LOCATION      NO ***
***                                                                                                                 ***
***  MKH  COMPUTE MATRIX K-EFF BY HOLE NUMBER    NO        MKA  COMPUTE MATRIX K-EFF BY ARRAY NUMBER         NO ***
***                                                                                                                 ***
***  CKH  COMPUTE COFACTOR K-EFF BY HOLE NUMBER  NO        CKA  COMPUTE COFACTOR K-EFF BY ARRAY NUMBER       NO ***
***                                                                                                                 ***
***  FMH  PRINT FISS PROD MATRIX BY HOLE NUMBER  NO        FMA  PRINT FISS PROD MATRIX BY ARRAY NUMBER       NO ***
***                                                                                                                 ***
***  HHL  COLLECT MATRIX BY HIGHEST HOLE LEVEL   NO        HAL  COLLECT MATRIX BY HIGHEST ARRAY LEVEL        NO ***
***                                                                                                                 ***
***  AMX  PRINT ALL MIXED CROSS SECTIONS         NO        FAR  PRINT FIS. AND ABS. BY REGION                NO ***
***                                                                                                                 ***
***  XS1  PRINT 1-D MIXTURE X-SECTIONS           NO        GAS  PRINT FAR BY GROUP                           NO ***
***                                                                                                                 ***
***  XS2  PRINT 2-D MIXTURE X-SECTIONS           NO        PAX  PRINT XSEC-ALBEDO CORRELATION TABLES         NO ***
***                                                                                                                 ***
***  XAP  PRINT MIXTURE ANGLES & PROBABILITIES   NO        PWT  PRINT WEIGHT AVERAGE ARRAY                   NO ***
***                                                                                                                 ***
***  PKI  PRINT FISSION SPECTRUM                 NO        PGM  PRINT INPUT GEOMETRY                         NO ***
***                                                                                                                 ***
***  P1D  PRINT EXTRA 1-D CROSS SECTIONS         NO        BUG  PRINT DEBUG INFORMATION                      NO ***
***                                                                                                                 ***
***                                                        TRK  PRINT TRACKING INFORMATION                   NO ***
***                                                                                                                 ***
***                                                                                                                 ***
***********************************************************************************************************************
***********************************************************************************************************************
***********************************************************************************************************************
                                        PARAMETER INPUT COMPLETED

                    ........     0 IO'S WERE USED READING THE PARAMETER DATA      ........

                    *************** DATA READING COMPLETED ***************
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
*******************************************************************************************************************
***                                                                                                             ***
***                        WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP                      ***
***                                                                                                             ***
*******************************************************************************************************************
*******************************************************************************************************************
***                                                                                                             ***
***        UNIT                                                  VOLUME                                         ***
***       NUMBER                DATA SET NAME                     NAME        UNIT FUNCTION                     ***
***       ------                -------------                     ----        -------------                     ***
***                                                                                                             ***
***     XSC  14     C:\svv\st-mr-wg\FT14F001                                  MIXED CROSS SECTIONS              ***
***                                                                                                             ***
***     ALB  79     G:\scale43\DATALIB\FT79F001                               INPUT ALBEDOS                     ***
***                                                                                                             ***
***     WTS  80     G:\scale43\DATALIB\FT80F001                               INPUT WEIGHTS                     ***
***                                                                                                             ***
***     SKT  16      UNKNOWN                                                  WRITE SCRATCH DATA                ***
***                                                                                                             ***
***     BIN  95     C:\svv\st-mr-wg\FT95F001                                  BINARY INPUT DATA                 ***
***                                                                                                             ***
***     RST  95     C:\svv\st-mr-wg\FT95F001                                  READ RESTART DATA                 ***
***                                                                                                             ***
***     LIB   4     C:\svv\st-mr-wg\FT04F001                                  INPUT AMPX WORKING LIBRARY        ***
***                                                                                                             ***
***           8     C:\svv\st-mr-wg\FT08F001                                  INPUT DATA DIRECT ACCESS          ***
***                                                                                                             ***
***           9      UNKNOWN                                                  SUPER GROUPED DIRECT ACCESS       ***
***                                                                                                             ***
***          10      UNKNOWN                                                  XSEC MIXING DIRECT ACCESS         ***
***                                                                                                             ***
*******************************************************************************************************************

                        ........    0 IO'S WERE USED PREPARING INPUT DATA    ........


                         CROSS SECTIONS READ FROM THE AMPX WORKING LIBRARY ON UNIT     4
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
                    WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP
                                          MIXING TABLE
                                  NUMBER OF SCATTERING ANGLES = 2
                              CROSS SECTION MESSAGE THRESHOLD =3.0E-05

MIXTURE =     1           DENSITY(G/CC) =  10.412
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   1008016  4.64617E-02  1.18487E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94
   1092235  9.40641E-04  3.52606E-02   92235   235.0441     URANIUM-235     ENDF/B-IV MAT 1261                          UPDATED
08/12/94
   1092238  2.22902E-02  8.46253E-01   92238   238.0510     URANIUM-238     ENDF/B-IV MAT 1262                          UPDATED
08/12/94

MIXTURE =     2           DENSITY(G/CC) =  6.5600
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   2040302  4.33078E-02  1.00000E+00   40000    91.2196     ZIRCALLOY       ENDF/B-IV MAT 1284                          UPDATED
08/12/94

MIXTURE =     3           DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   3001001  6.67692E-02  1.11927E-01    1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   3008016  3.33846E-02  8.88074E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94

MIXTURE =     4           DENSITY(G/CC) =  2.7020
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   4013027  6.03066E-02  1.00000E+00   13027    26.9818    AL-27 1193 218 GP 040375(5)                                  UPDATED
08/12/94

MIXTURE =     5           DENSITY(G/CC) =  7.9200
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   5024304  1.74286E-02  1.90000E-01   24000    51.9957    CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'             UPDATED
08/12/94
   5025055  1.73633E-03  1.99999E-02   25055    54.9379     MANGANESE-55    ENDF/B-IV MAT 1197                          UPDATED
08/12/94
   5026304  5.93579E-02  6.95000E-01   26000    55.8447    FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'             UPDATED
08/12/94
   5028304  7.72070E-03  9.50001E-02   28000    58.6872    NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'             UPDATED
08/12/94

MIXTURE =     6           DENSITY(G/CC) =  2.5833
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   6005010  7.09799E-03  4.56855E-02    5010    10.0130    B-10 1273 218NGP 042375 P-3 293K                             UPDATED
08/12/94
   6005011  3.92499E-02  2.77771E-01    5011    11.0096     BORON-11        ENDF/B-IV MAT 1160                          UPDATED
08/12/94
   6006012  1.22006E-02  9.41116E-02    6000    12.0001     CARBON-12       ENDF/B-IV MAT 1274/THRM1065                 UPDATED
08/12/94
   6013027  3.35812E-02  5.82432E-01   13027    26.9818    AL-27 1193 218 GP 040375(5)                                  UPDATED
08/12/94

MIXTURE =     7           DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   7001001  6.67692E-02  1.11927E-01    1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   7008016  3.33846E-02  8.88074E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94

MIXTURE =     8           DENSITY(G/CC) =  7.8212
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   8006012  3.92503E-03  1.00001E-02    6000    12.0001     CARBON-12       ENDF/B-IV MAT 1274/THRM1065                 UPDATED
08/12/94
   8026000  8.34982E-02  9.90000E-01   26000    55.8447     IRON            ENDF/B-IV MAT 1192                          UPDATED
08/12/94

MIXTURE =     9           DENSITY(G/CC) =  2.2430
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
   9001001  1.34031E-02  9.99867E-03    1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   9008016  4.49394E-02  5.31997E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94
   9011023  1.70392E-03  2.90003E-02   11023    22.9895     SODIUM-23       ENDF/B-IV MAT 1156                          UPDATED
08/12/94
   9013027  1.70211E-03  3.40003E-02   13027    26.9818    AL-27 1193 218 GP 040375(5)                                  UPDATED
08/12/94
   9014000  1.62080E-02  3.37003E-01   14000    28.0853     SILICON         ENDF/B-IV MAT 1194                          UPDATED
08/12/94
   9020000  1.48287E-03  4.40004E-02   20000    40.0803    CALCIUM ENDF/B-IV MAT 1195                                   UPDATED
08/12/94
   9026000  3.38630E-04  1.40001E-02   26000    55.8447     IRON            ENDF/B-IV MAT 1192                          UPDATED
08/12/94

MIXTURE =    10           DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
  10001001  6.67692E-02  1.11927E-01    1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
  10008016  3.33846E-02  8.88074E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94

MIXTURE =    11           DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA       AWT             NUCLIDE TITLE
  11001001  6.67692E-02  1.11927E-01    1001     1.0077     HYDROGEN        ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
  11008016  3.33846E-02  8.88074E-01    8016    15.9904     OXYGEN-16       ENDF/B-IV MAT 1276                          UPDATED
08/12/94
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

```
*************************************************************************************************
***                                                                                           ***
***        WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP                   ***
***                                                                                           ***
*************************************************************************************************
*************************************************************************************************
***                                                                                           ***
***                          ****** ADDITIONAL INFORMATION ******                             ***
***                                                                                           ***
***  NUMBER OF ENERGY GROUPS               27       USE LATTICE GEOMETRY                 YES  ***
***                                                                                           ***
***  NO. OF FISSION SPECTRUM SOURCE GROUP  1        GLOBAL ARRAY NUMBER                  60   ***
***                                                                                           ***
***  NO. OF SCATTERING ANGLES IN XSECS     2        NUMBER OF UNITS IN THE GLOBAL X DIR.   1  ***
***                                                                                           ***
***  ENTRIES/NEUTRON IN THE NEUTRON BANK  33        NUMBER OF UNITS IN THE GLOBAL Y DIR.   1  ***
***                                                                                           ***
***  ENTRIES/NEUTRON IN THE FISSION BANK  26        NUMBER OF UNITS IN THE GLOBAL Z DIR.   4  ***
***                                                                                           ***
***  NUMBER OF MIXTURES USED               11       USE A GLOBAL REFLECTOR               YES  ***
***                                                                                           ***
***  NUMBER OF BIAS ID'S USED               1       USE NESTED HOLES                     YES  ***
***                                                                                           ***
***  NUMBER OF DIFFERENTIAL ALBEDOS USED    0       NUMBER OF HOLES                      48   ***
***                                                                                           ***
***  TOTAL INPUT GEOMETRY REGIONS         127       MAXIMUM HOLE NESTING LEVEL            3   ***
***                                                                                           ***
***  NUMBER OF GEOMETRY REGIONS USED      127       USE NESTED ARRAYS                    YES  ***
***                                                                                           ***
***  LARGEST GEOMETRY UNIT NUMBER         120       NUMBER OF ARRAYS USED                27   ***
***                                                                                           ***
***  LARGEST ARRAY NUMBER                  60       MAXIMUM ARRAY NESTING LEVEL           4   ***
***                                                                                           ***
***                                                                                           ***
***  +X BOUNDARY CONDITION            REFLECT       -X BOUNDARY CONDITION            REFLECT  ***
***                                                                                           ***
***  +Y BOUNDARY CONDITION            REFLECT       -Y BOUNDARY CONDITION            REFLECT  ***
***                                                                                           ***
***  +Z BOUNDARY CONDITION                PER       -Z BOUNDARY CONDITION                PER  ***
***                                                                                           ***
*************************************************************************************************
```

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
KENO MESSAGE	NUMBER K5-132	WARNING....ONLY	945 INDEPENDENT	FISSION POINTS WERE	GENERATED	
1	8.75112E-01	1.52000E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE	NUMBER K5-132	WARNING....ONLY	946 INDEPENDENT	FISSION POINTS WERE	GENERATED	
2	8.62201E-01	1.90333E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE	NUMBER K5-132	WARNING....ONLY	940 INDEPENDENT	FISSION POINTS WERE	GENERATED	
3	8.50943E-01	2.29667E-01	8.50943E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	8.68023E-01	2.69167E-01	8.59483E-01	8.53997E-03	0.00000E+00	0.00000E+00
5	8.80813E-01	3.08500E-01	8.66593E-01	8.65244E-03	0.00000E+00	0.00000E+00
6	8.93980E-01	3.48667E-01	8.73440E-01	9.18214E-03	0.00000E+00	0.00000E+00
7	8.98812E-01	3.88167E-01	8.78514E-01	8.73714E-03	0.00000E+00	0.00000E+00
8	8.47197E-01	4.27500E-01	8.73295E-01	8.83944E-03	0.00000E+00	0.00000E+00
9	8.54501E-01	4.66833E-01	8.70610E-01	7.93847E-03	0.00000E+00	0.00000E+00
10	9.10492E-01	5.05333E-01	8.75595E-01	8.49217E-03	0.00000E+00	0.00000E+00
11	8.71962E-01	5.44667E-01	8.75191E-01	7.50026E-03	0.00000E+00	0.00000E+00
12	8.74146E-01	5.82167E-01	8.75087E-01	6.70925E-03	0.00000E+00	0.00000E+00
13	8.90500E-01	6.22500E-01	8.76488E-01	6.22840E-03	0.00000E+00	0.00000E+00
14	9.06346E-01	6.61833E-01	8.78976E-01	6.20632E-03	0.00000E+00	0.00000E+00
15	8.56646E-01	7.01167E-01	8.77258E-01	5.96178E-03	0.00000E+00	0.00000E+00
16	8.87238E-01	7.40500E-01	8.77971E-01	5.56538E-03	0.00000E+00	0.00000E+00
17	8.59775E-01	7.79000E-01	8.76758E-01	5.32121E-03	0.00000E+00	0.00000E+00
18	8.72739E-01	8.18333E-01	8.76507E-01	4.98387E-03	0.00000E+00	0.00000E+00
19	9.20344E-01	8.58667E-01	8.79086E-01	5.34473E-03	0.00000E+00	0.00000E+00
20	8.86820E-01	8.98000E-01	8.79515E-01	5.05735E-03	0.00000E+00	0.00000E+00
21	8.94988E-01	9.37333E-01	8.80330E-01	4.85259E-03	0.00000E+00	0.00000E+00
22	8.22904E-01	9.78500E-01	8.77458E-01	5.42559E-03	0.00000E+00	0.00000E+00
23	8.95033E-01	1.01783E+00	8.78295E-01	5.22818E-03	0.00000E+00	0.00000E+00
24	8.61764E-01	1.05733E+00	8.77544E-01	5.04120E-03	0.00000E+00	0.00000E+00
25	8.54758E-01	1.09667E+00	8.76553E-01	4.91785E-03	0.00000E+00	0.00000E+00
26	8.56199E-01	1.13600E+00	8.75705E-01	4.78425E-03	0.00000E+00	0.00000E+00
27	9.04067E-01	1.17533E+00	8.76840E-01	4.72705E-03	0.00000E+00	0.00000E+00
28	8.47527E-01	1.21283E+00	8.75712E-01	4.67944E-03	0.00000E+00	0.00000E+00
29	8.77057E-01	1.25133E+00	8.75762E-01	4.50307E-03	0.00000E+00	0.00000E+00
30	8.71278E-01	1.29067E+00	8.75602E-01	4.34222E-03	0.00000E+00	0.00000E+00
31	8.89074E-01	1.33000E+00	8.76066E-01	4.21549E-03	0.00000E+00	0.00000E+00
32	8.82954E-01	1.36850E+00	8.76296E-01	4.07902E-03	0.00000E+00	0.00000E+00
33	8.89828E-01	1.40783E+00	8.76733E-01	3.96932E-03	0.00000E+00	0.00000E+00
34	8.42340E-01	1.44717E+00	8.75658E-01	3.99072E-03	0.00000E+00	0.00000E+00
35	9.05755E-01	1.48667E+00	8.76570E-01	3.97397E-03	0.00000E+00	0.00000E+00
36	8.49054E-01	1.52600E+00	8.75760E-01	3.93935E-03	0.00000E+00	0.00000E+00
37	9.04573E-01	1.56533E+00	8.76584E-01	3.91272E-03	0.00000E+00	0.00000E+00
38	8.49513E-01	1.60467E+00	8.75832E-01	3.87612E-03	0.00000E+00	0.00000E+00
39	8.83531E-01	1.64317E+00	8.76040E-01	3.77564E-03	0.00000E+00	0.00000E+00
40	8.74548E-01	1.68067E+00	8.76001E-01	3.67515E-03	0.00000E+00	0.00000E+00
41	9.01435E-01	1.71917E+00	8.76653E-01	3.63860E-03	0.00000E+00	0.00000E+00
42	8.52901E-01	1.75750E+00	8.76059E-01	3.59583E-03	0.00000E+00	0.00000E+00
43	8.85406E-01	1.79700E+00	8.76287E-01	3.51443E-03	0.00000E+00	0.00000E+00
44	8.89607E-01	1.83450E+00	8.76604E-01	3.44437E-03	0.00000E+00	0.00000E+00
45	9.31113E-01	1.87383E+00	8.77872E-01	3.59427E-03	0.00000E+00	0.00000E+00
46	9.03644E-01	1.91133E+00	8.78457E-01	3.56015E-03	0.00000E+00	0.00000E+00
47	9.05612E-01	1.94883E+00	8.79061E-01	3.53207E-03	0.00000E+00	0.00000E+00
48	8.97927E-01	1.98733E+00	8.79471E-01	3.47869E-03	0.00000E+00	0.00000E+00
49	9.02912E-01	2.02583E+00	8.79970E-01	3.44022E-03	0.00000E+00	0.00000E+00
50	8.96326E-01	2.06417E+00	8.80311E-01	3.38498E-03	0.00000E+00	0.00000E+00
.						
.						
.						
950	8.70416E-01	3.74143E+01	8.83893E-01	7.43957E-04	0.00000E+00	0.00000E+00
951	9.05133E-01	3.74527E+01	8.83915E-01	7.43510E-04	0.00000E+00	0.00000E+00
952	8.63683E-01	3.74930E+01	8.83894E-01	7.43032E-04	0.00000E+00	0.00000E+00
953	8.91555E-01	3.75315E+01	8.83902E-01	7.42294E-04	0.00000E+00	0.00000E+00
954	8.66491E-01	3.75698E+01	8.83884E-01	7.41739E-04	0.00000E+00	0.00000E+00
955	8.72970E-01	3.76093E+01	8.83872E-01	7.41049E-04	0.00000E+00	0.00000E+00
956	8.81615E-01	3.76477E+01	8.83870E-01	7.40276E-04	0.00000E+00	0.00000E+00
957	8.99857E-01	3.76862E+01	8.83887E-01	7.39690E-04	0.00000E+00	0.00000E+00
958	8.25766E-01	3.77247E+01	8.83826E-01	7.41412E-04	0.00000E+00	0.00000E+00
959	9.07246E-01	3.77622E+01	8.83850E-01	7.41041E-04	0.00000E+00	0.00000E+00
960	9.17018E-01	3.78007E+01	8.83885E-01	7.41076E-04	0.00000E+00	0.00000E+00
961	8.82141E-01	3.78390E+01	8.83883E-01	7.40306E-04	0.00000E+00	0.00000E+00
962	8.64857E-01	3.78783E+01	8.83863E-01	7.39799E-04	0.00000E+00	0.00000E+00
963	9.01438E-01	3.79168E+01	8.83882E-01	7.39256E-04	0.00000E+00	0.00000E+00
964	8.81430E-01	3.79553E+01	8.83879E-01	7.38491E-04	0.00000E+00	0.00000E+00
965	8.49840E-01	3.79938E+01	8.83844E-01	7.38570E-04	0.00000E+00	0.00000E+00
966	8.75750E-01	3.80313E+01	8.83835E-01	7.37851E-04	0.00000E+00	0.00000E+00
967	8.99929E-01	3.80697E+01	8.83852E-01	7.37275E-04	0.00000E+00	0.00000E+00
968	9.04655E-01	3.81082E+01	8.83873E-01	7.36826E-04	0.00000E+00	0.00000E+00
969	8.62628E-01	3.81467E+01	8.83851E-01	7.36392E-04	0.00000E+00	0.00000E+00
970	8.59757E-01	3.81850E+01	8.83827E-01	7.36051E-04	0.00000E+00	0.00000E+00
971	8.49649E-01	3.82235E+01	8.83791E-01	7.36137E-04	0.00000E+00	0.00000E+00
972	8.52009E-01	3.82628E+01	8.83759E-01	7.36107E-04	0.00000E+00	0.00000E+00
973	8.89858E-01	3.83023E+01	8.83765E-01	7.35376E-04	0.00000E+00	0.00000E+00
974	8.73960E-01	3.83407E+01	8.83755E-01	7.34688E-04	0.00000E+00	0.00000E+00
975	8.82652E-01	3.83800E+01	8.83754E-01	7.33933E-04	0.00000E+00	0.00000E+00
976	8.85957E-01	3.84195E+01	8.83756E-01	7.33183E-04	0.00000E+00	0.00000E+00
977	8.95017E-01	3.84588E+01	8.83767E-01	7.32521E-04	0.00000E+00	0.00000E+00
978	8.90552E-01	3.84982E+01	8.83774E-01	7.31804E-04	0.00000E+00	0.00000E+00
979	8.91674E-01	3.85367E+01	8.83782E-01	7.31099E-04	0.00000E+00	0.00000E+00
980	8.89774E-01	3.85768E+01	8.83789E-01	7.30377E-04	0.00000E+00	0.00000E+00
981	9.12959E-01	3.86153E+01	8.83818E-01	7.30238E-04	0.00000E+00	0.00000E+00
982	8.94913E-01	3.86528E+01	8.83830E-01	7.29581E-04	0.00000E+00	0.00000E+00
983	8.86619E-01	3.86922E+01	8.83833E-01	7.28842E-04	0.00000E+00	0.00000E+00
984	8.51460E-01	3.87317E+01	8.83800E-01	7.28845E-04	0.00000E+00	0.00000E+00
985	8.76222E-01	3.87710E+01	8.83792E-01	7.28144E-04	0.00000E+00	0.00000E+00

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

986	9.00091E-01	3.88093E+01	8.83808E-01	7.27593E-04	0.00000E+00	0.00000E+00
987	9.10388E-01	3.88478E+01	8.83835E-01	7.27354E-04	0.00000E+00	0.00000E+00
988	8.52857E-01	3.88863E+01	8.83804E-01	7.27295E-04	0.00000E+00	0.00000E+00
989	9.04577E-01	3.89257E+01	8.83825E-01	7.26863E-04	0.00000E+00	0.00000E+00
990	8.96359E-01	3.89650E+01	8.83838E-01	7.26237E-04	0.00000E+00	0.00000E+00
991	8.80578E-01	3.90053E+01	8.83834E-01	7.25510E-04	0.00000E+00	0.00000E+00
992	8.72468E-01	3.90428E+01	8.83823E-01	7.24868E-04	0.00000E+00	0.00000E+00
993	8.68384E-01	3.90822E+01	8.83807E-01	7.24304E-04	0.00000E+00	0.00000E+00
994	8.74362E-01	3.91215E+01	8.83798E-01	7.23636E-04	0.00000E+00	0.00000E+00
995	8.95072E-01	3.91610E+01	8.83809E-01	7.22996E-04	0.00000E+00	0.00000E+00
996	8.46965E-01	3.92012E+01	8.83772E-01	7.23219E-04	0.00000E+00	0.00000E+00
997	8.40963E-01	3.92397E+01	8.83729E-01	7.23771E-04	0.00000E+00	0.00000E+00
998	8.79300E-01	3.92782E+01	8.83725E-01	7.23058E-04	0.00000E+00	0.00000E+00
999	8.98173E-01	3.93165E+01	8.83739E-01	7.22478E-04	0.00000E+00	0.00000E+00
1000	9.04993E-01	3.93550E+01	8.83760E-01	7.22068E-04	0.00000E+00	0.00000E+00
1001	8.72868E-01	3.93935E+01	8.83750E-01	7.21427E-04	0.00000E+00	0.00000E+00
1002	8.84715E-01	3.94318E+01	8.83751E-01	7.20706E-04	0.00000E+00	0.00000E+00
1003	8.57689E-01	3.94712E+01	8.83724E-01	7.20456E-04	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123 EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP

LIFETIME = 3.61325E-05 + OR - 7.57716E-08 GENERATION TIME = 2.47869E-05 + OR - 3.65111E-08
NU BAR = 2.44283E+00 + OR - 7.03085E-05 AVERAGE FISSION GROUP = 2.16146E+01 + OR - 3.98016E-03
ENERGY(EV) OF THE AVERAGE LETHARGY CAUSING FISSION = 3.02918E-01 + OR - 9.69277E-04

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.88376	+ OR - 0.00072	0.88304 TO 0.88448	0.88232 TO 0.88520	0.88160 TO 0.88592	1000000
4	0.88377	+ OR - 0.00072	0.88305 TO 0.88449	0.88233 TO 0.88521	0.88161 TO 0.88594	999000
5	0.88378	+ OR - 0.00072	0.88305 TO 0.88450	0.88233 TO 0.88522	0.88161 TO 0.88594	998000
6	0.88377	+ OR - 0.00072	0.88304 TO 0.88449	0.88232 TO 0.88521	0.88160 TO 0.88593	997000
7	0.88375	+ OR - 0.00072	0.88303 TO 0.88447	0.88230 TO 0.88520	0.88158 TO 0.88592	996000
8	0.88379	+ OR - 0.00072	0.88306 TO 0.88451	0.88234 TO 0.88523	0.88162 TO 0.88596	995000
9	0.88382	+ OR - 0.00072	0.88309 TO 0.88454	0.88237 TO 0.88526	0.88165 TO 0.88599	994000
10	0.88379	+ OR - 0.00072	0.88307 TO 0.88451	0.88234 TO 0.88524	0.88162 TO 0.88596	993000
11	0.88380	+ OR - 0.00072	0.88308 TO 0.88453	0.88235 TO 0.88525	0.88163 TO 0.88597	992000
12	0.88381	+ OR - 0.00072	0.88309 TO 0.88454	0.88236 TO 0.88526	0.88164 TO 0.88598	991000
17	0.88383	+ OR - 0.00073	0.88310 TO 0.88456	0.88238 TO 0.88528	0.88165 TO 0.88601	986000
22	0.88385	+ OR - 0.00073	0.88313 TO 0.88458	0.88240 TO 0.88531	0.88167 TO 0.88603	981000
27	0.88390	+ OR - 0.00073	0.88317 TO 0.88463	0.88244 TO 0.88536	0.88172 TO 0.88609	976000
32	0.88395	+ OR - 0.00073	0.88322 TO 0.88469	0.88249 TO 0.88542	0.88176 TO 0.88615	971000
37	0.88398	+ OR - 0.00073	0.88325 TO 0.88472	0.88252 TO 0.88545	0.88179 TO 0.88618	966000
42	0.88404	+ OR - 0.00073	0.88331 TO 0.88478	0.88258 TO 0.88551	0.88184 TO 0.88625	961000
47	0.88394	+ OR - 0.00074	0.88321 TO 0.88468	0.88247 TO 0.88541	0.88174 TO 0.88615	956000
52	0.88392	+ OR - 0.00074	0.88318 TO 0.88466	0.88244 TO 0.88540	0.88170 TO 0.88613	951000
57	0.88396	+ OR - 0.00074	0.88322 TO 0.88470	0.88248 TO 0.88544	0.88174 TO 0.88618	946000
62	0.88397	+ OR - 0.00074	0.88323 TO 0.88472	0.88249 TO 0.88546	0.88174 TO 0.88620	941000
67	0.88399	+ OR - 0.00075	0.88324 TO 0.88474	0.88250 TO 0.88548	0.88175 TO 0.88623	936000
72	0.88412	+ OR - 0.00075	0.88337 TO 0.88486	0.88262 TO 0.88561	0.88188 TO 0.88635	931000
77	0.88415	+ OR - 0.00075	0.88341 TO 0.88490	0.88266 TO 0.88565	0.88191 TO 0.88640	926000
82	0.88410	+ OR - 0.00075	0.88335 TO 0.88486	0.88260 TO 0.88561	0.88185 TO 0.88636	921000
87	0.88419	+ OR - 0.00075	0.88344 TO 0.88494	0.88269 TO 0.88570	0.88193 TO 0.88645	916000
92	0.88429	+ OR - 0.00076	0.88353 TO 0.88504	0.88278 TO 0.88580	0.88202 TO 0.88656	911000

Figure 6.7-4 CSAS Input/Output Summary for Storage Cask - Accident Conditions (Continued)

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WRR EC455-5302 STORAGE CASK CRITICALITY: WATER IN FUEL/CLAD GAP

                              FREQUENCY FOR GENERATIONS     4 TO 1003
0.8075 TO 0.8107     *
0.8107 TO 0.8140
0.8140 TO 0.8173     *
0.8173 TO 0.8205
0.8205 TO 0.8238     **
0.8238 TO 0.8271     *
0.8271 TO 0.8303     ******
0.8303 TO 0.8336     *****
0.8336 TO 0.8369     *****
0.8369 TO 0.8401     ******
0.8401 TO 0.8434     ***********
0.8434 TO 0.8467     **********
0.8467 TO 0.8500     *********************
0.8500 TO 0.8532     *******************
0.8532 TO 0.8565     *************************
0.8565 TO 0.8598     *****************************
0.8598 TO 0.8630     ***********************************************
0.8630 TO 0.8663     *****************************************
0.8663 TO 0.8696     ********************************************
0.8696 TO 0.8728     ********************************************
0.8728 TO 0.8761     *********************************************
0.8761 TO 0.8794     ************************************************************
0.8794 TO 0.8826     ******************************************************************
0.8826 TO 0.8859     ***************************************************
0.8859 TO 0.8892     ***********************************************
0.8892 TO 0.8925     ********************************************************
0.8925 TO 0.8957     ***********************************************
0.8957 TO 0.8990     **********************************************
0.8990 TO 0.9023     *****************************************************
0.9023 TO 0.9055     ***************************************
0.9055 TO 0.9088     **************************************
0.9088 TO 0.9121     *************************
0.9121 TO 0.9153     ************************
0.9153 TO 0.9186     *********************
0.9186 TO 0.9219     ********************
0.9219 TO 0.9251     **************
0.9251 TO 0.9284     *********
0.9284 TO 0.9317     ******
0.9317 TO 0.9349     *****
0.9349 TO 0.9382     ****
0.9382 TO 0.9415     *
0.9415 TO 0.9448     **
0.9448 TO 0.9480     *
0.9480 TO 0.9513
0.9513 TO 0.9546
0.9546 TO 0.9578
0.9578 TO 0.9611     *
0.9611 TO 0.9644
0.9644 TO 0.9676
0.9676 TO 0.9709     *
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