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Revision 7

MAGNASTOR®

(Modular Advanced Generation Nuclear All-purpose STORage)

FINAL SAFETY ANALYSIS REPORT

NON-PROPRIETARY VERSION

Docket No. 72-1031

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

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Chapter 1
General Description

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1 GENERAL DESCRIPTION

This Safety Analysis Report (SAR) describes the NAC International Inc. (NAC) MAGNASTOR® System for the storage of spent fuel. It demonstrates that MAGNASTOR satisfies the requirements of the U.S. Nuclear Regulatory Commission (NRC) for spent nuclear fuel storage as prescribed in Title 10 of the Code of Federal Regulations, Part 72 (10 CFR 72) [1] and NUREG-1536 [2]. MAGNASTOR is a canister-based system that accommodates both the storage and transport of Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) spent fuel.

The principal components of MAGNASTOR are:

- transportable storage canister (TSC)
- concrete cask (CC)
- transfer cask (MTC)

The TSC is designed and fabricated to meet the requirements for storage in the concrete cask, for transport in a transport cask and to be compatible with the U.S. Department of Energy planning for permanent disposal in a Mined Geological Disposal System. The TSC incorporates a welded closure to preclude the loss of contents and to preserve the general health and safety of the public during long-term storage of spent fuel.

In long-term storage, the TSC is installed in a concrete cask, which provides structural protection and radiation shielding, as well as natural convection cooling. The concrete cask also provides protection during storage for the TSC under adverse environmental conditions.

The transfer cask is used to move the TSC between the workstations during TSC loading and preparation activities. It is also used to transfer the TSC to or from the concrete cask and to a transport cask.

This SAR is formatted in accordance with NRC Regulatory Guide 3.61 [4], except that Chapter 8, Materials Evaluation, is added in accordance with the requirement of Interim Staff Guidance (ISG)-15 [5], with the subsequent renumbering of the remaining chapters. The terminology used in this report is presented in Section 1.1. The term TSC refers to both the PWR and BWR TSCs where the discussion is common to both configurations. Discussion of features unique to the PWR and BWR configurations is addressed in subsections, as appropriate, within each chapter.

1.1 Terminology

This section lists and defines the terms used in this SAR.

Adapter Plate

A carbon steel plate assembly positioned on the top of the concrete cask and used to align the transfer cask. It supports the operating mechanism for opening and closing the transfer cask shield doors.

Assembly Average Fuel Enrichment

Value calculated by averaging the ^{235}U wt % enrichment over the entire fuel region (UO_2) of an individual fuel assembly, including axial blankets, if present.

Assembly Defect

Any change in the physical as-built condition of the assembly, with the exception of normal in-reactor changes such as elongation from irradiation growth or assembly bow. Example of assembly defects include: (a) missing rods, (b) broken or missing grids or grid straps (spacer), and (c) missing or broken grid springs, etc. An assembly with a defect is damaged only if it cannot meet its fuel-specific and system-related functions.

Breached Spent Fuel Rod

Spent fuel with cladding defects that permit the release of gas from the interior of the fuel rod. A fuel rod breach may be a minor defect (i.e., hairline crack or pinhole), allowing the rod to be classified as undamaged, or be a gross breach requiring a damaged fuel classification.

Burnup

Amount of energy generated during irradiation – measured in MWd/MTU.

Assembly Average Burnup

Value calculated by averaging the burnup over the entire fuel region (UO_2) of an individual fuel assembly, including axial blankets, if present. Assembly average burnup represents the reactor record, nominal value. The assembly average burnup is equal to the reactor record, nominal, energy production (MWd) over the life of the fuel assembly divided by the fuel assembly pre-irradiation heavy metal (U) mass in metric tons.

Nonfuel Hardware Burnup

Equivalent accumulated irradiation exposure for activation evaluation.

Concrete Cask

The vertical storage module that receives, holds and protects the sealed TSC for storage at the ISFSI. The concrete cask passively provides the radiation shielding, structural protection and heat dissipation capabilities for the safe storage of spent fuel In the TSC.

Base

A carbon steel weldment incorporating the air inlets and the pedestal that supports the TSC inside of the concrete cask.

Lid

A thick concrete and carbon steel closure for the concrete cask. The lid precludes access to the TSC and provides radiation shielding.

Liner

A carbon steel shell that forms the inside diameter of the concrete cask. The liner serves as the inner form during concrete pouring and provides radiation shielding and structural protection for the TSC.

Standoffs (Channels)

Carbon steel weldments attached to the liner that assist in centering the TSC in the concrete cask and supporting the TSC and its contents in a nonmechanistic tip-over event.

Confinement System

The components of the TSC assembly that retain the spent fuel during storage.

Contents

The system is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly or POR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

Damaged Fuel (DF)

Spent nuclear fuel (SNF) that cannot fulfill its fuel-specific or system-related function. Spent fuel is classified as damaged under the following conditions.

1) There is visible deformation of the rods in the SNF assembly.
   Note: This is not referring to the uniform bowing that occurs in the reactor; this refers to bowing that significantly opens up the lattice spacing.
2) Individual fuel rods are missing from the assembly and the missing rods are not replaced by a solid stainless steel or zirconium dummy rod that displaces a volume equal to, or greater than, the original fuel rod.
3) The SNF assembly has missing, displaced or damaged structural components such that:
   3.1) Radiological and/or criticality safety is adversely affected (e.g., significantly changed rod pitch); or
   3.2) The assembly cannot be handled by normal means (i.e., crane and grapple); or
   3.3) The SNF assembly contains fuel rods with damaged or missing grids, grid straps, and/or grid springs producing an unsupported length greater than 60 inches.

   Note: SNF assemblies with the following structural defects meet MAGNASTOR system-related functional requirements and are, therefore, classified as

undamaged: Assemblies with missing or damaged grids, grid straps and/or grid springs resulting in an unsupported fuel rod length not to exceed 60 inches.

4) Any SNF assembly that contains fuel rods for which reactor operating records (or other records or tests) cannot support the conclusion that they do not contain gross breaches.

   Note: Breached fuel rods with minor cladding defects (i.e, pinhole leaks or hairline cracks that will not permit significant release of particulate matter from the spent fuel rod) meet MAGNASTOR system-related functional requirements and are, therefore, classified as undamaged.

5) FUEL DEBRIS such as ruptured fuel rods, severed rods, loose fuel pellets, containers or structures that are supporting loose PWR fuel assembly parts.

Damaged Fuel Can (DFC)

A specially designed stainless steel screened can sized to hold undamaged PWR fuel, damaged PWR fuel and/or fuel debris. The screens preclude the release of gross particulate from the DFC into the canister cavity. DFCs are only authorized for loading in specified locations of a DF Basket Assembly.

Factor of Safety

An analytically determined value defined as the allowable stress or displacement of a material divided by its calculated stress or displacement.

Fuel Basket (Basket)

The structure inside the TSC that provides structural support, criticality control, and heat transfer paths for the fuel assemblies.

Developed Cell

A basket opening formed by either four fuel tubes or fuel tubes and basket weldments. Fuel assemblies are loaded into the developed cells.

Fuel Tube

A carbon steel tube with a square cross-section. Fuel assemblies are loaded into the fuel tubes. A fuel tube may have neutron absorber material attached on its interior faces.

Neutron Absorber

A borated aluminum metal matrix or composite with neutron absorption capability.

Grossly Breached Spent Fuel Rod

A breach in the spent fuel cladding that is larger than a pinhole or hairline crack. A gross cladding breach may be established by visual examination with the capability to determine if the fuel pellet can be seen through the cladding, or through a review of reactor operating records indicating the presence of heavy metal isotopes.

MAGNASTOR (**M**odular **A**dvanced **G**eneration, **N**uclear, **A**ll-purpose **STOR**age) SYSTEM

The components certified for the storage of spent fuel assemblies at an ISFSI. The MAGNASTOR System consists of a concrete cask and a TSC. A transfer cask is provided and utilized to load and place a TSC in a concrete cask or to remove a TSC from a concrete cask.

Nonfuel Hardware

Nonfuel hardware is defined as reactor control components (RCCs), burnable poison absorber assemblies (BPAAs), guide tube plug devices (GTPDs), neutron sources/neutron source assemblies (NSAs), hafnium absorber assemblies (HFRAs), instrument tube tie components, in-core instrument thimbles, and steel rod inserts (used to displace water from lower section of guide tube), and components of these devices such as individual rods. All nonfuel hardware, with the exception of instrument tube tie components and steel rod inserts, may be activated during in-core operations.

RCCs are commonly referred to as rod cluster control assemblies (RCCAs), control rod assemblies (CRAs), or control element assemblies (CEAs). RCCs are primarily designed to provide reactor shutdown reactivity control, are inserted into the guide tubes of the assembly, and are typically employed for a significant number of operating cycles. Burnup poison absorber assemblies (BPAAs) are commonly referred to as burnup poison rod assemblies (BPRAs), but may have vendor specific nomenclature such as BPRA, Pyrex BPRA or WABA (wet annular burnable absorber). BPAAs are used to control reactivity of fresh fuel or high reactivity fuels and are commonly used for a single cycle, but may be used for multiple cycles. GTPDs are designed to block guide tube openings when no BPAA is employed and are commonly referred to as thimble plugs (TPs), thimble plug devices (TPDs), flow mixers (FMs), water displacement guide tube plugs, or vibration suppressor inserts. GTPDs may be employed for multiple cycles. NSAs are primary and secondary neutron sources used during reactor startup and may be used for multiple cycles.

Integral fuel burnable absorbers, either integral to a fuel rod or as a substitution for a fuel rod, and fuel replacement rods (fueled, stainless steel, or zirconium alloy) are considered components of spent nuclear fuel (SNF) assemblies and are not considered to be nonfuel hardware.

Spent Nuclear Fuel (SNF), Spent Fuel

Irradiated fuel assemblies consisting of end-fittings, grids, fuel rods and integral hardware. Integral hardware for PWR assemblies primarily consists of guide/instrument tubes, but may contain integral fuel burnable absorbers, either integral to a fuel rod or as a fuel rod substitution, and fuel replacement rods (fueled, stainless steel, or zirconium alloy). For BWR fuel, integral hardware may consist of water rods in various shapes, inert rods, fuel rod cluster dividers, and/or fuel assembly channels (optional). PWR SNF may contain nonfuel hardware.

Transfer Cask

A shielded device used to lift and handle the TSC during fuel loading and closure operations, as well as to transfer the TSC in/out of the concrete cask during storage or in/out of a

transport cask. The transfer cask includes two lifting trunnions and two shield doors that can be opened to permit the vertical transfer of the TSC.

Lifting Trunnions

Two low-alloy steel components used to lift the transfer cask in a vertical orientation via a lifting assembly.

TSC (Transportable Storage Canister)

The stainless steel cylindrical shell, bottom-end plate, closure lid, closure ring, and redundant port covers that contain the fuel basket structure and the spent fuel contents.

Closure Lid

A thick, stainless steel disk or a composite closure lid consisting of stainless steel and carbon steel plates bolted together and installed directly above the fuel basket following fuel loading. The closure lid is welded to the TSC shell and provides the confinement boundary for storage and operational shielding during TSC closure.

Drain and Vent Ports

Penetrations located in the closure lid to permit draining, drying, and helium backfilling of the TSC.

Port Cover

The stainless steel plates covering the vent and drain ports that are welded in place following draining, drying, and backfilling operations.

Shield Plate

An electroless nickel-plated carbon steel disk that is bolted to the bottom of the closure lid of the composite closure lid assembly. The shield plate is installed directly above the fuel basket following fuel loading. The shield plate provides operational shielding during TSC closure.

Closure Ring

A stainless steel ring welded to the closure lid and TSC shell to provide a double weld redundant sealing closure of the TSC satisfying 10 CFR 72.236(e) requirements.

Undamaged Fuel

SNF that can meet all fuel-specific and system-related functions. Undamaged fuel is SNF that is not Damaged Fuel, as defined herein, and does not contain assembly structural defects that adversely affect radiological and/or criticality safety. As such, undamaged fuel may contain:

a) Breached spent fuel rods (i.e, rods with minor defects up to hairline cracks or pinholes), but cannot contain grossly breached fuel rods;

b) Grid, grid strap and/or grid spring damage, provided that the unsupported length of the fuel rod does not exceed 60 inches.

1.2 Introduction

MAGNASTOR is a spent fuel dry storage system consisting of a concrete cask and a welded stainless steel TSC with a welded closure to safely store spent fuel. The TSC is stored in the central cavity of the concrete cask. The concrete cask provides structural protection, radiation shielding, and internal airflow paths that remove the decay heat from the TSC contents by natural air circulation. MAGNASTOR is designed and analyzed for a 50-year service life.

The loaded TSC is moved to and from the concrete cask using the transfer cask. The transfer cask provides radiation shielding during TSC closure and preparation activities. The TSC is transferred into the concrete cask by positioning the transfer cask with the loaded TSC on top of the concrete cask, opening the shield doors, and lowering the TSC into the concrete cask. Figure 1.3-1 depicts the major components of MAGNASTOR in such a configuration.

MAGNASTOR is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly. These capacities, combined with enhanced operational features, ensure that MAGNASTOR reduces the time required and the personnel dose received on a per-assembly basis when placing spent fuel into dry storage. The fuel specifications and parameters that establish the design basis for the PWR and BWR fuel assemblies are presented in Chapter 2. The spent fuel considered in the design includes fuel assemblies that have different overall lengths. The PWR and BWR fuel assembly populations are divided into two groups based on fuel assembly length, and are accommodated by two different lengths of TSCs. There are multiple concrete and transfer casks of different sizes that are used to accommodate the different lengths of TSCs. The designations and corresponding lengths of the TSCs are shown on the License Drawings.

For PWR fuel, the inclusion of nonfuel assembly hardware can increase an assembly's overall length, resulting in the need to use the longer TSC. Fuel assembly spacers may be used in a given TSC to allow loading of fuel assemblies that are significantly shorter than the TSC length. A DFC spacer may be required for damaged fuel cans to ensure the proper design function of the damaged fuel can. A DFC may not contain a fuel assembly that includes core components.

The BWR fuel assembly groups are evaluated for the effects of the zirconium alloy channel that surrounds the fuel assembly in reactor operations. Fuel assembly channel effects are addressed in both the thermal heat transfer and criticality analyses. BWR assembly channels are included in the assembly weight assigned to each basket opening in the structural analysis. The mass associated with the channel is conservatively neglected from the material homogenization in the shielding analysis. Fuel assembly spacers may be used in a given TSC to facilitate the loading of fuel assemblies.

The system design and analyses are in accordance with 10 CFR 72, ANSI/ANS 57.9 [6], the applicable sections of the ASME Boiler and Pressure Vessel Code (ASME Code), and the American Concrete Institute (ACI) code [7]. The analyses demonstrate that MAGNASTOR meets the regulatory requirements of 10 CFR 72 and the guidance of NUREG-1536 [2].

1.3 General Description of MAGNASTOR

MAGNASTOR provides for the long-term storage of PWR and BWR fuel assemblies as listed in Chapter 2. During long-term storage, the system provides an inert environment, passive structural shielding, cooling and criticality control, and a welded confinement boundary. 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.

1.3.1 MAGNASTOR Components

The design and operation of the principal components of MAGNASTOR and the associated auxiliary equipment are described in this section. The design characteristics of the principal components of the system are presented in Table 1.3-1.

This list shows the auxiliary equipment generally needed to use MAGNASTOR.

- automated, remote, and /or manual welding equipment to perform TSC field closure welding operations
- an engine-driven or towed frame or a heavy-haul trailer to move the concrete cask to and from the storage pad and to position the concrete cask on the storage pad
- draining, drying, hydrostatic testing, helium backfill, and water cooling systems for preparing the TSC and contents for storage
- hydrogen monitoring equipment to confirm the absence of explosive or combustible gases during TSC closure welding
- an adapter plate and a hydraulic supply system
- a lifting yoke for lifting and handling the transfer cask and rigging equipment for lifting and handling system components

In addition to these items, the system requires utility services (electric, helium, air, clean borated water, etc.), standard torque wrenches, tools and fittings, and miscellaneous hardware.

1.3.1.1 Transportable Storage Canister (TSC)

Two lengths of TSCs accommodate all evaluated PWR and BWR fuel assemblies. The TSC is designed for transport per 10 CFR 71 [3]. The load conditions in transport produce higher stresses in the TSC than are produced during storage conditions, except for TSC lifting. Consequently, transport load conditions establish the design basis for the TSC and, therefore, the TSC design is conservative with respect to storage conditions.

The stainless steel TSC assembly holds the fuel basket structure and confines the contents (see Figure 1.3-2). The TSC is defined as the confinement boundary during storage. The welded TSC weldment, closure lid, closure ring, and redundant port covers prevent the release of contents under normal conditions and off-normal or accident events. The fuel basket assembly

provides the structural support and a heat transfer path for the fuel assemblies, while maintaining a subcritical configuration for all of the evaluated normal conditions and off-normal or accident events.

The major components of the TSC assembly are the shell, base plate, closure lid assembly, closure ring, and redundant port covers for the vent and drain ports, which provide the confinement boundary during storage. TSCs are provided in four configurations designated TSC1 through TSC4. The design characteristics, overall dimensions and materials of fabrication for the different TSC configurations are provided in Table 1.3-1.

The TSC consists of a cylindrical stainless steel shell with a welded stainless steel bottom plate and a closure lid assembly at its top end. The stainless steel shell and bottom plate are dual-certified Type 304/304L. TSC1 and TSC2 include a 9-inch thick solid stainless steel closure lid assembly. TSC3 and TSC4 include a composite lid assembly consisting of a 4-inch thick stainless steel closure lid and a 5-inch thick carbon steel shield plate that is coated using electroless nickel plating. Closure ring alternative designs for all four TSC configurations are defined on the applicable drawings. The closure lid, closure rings and port covers are dual certified Type 304/304L stainless steel.

Following loading of fuel into the fuel basket assembly inside the TSC, the closure lid assembly is lowered into the top end of the TSC and positioned and supported by the TSC lifting lugs. After the closure lid assembly is placed on the TSC, the TSC is moved to a workstation, and the closure lid is welded to the TSC. After nondestructive examination and pressure testing of the closure lid weld, the closure ring is welded to the closure lid and TSC shell. The vent and drain ports are penetrations through the lid, which provide access for auxiliary systems to drain, dry, and backfill the TSC. The drain port has a threaded fitting for installing the drain tube. The drain tube extends the full length of the TSC and ends in a sump in the bottom plate. The vent port also provides access to the TSC cavity for draining, drying, and backfilling operations. Following completion of backfilling, the inner port covers at the vent and drain ports are installed and welded in place. The final surface of the inner port cover weld is visually and nondestructively examined. The inner vent and drain port cover welds are then helium leak tested to verify the absence of helium leakage past the port cover welds. The outer port covers are then installed and welded, and the final weld surfaces are nondestructively examined.

The TSC confinement boundary is designed, fabricated and inspected to the requirements of the ASME Boiler and Pressure Vessel Code (ASME Code), Section III, Division 1, Subsection NB [8], except as noted in the Alternatives to the ASME Code as provided in Table 2.1-2.

Refer to Table 1.3-2 for a summary of the TSC fabrication requirements.

1.3.1.2 Fuel Baskets

Each TSC contains either a PWR or BWR fuel basket, which positions and supports the stored fuel. As described in the following sections, the design of the basket is similar for the PWR and BWR configurations. The fuel basket for each fuel type is designed, fabricated, and inspected to the requirements of the ASME Code, Section III, Division 1, Subsection NG [9], except as noted in Table 2.1-2.

The structural components of both the PWR and BWR baskets are fabricated from ASME SA537, Class 1, carbon steel. To minimize corrosion and preclude significant generation of combustible gases during fuel loading, the assembled basket is coated with electroless nickel plating using an immersion process. Following plating of the structural components, the neutron absorber panels and the stainless steel retainers are installed on the basket structure as shown on the License Drawings. The principal dimensions and materials of fabrication of the fuel basket and PWR damaged fuel cans are provided in Table 1.3-1.

Both fuel basket designs minimize horizontal surfaces that could entrain water and provide an open path for water flow to the drain tube and sump in the bottom of the TSC. The fuel baskets are supported from the TSC bottom plate by 3-in high standoffs at the corner of the fuel tubes enabling the TSC to fill and drain evenly.

Spacers may be used to facilitate the loading of the spent fuel assemblies, or damaged fuel cans, during storage operations.

PWR Fuel Basket

The PWR fuel basket design is an arrangement of square fuel tubes held in a right-circular cylinder configuration using support weldments that are bolted to the outer fuel tubes. The design parameters for the two lengths of PWR fuel baskets are provided in Table 1.3-1.

Fuel tubes support an enclosed neutron absorber sheet on up to four interior sides of the fuel tube. The neutron absorber panels, in conjunction with minimum TSC cavity water boron levels, provide criticality control in the basket. Each neutron absorber panel is covered by a sheet of stainless steel to protect the material during fuel loading and to keep it in position. The neutron absorber and stainless steel cover are secured to the fuel tube using weld posts located across the width and along the length of the fuel tube.

Each PWR fuel basket has a capacity of up to 37 undamaged fuel assemblies. Square tubes are assembled in an array where the tubes function as independent fuel positions and as sidewalls for the adjacent fuel positions in what is called a developed cell array. Consequently, the 37 fuel positions are developed using only 21 tubes. The array is surrounded by weldments that serve both as sidewalls for some perimeter fuel positions and as the structural load path from the array

to the TSC shell wall. Each PWR basket fuel tube has a nominal 8.86-in square opening. Each developed cell fuel position has a nominal 8.76-in square opening.

The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. The arrangement of tubes and fuel positions is the same as in the standard fuel basket, but the design of each of the four corner support weldments is modified with additional structural support to provide an enlarged position for a damaged fuel can at the outermost corners of the fuel basket. Each damaged fuel can location has a nominal 9.80-in square opening. A damaged fuel can or an undamaged fuel assembly may be loaded in a damaged fuel can corner location.

BWR Fuel Basket

The BWR fuel basket design is an arrangement of square fuel tubes held in a right-circular cylinder configuration using support weldments that are bolted to the outer fuel tubes. The design parameters for the two lengths of BWR fuel baskets are provided in Table 1.3-1.

Each fuel tube supports an enclosed neutron absorber sheet on up to four interior sides of the fuel tube, which provides criticality control in the basket. The neutron absorber is covered by a sheet of stainless steel to protect the material during fuel loading and to keep it in position. The neutron absorber and stainless steel cover are secured to the fuel tube using weld posts located across the width and along the length of the fuel tube.

Each BWR fuel basket has a capacity of 87 fuel assemblies in an aligned configuration. Square tubes are assembled in an array where the tubes function as independent fuel positions and as sidewalls for the adjacent fuel positions in what is called a developed cell array. Consequently, the 87 fuel positions are developed using only 45 tubes. The array is surrounded by weldments that serve both as sidewalls for some perimeter fuel positions and as the structural load path from the array to the TSC shell wall. Each BWR basket fuel tube has a nominal 5.86-in square opening. Each developed cell fuel position has a nominal 5.77-in square opening.

1.3.1.3 Concrete Cask

The concrete cask is the storage overpack for the TSC and it is designed to hold both lengths of TSCs. The concrete cask provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the TSC during long-term storage. The principal dimensions and materials of fabrication of the concrete cask are shown in Table 1.3-1.

The concrete cask is a reinforced structural plain concrete shield wall with a structural steel inner liner and base. The reinforced structural plain concrete shield wall and steel liner provide the neutron and gamma radiation shielding for the stored spent fuel. Reinforcing steel (rebar) is encased within the concrete. The reinforced structural plain concrete shield wall provides the

structural strength to protect the TSC and its contents in natural phenomena events such as tornado wind loading and wind-driven missiles and during nonmechanistic tip-over events (refer to Figure 1.3-3). The concrete surfaces remain accessible for inspection and maintenance over the life of the cask, so that any necessary restoration actions may be taken to maintain shielding and structural conditions.

The concrete cask may be supplied in four different configurations designated CC1 through CC4. CC1 is the standard 225.27-in high cylinder. CC2 is also 225.27-in high, but is a segmented design. The CC3 and CC4 configurations are shorter variants at 218.3 inches high. CC1, CC2 and CC4 are equipped with a 1.75-in thick carbon steel liner, while CC3 has a 3-in thick carbon steel liner. CC1, CC2 and CC4 are equipped with standard concrete lids, having a constant thickness, while CC3 lid has a thicker center section for enhanced shielding. Both the CC3 and CC4 cask configurations are equipped with additional shielding at the air inlets.

The concrete cask provides an annular air passage to allow the natural circulation of air around the TSC to remove the decay heat from the contents. The lower air inlets and upper air outlets are steel-lined penetrations in the concrete cask body. Each air inlet/outlet is covered with a screen. The weldment baffle directs the air upward and around the pedestal that supports the TSC. Decay heat is transferred from the fuel assemblies to the TSC wall by conduction, convection, and radiation. Heat is removed by convection and radiation from the TSC shell to the air flowing upward through the annular air passage and to the concrete cask inner liner, respectively. Heat radiated to the liner can be transferred to the air annulus and by conduction through the concrete cask wall. The heated air in the annulus exhausts through the air outlets. The passive cooling system is designed to maintain the peak fuel cladding temperature below acceptable limits during long-term storage [10]. The concrete cask thermal design also maintains the bulk concrete temperature and surface temperatures below the American Concrete Institute (ACI) limits under normal operating conditions. The inner liner of the concrete cask incorporates standoffs that provide lateral support to the TSC in side impact accident events.

A carbon steel and concrete lid is bolted to the top of the concrete cask. (See Table 1.3-4 for the Concrete Cask Lid – Concrete Specification Summary.) The lid reduces skyshine radiation and provides a cover to protect the TSC from the environment and postulated tornado missiles.

Fabrication of the concrete cask requires no unique or unusual forming, concrete placement, or reinforcement operations. The concrete portion of the cask is constructed by placing concrete between a reusable, exterior form and the steel liner. Reinforcing bars are used near the inner and outer concrete surfaces to provide structural integrity. Note: inner rebar cage is optional. The structural steel liner and base are shop fabricated. Refer to Table 1.3-3 for the fabrication specifications for the concrete cask.

Daily visual inspection of the air inlet and outlet screens for blockage assures that airflow through the cask meets licensed requirements. A description of the visual inspection is included

in the Technical Specifications, Chapter 13. As an alternative to daily visual inspections, the loaded concrete cask in storage may include the capability to measure air temperature at the four outlets. Each air outlet may be equipped with a remote temperature detector mounted in the outlet air plenum. The air temperature-monitoring system, designed to provide verification of heat dissipation capabilities, can be designed for remote or local read-out capabilities at the option of the licensee. The temperature-monitoring system can be installed on all or some of the concrete casks at the Independent Spent Fuel Storage Installation (ISFSI) facility.

1.3.1.4 Transfer Cask

The transfer cask is designed, fabricated, and tested to meet the requirements of ANSI N14.6 [11] as a special lifting device. The transfer cask provides biological shielding and structural protection for a loaded TSC, and is used to lift and move the TSC between workstations. The transfer cask is also used to shield the vertical transfer of a TSC into a concrete cask or a transport cask.

The transfer cask is available in two configurations—MTC1 and MTC2. MTC1 consists of carbon steel shells. MTC2 is a shorter version consisting of stainless steel shells. The principal dimensions and materials of fabrication of the transfer cask are provided in Table 1.3-1.

The transfer cask designs incorporate a retaining ring or three retaining blocks, pin-locked in place, or a bolted retaining ring, to prevent a loaded TSC from being inadvertently lifted through its top opening. The transfer cask has retractable bottom shield doors. During TSC loading and handling operations, the shield doors are closed and secured. After placement of the transfer cask on the concrete cask, the doors are retracted using hydraulic cylinders and a hydraulic supply. The TSC is then lowered into a concrete cask for storage. Refer to Figure 1.3-1 for the general arrangement of the transfer cask, TSC, and concrete cask during loading.

Sixteen penetrations, eight at the top and eight at the bottom, are available to provide a water supply to the transfer cask annulus. Penetrations not used for water supply or draining are capped. The transfer cask annulus is isolated using inflatable seals located between the transfer cask inner shell and the TSC near the upper and lower ends of the transfer cask

During TSC closure, clean or demineralized spent fuel pool water is circulated through these penetrations into the annulus region to minimize component temperatures and improve canister preparation time limits. The annulus circulating water system can be utilized through completion of TSC activities. The annulus circulating water system is turned off and disconnected prior to movement of the transfer cask for TSC transfer operations into the concrete cask.

A similar process of clean or demineralized spent fuel pool water flow into the annulus is used during in-pool fuel loading to minimize the potential for contamination of the TSC exterior surfaces.

The transfer cask penetrations can also be used for the introduction of auxiliary forced air or gas to cool the exterior of the TSC. Alternately, if auxiliary cooling is required to lower fuel cladding or TSC component temperatures, the loaded TSC may be returned to the spent fuel pool or shelf for cooling.

1.3.1.5 Damaged Fuel Can

The MAGNASTOR Damaged Fuel Can (DFC), shown in Figure 1.3-4, is provided to accommodate damaged PWR fuel assemblies or fuel debris equivalent to one PWR fuel assembly. Up to four DFCs may be loaded, one into each outer corner, in the MAGNASTOR DF Basket Assembly.

The primary function of the DFC is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the TSC cavity. In normal operation, the DFC is in a vertical orientation.

The DFC is fabricated from Type 304 stainless steel and has an 8.7-in square inside dimension. The side plates that form the upper end of the DFC are 0.15-in thick and the tube body walls are 0.048-in thick (18-gage sheet). The DFC lid plate and bottom thicknesses total 11/16 (0.688) inch and the lid overall height is 2.32 inches. The DFC bottom plate thickness is 5/8 (0.625) inch. The DFC lid and bottom include screened drain holes.

1.3.2 Operational Features

In storage, MAGNASTOR does not require any active operational systems. The principal MAGNASTOR operational activities are loading, welding, and preparing the TSC for storage and transferring the TSC to the concrete cask. The transfer cask (MTC) is designed to meet the requirements of these operations. The transfer cask holds the TSC during fuel loading operations, provides biological shielding during TSC closure and preparation, and positions the TSC for transfer into the concrete cask. The lid design of the TSC assures structural integrity, while reducing the time and dose involved in TSC closure.

The detailed generic step-by-step operating procedures for the loading and transferring of MAGNASTOR are presented in Chapter 9. The following is a list of the major loading activities. This list assumes that the empty TSC is installed in the transfer cask.

- Fill the TSC with water or borated water if required.
- Lift the transfer cask over the pool and start the flow of water to the transfer cask annulus and lower the cask to the bottom of the pool.
- Load the selected spent fuel assemblies and damaged fuel cans (if applicable) into the TSC.
- Install the closure lid assembly.

- Remove the transfer cask from the pool and place it in the cask preparation workstation.
- Decontaminate the transfer cask.
- Lower the TSC water level and weld the closure lid to the TSC shell. Examine the weld.
- Hydrostatically test the TSC.
- Install and weld the closure ring. Examine the weld.
- Drain the remaining pool water from the TSC.
- Vacuum dry the TSC cavity. Verify cavity dryness.
- Establish a helium backfill.
- Install and weld the inner vent and drain port covers. Examine the welds.
- Helium leak test the inner vent and drain port covers.
- Install and weld the outer vent and drain port covers. Examine the welds.
- Install the TSC lifting system.
- Install the adapter plate on the concrete cask.
- Lift and place the transfer cask on the transfer adapter.
- Attach the TSC lifting system to the crane hook and raise the TSC off of the shield doors.
- Open the shield doors.
- Lower the TSC into the concrete cask (see Figure 1.3-1).
- Remove the transfer cask, transfer adapter, and TSC lifting systems.
- Install the lid on the concrete cask.
- Move the loaded concrete cask to the storage pad.
- Move the concrete cask to its designated location on the storage pad.

The TSC unloading and spent fuel removal from the TSC are essentially the reverse of these steps, except that weld removal and cooldown of the contents is required. This typical sequence of operations, and individual steps, may be modified by the approved site procedure to accommodate specific site requirements, as long as the requirements of the Technical Specifications and the Certificate of Compliance (CoC) are met.

Figure 1.3-1 Major Component Configuration for Loading the Concrete Cask

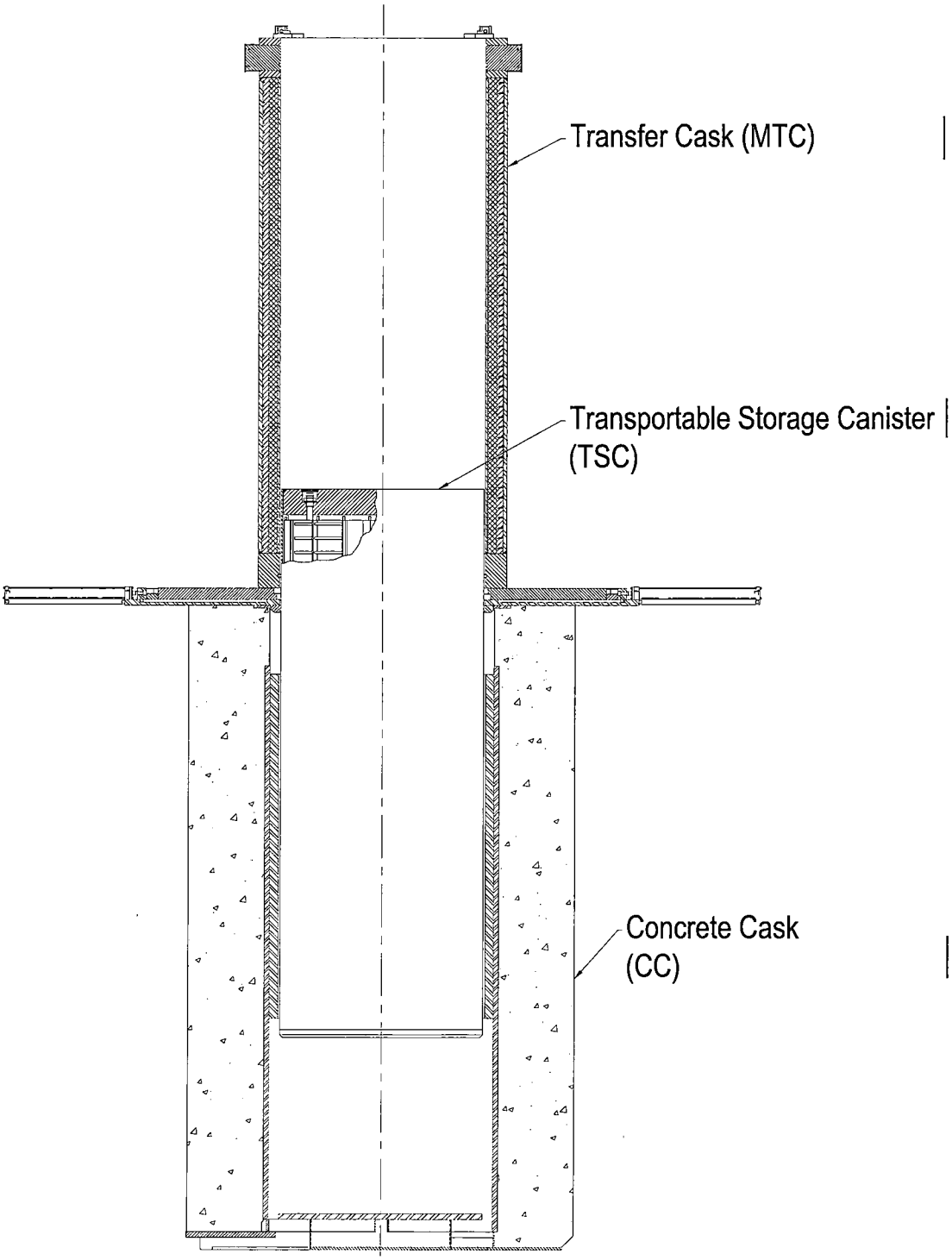
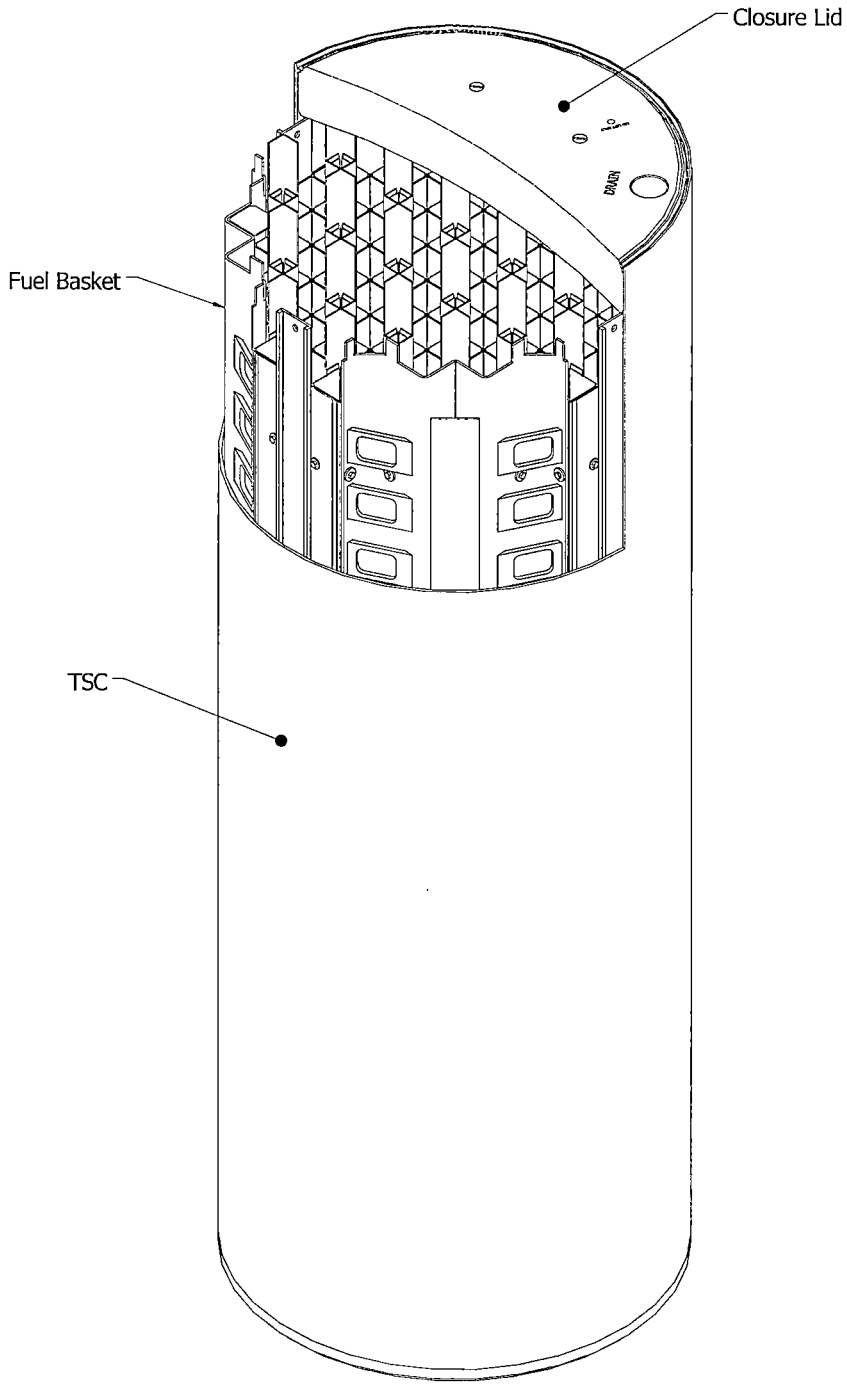
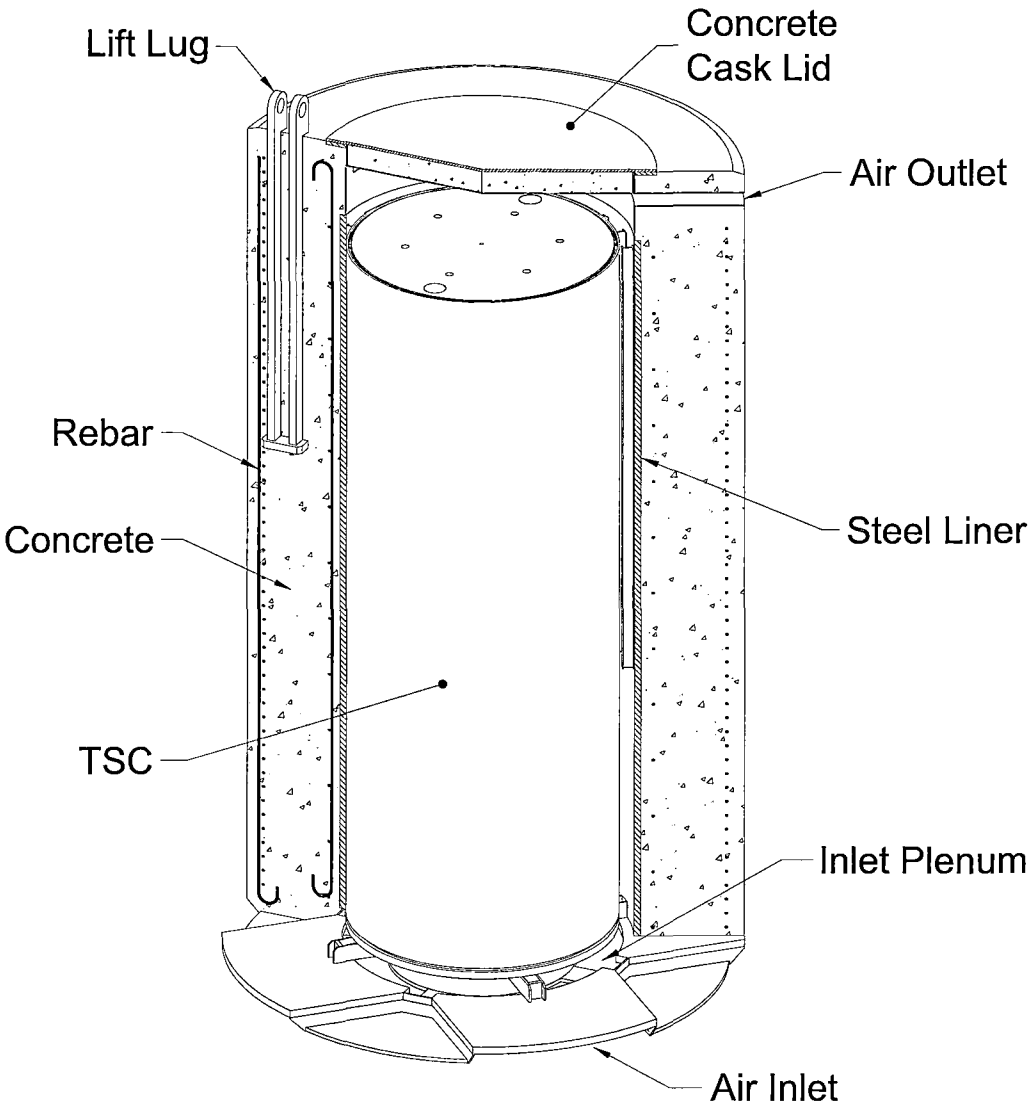


Figure 1.3-2 TSC and Basket



Note: Solid 9-in thick stainless steel closure lid shown.

Figure 1.3-3 Concrete Cask



Note: Inner rebar optional.

Figure 1.3-4 MAGNASTOR Damaged Fuel Can

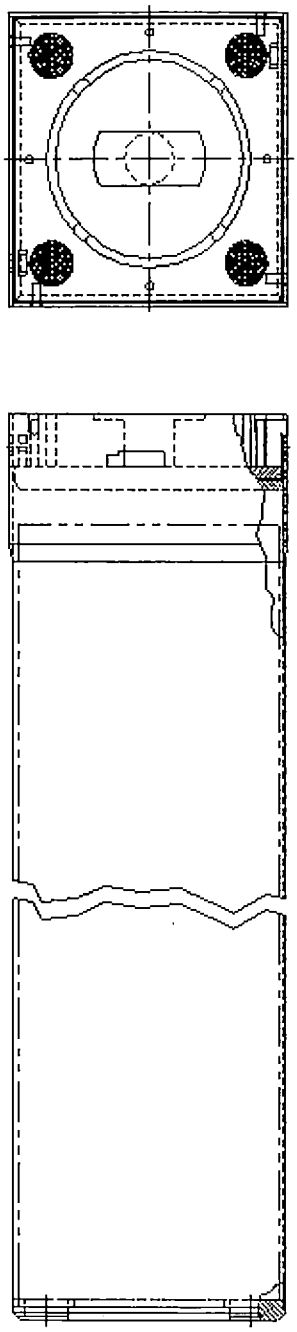


Table 1.3-1 Design Characteristics

	Design Characteristic	Nominal Value (in)[a]	Material
TSC	Shell	0.5 × 72 dia.	Stainless Steel
	Bottom	2.75	Stainless Steel
	Closure Lid Assembly		
	TSC1 & TSC2	9.0-in. thick	Stainless Steel
	TSC3 & TSC4	4.0-in thick/5.0-in thick	Stainless Steel/Carbon Steel
	Closure Ring		
	TSC1 & TSC2	0.75 square	Stainless Steel
	TSC3 & TSC4	0.75 square or 1.5 × 0.75	Stainless Steel
	Length		
	TSC1 & TSC3	191.8	
	TSC2 & TSC4	184.8	
	Capacity (# of fuel assemblies)	37 PWR/87 BWR	
Fuel Basket	PWR Fuel Tube Wall	0.31	Carbon Steel
	BWR Fuel Tube Wall	0.25	Carbon Steel
	Neutron Absorber	0.125 (PWR), 0.1 (BWR)	Metallic Composite/Matrix
	Neutron Absorber Retainer	0.015	Stainless Steel
	Support Plates & Gussets	0.5 to 0.75	Carbon Steel
	Support Bars (PWR)	0.875	Carbon Steel
	Support Plate (BWR)	0.75	Carbon Steel
	Length	172.5 or 179.5	
	Assembly dia.	70.76	
	# of Fuel Tubes/Fuel Loading Positions		
	PWR	21/37	
	BWR	45/87	
	DFC Corner Support Weldment		
	Inner-Formed Plate	1.125	Carbon Steel
	Outer-Formed Plate	0.75	Carbon Steel
	Ridge Gusset	0.75	Carbon Steel
	Damaged Fuel Can Wall		
	Tube Body	0.048	Stainless Steel
	Side Plate	0.15	Stainless Steel
Transfer Cask	MTC1		
	Outer Shell	1.25 × 88 dia.	Low Alloy Steel
	Inner Shell	0.75 × 74.5 dia.	Low Alloy Steel
	Retaining Block	8 × 8.75 × 1.50	Stainless Steel
	Trunnions	9 dia.	Low Alloy Steel
	Bottom Forging	12 × 88 dia.	Low Alloy Steel
	Top Forging	14 × 88 dia.	Low Alloy Steel
	Shield Doors	5.0	Low Alloy Steel
	Door Rails	5.25 × 7.5 × 52.0	Low Alloy Steel
	Gamma Shield	3.25	Lead
	Neutron Shield	2.25	NS-4-FR, Solid Synthetic Polymer
	Length	202.0	

[a] Thickness unless otherwise indicated.

Table 1.3-1 Design Characteristics (continued)

	Design Characteristic	Nominal Value (in) [a]	Material
Transfer Cask (continued)	MTC2		
	Outer Shell	1.25 × 88 dia.	Stainless Steel
	Inner Shell	0.75 × 74.5 dia.	Stainless Steel
	Retaining Ring	1 × 84 dia.	Stainless Steel
	Retaining Block	8 × 8.75 × 1.50	Stainless Steel
	Trunnions	9 dia.	Stainless Steel
	Bottom Forging	12 × 88 dia.	Stainless Steel
	Top Forging	14 × 88 dia.	Stainless Steel
	Shield Doors	5.0	Stainless Steel
	Door Rails	5.25 × 7.5 × 52.0	Stainless Steel
	Gamma Shield	3.25	Lead
	Neutron Shield	2.25	NS-4-FR, Solid Synthetic Polymer
	Length	192.2	
Transfer Adapter	Base Plate	2.0	Carbon Steel
	Guide Ring	2.5 × 79 dia.	Carbon Steel
Concrete Cask	CC1 & CC2		
	Weldment Structures		
	Liner	1.75 × 83 dia	Carbon Steel
	Top Flange	1 × 91.0 dia.	Carbon Steel
	Standoffs (Channels)	3 × 7.5 (s-beam)	Carbon Steel
	Pedestal Plate	2 × 72 dia.	Carbon Steel
	Base Plate	1 × 128 dia.	Carbon Steel
	Inlet Top	2 × 136 dia.	Carbon Steel
	Concrete Cask		Carbon Steel
	Concrete Shell	26.5 × 136 dia.	Type II Portland Cement
	Lid	6.8 × 88 dia.	Carbon Steel
			Type II Portland Cement
	Rebar	various lengths	Carbon Steel
	Length	225.3	
	CC3		
	Weldment Structures		
	Liner	3 × 83 dia	Carbon Steel
	Top Flange	1 × 93.5 dia.	Carbon Steel
	Standoffs (Channels)	3 × 7.5 (s-beam)	Carbon Steel
	Pedestal Plate	2 × 72 dia.	Carbon Steel
	Base Plate	1 × 128 dia.	Carbon Steel
	Inlet Top	2 × 136 dia.	Carbon Steel
	Concrete Cask		Carbon Steel
	Concrete Shell	25.3 × 136 dia.	Type II Portland Cement
	Lid	12.8 × 91.5 dia.	Carbon Steel
			Type II Portland Cement
	Rebar	various lengths	Carbon Steel
	Length	218.3	

[a] Thickness unless otherwise indicated.

Table 1.3-1 Design Characteristics (continued)

	Design Characteristic	Nominal Value (in) [a]	Material
Concrete Cask (continued)	CC4		
	Weldment Structures		
	Liner	1.75 × 83 dia	Carbon Steel
	Top Flange	1 × 93.5 dia.	Carbon Steel
	Standoffs (Channels)	3 × 7.5 (s-beam)	Carbon Steel
	Pedestal Plate	2 × 72 dia.	Carbon Steel
	Base Plate	1 × 128 dia.	Carbon Steel
	Inlet Top	2 × 136 dia.	Carbon Steel
	Concrete Cask		Carbon Steel
	Concrete Shell	26.5 × 136 dia.	Type II Portland Cement
	Lid	6.8 × 91.5 dia.	Carbon Steel
			Type II Portland Cement
	Rebar	various lengths	Carbon Steel
	Length	218.3	

[a] Thickness unless otherwise indicated.

Table 1.3-2 TSC Fabrication Specification Summary

Materials

- All materials shall be governed by the referenced drawings and meet the applicable ASME Code sections.

Welding

- Welds shall be in accordance with the referenced drawings.
- Filler metals shall be appropriate ASME Code materials.
- Welders and welding operators shall be qualified in accordance with ASME Code Section IX [12].
- Welding procedures shall be written and qualified in accordance with ASME Code Section IX.
- Personnel performing weld examinations shall be qualified in accordance with the NAC International Quality Assurance Program and SNT-TC-1A [13].
- Weld inspection and examination requirements and acceptance criteria are specified in Chapter 10.

Fabrication

- Cutting, welding, and forming shall be in accordance with ASME Code, Section III, NB-4000 [8] unless otherwise specified. Code stamping is not required.
- Surfaces shall be cleaned to a surface cleanness classification C, or better, as defined in ANSI N45.2.1 [14], Section 2.
- 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 [15].

Quality Assurance

- The TSC shall be fabricated under a quality assurance program that meets 10 CFR 72, Subpart G, and 10 CFR 71, Subpart H.

Table 1.3-3 Concrete Cask Construction Specification Summary

Materials

- Concrete mix shall be in accordance with the requirements of ACI 318 and ASTM C94 [16].
- Type II Portland Cement, ASTM C150 [17].
- Fine aggregate ASTM C33 [18] or C637 [19].
- Coarse aggregate ASTM C33.
- Aggregates that conform to the particle size requirements of a U.S. state's transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by the respective grading requirement.
- Admixtures
  - Water Reducing and Superplasticizing ASTM C494 [20].
  - Pozzolanic Admixture (loss on ignition 6% or less) ASTM C618 [21].
- Compressive strength 4000 psi minimum at 28 days.
- Specified air entrainment per ACI 318.
- All steel components shall be of the material as specified in the referenced drawings.

Construction

- A minimum of two samples for each concrete cask shall be taken in accordance with ASTM C172 [22] and ASTM C31 [23] for the purpose of obtaining concrete slump, density, air entrainment, and 28-day compressive strength values. The two samples shall not be taken from the same batch or truck load.
- Test specimens shall be tested in accordance with ASTM C39 [24].
- Formwork shall be in accordance with ACI 318.
- All sidewall formwork shall remain in place in accordance with the requirements of ACI 318.
- 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.
- Welding and inspection requirements and acceptance criteria are specified in Chapter 10.

Quality Assurance

- The concrete cask shall be constructed under a quality assurance program that meets 10 CFR 72, Subpart G.

Table 1.3-4 Concrete Cask Lid – Concrete Specification Summary

Concrete mix shall be in accordance with the following ACI 318 requirements:

- Standard weight concrete density shall be 140 pcf (minimum)
- No strength requirements – commercial grade concrete from a commercial grade supplier

1.4 MAGNASTOR Contents

The MAGNASTOR system is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

PWR fuel assemblies may be stored with nonfuel hardware. Nonfuel hardware stored in a damaged or undamaged fuel assembly placed into a DFC is limited to steel rod inserts for guide tube dashpots and instrument tube tie components. BWR fuel assemblies may be stored with or without channels. Assemblies may contain solid filler rods or burnable absorber rods replacing fuel rods in the assembly lattice. Irradiated (i.e., activated during in-core operation) steel filler rods are limited to five rods per assembly and there may be no more than one assembly with irradiated rods per TSC. The design content conditions are specified in the CoC for MAGNASTOR. Unenriched PWR fuel assemblies are not evaluated and are not included as allowable contents. Unenriched BWR fuel assemblies are allowed with a maximum assembly average burnup of 5,000 MWd/MTU. Assemblies may contain axial end blankets. Axial end blankets may be low enriched, be unenriched, and/or contain annular fuel pellets.

1.5 Identification of Agents and Contractors

The prime contractor for the MAGNASTOR design is NAC. All design, analysis, licensing, and procurement activities are performed by NAC in accordance with its approved Quality Assurance Program, as described in Chapter 14. Fabrication of the steel components will be by qualified vendors. A qualified concrete contractor will perform construction of the concrete cask. All vendors and contractors will be selected and their performance monitored in accordance with the NAC Quality Assurance Program. All MAGNASTOR fabrication and assembly activities will be performed in accordance with quality assurance programs that meet the requirements of 10 CFR 72, Subpart G.

NAC as a contractor, or the licensee, may perform construction of the ISFSI and MAGNASTOR loading operations on site in accordance with the NAC or licensee quality assurance program, as appropriate. The licensee will perform decommissioning of the ISFSI in accordance with the licensee quality assurance program.

NAC was founded as a private corporation in 1968, with the primary focus of tracking, inspecting, handling, storing, and transporting spent nuclear fuel. NAC is a wholly owned subsidiary of USEC, Inc., since completion of its acquisition in November 2004. NAC is recognized in the industry as an 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.

Within the past 15 years, NAC has completed fabrication or has under construction the following transportation and/or storage systems.

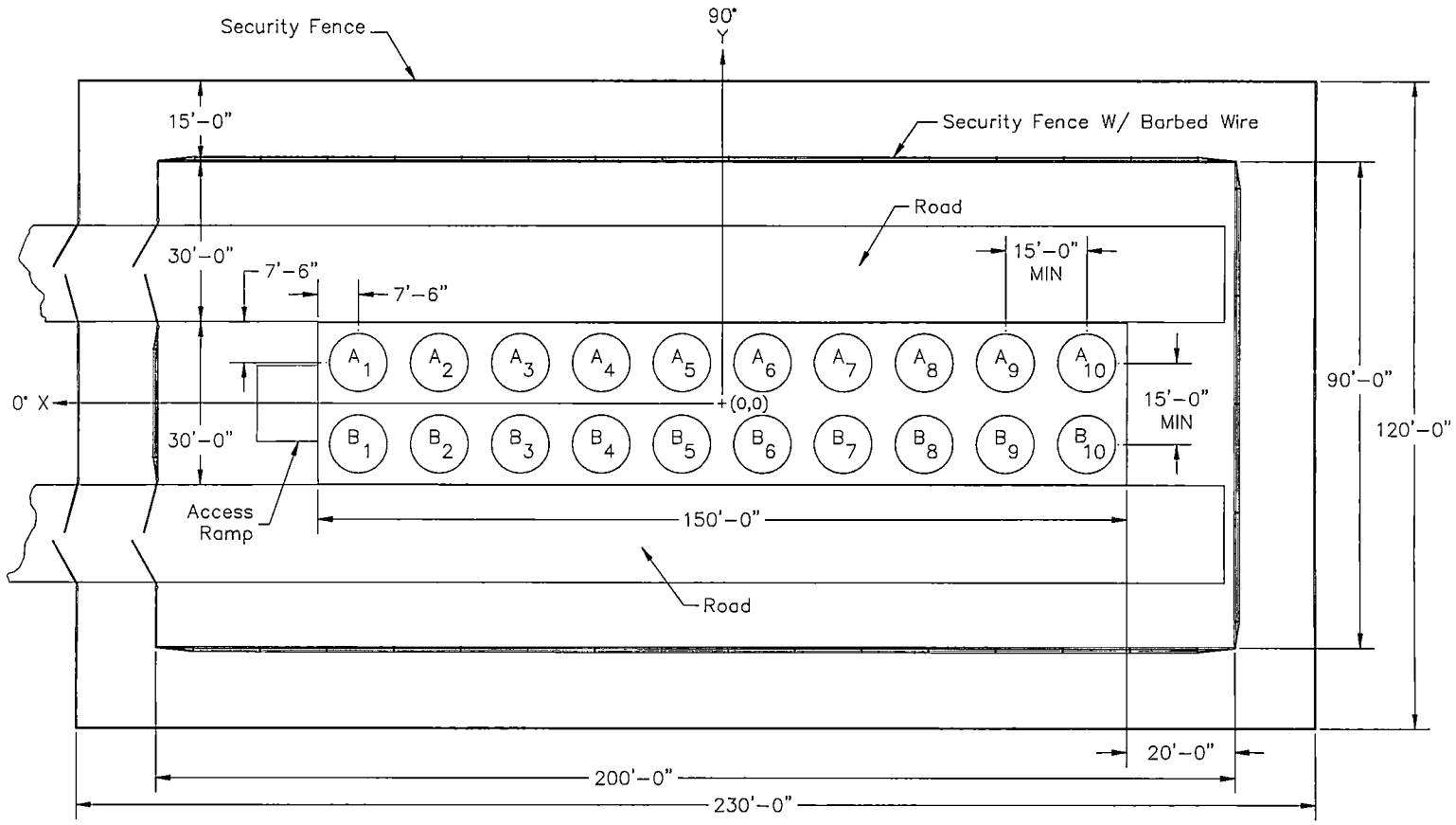
Part 71 (Transport Casks)	Part 72 (Storage System Casks and Components)
8 NAC-LWT	> 8 UMS®/MPC transfer casks
16 TRUPACT-II	2 NAC-I28 S/T metal casks
6 RH-TRU 72B	1 NAC-I26 S/T metal cask
2 NAC-STC	> 240 UMS®/MPC TSCs
	> 240 UMS®/MPC concrete casks
	8 MAGNASTOR TSCs
	8 MAGNASTOR concrete casks

1.6 Generic Concrete Cask Arrays

A typical ISFSI storage pad layout for 20 MAGNASTOR systems is provided in Figure 1.6-1. As shown in this figure, roads parallel the sides of the pad to facilitate transfer of the concrete cask from the transporter to the designated storage position on the pad. Alternately, a ramp or low-profile concrete pad may be used to allow access for a motorized or towed frame for concrete cask transfer and placement. Loaded concrete casks are placed in the vertical orientation on the pad in a linear array. Array sizes could accommodate from 1 to more than 200 casks. Figure 1.6-1 shows the minimum concrete cask spacing and representative site dimensions. Actual spacing and facility dimensions are dependent on the general site layout, access roads, site boundaries, and transfer equipment selection.

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

Figure 1.6-1 Typical ISFSI Storage Pad Layout



1.7 References

1. 10 CFR 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste and Reactor-Related Greater Than Class C Waste," Code of Federal Regulations, US Nuclear Regulatory Commission, Washington, DC.
2. NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," US Nuclear Regulatory Commission, Washington, DC, January 1997.
3. 10 CFR 71, "Packaging and Transportation of Radioactive Materials," Code of Federal Regulations, US Nuclear Regulatory Commission, Washington, DC.
4. Regulatory Guide 3.61, "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Concrete Cask," US Nuclear Regulatory Commission, Washington, DC, February 1989.
5. ISG-15, "Materials Evaluation," US Nuclear Regulatory Commission, Washington, DC, Revision 0, January 10, 2001.
6. ANSI/ANS 57.9-1992, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)," American Nuclear Society, La Grange Park, IL, May 1992.
7. ACI 318-95, "Building Code Requirements for Structural Concrete," American Concrete Institute, Farmington Hills, MI.
8. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, "Class I Components," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
9. ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, "Core Support Structures," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
10. ISG-11, "Cladding Considerations for the Transport and Storage of Spent Fuel," US Nuclear Regulatory Commission, Washington, DC, Revision 3, November 17, 2003.
11. ANSI N14.6-1993, "American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More," American National Standards Institute, Inc., Washington, DC, June 1993.
12. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standards for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
13. Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing," The American Society for Nondestructive Testing, Inc., Columbus OH, edition as invoked by the applicable ASME Code.

14. ANSI N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants," American National Standards Institute, Inc., Washington, DC.
15. ANSI N45.2.2-1978, "Packaging, Shipping, Receiving, Storage, and Handling of Items for Nuclear Power Plants," American National Standards Institute, Inc., Washington, DC.
16. ASTM C94[a], "Standard Specification for Ready-Mixed Concrete," American Society for Testing and Materials, West Conshohocken, PA.
17. ASTM C150[a], "Standard Specification for Portland Cement," American Society for Testing and Materials, West Conshohocken, PA.
18. ASTM C33[a], "Standard Specification for Concrete Aggregates," American Society for Testing and Materials, West Conshohocken, PA.
19. ASTM C637[a], "Specification for Aggregates for Radiation-Shielding Concrete," American Society for Testing and Materials, West Conshohocken, PA.
20. ASTM C494[a], "Standard Specification for Chemical Admixtures for Concrete," American Society for Testing and Materials, West Conshohocken, PA.
21. ASTM C618[a], "Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete," American Society for Testing and Materials, West Conshohocken, PA.
22. ASTM C172[a], "Standard Practice for Sampling Freshly Mixed Concrete," American Society for Testing and Materials, West Conshohocken, PA.
23. ASTM C31[a], "Method of Making and Curing Concrete Test Specimens in the Field," American Society for Testing and Materials, West Conshohocken, PA.
24. ASTM C39[a], "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," American Society for Testing and Materials, West Conshohocken, PA.

[a] Current edition of testing standards at time of fabrication/construction is to be used.

1.8 License Drawings

This section presents the list of License Drawings for MAGNASTOR.

Drawing Number	Title	Revision No.
71160-551	Fuel Tube Assembly, MAGNASTOR – 37 PWR	10NP*
71160-556	Assembly, MAGNASTOR Transfer Cask (MTC), Stainless Steel	4
71160-560	Assembly, Standard Transfer Cask, MAGNASTOR	2
71160-561	Structure, Weldment, Concrete Cask, MAGNASTOR	8
71160-562	Reinforcing Bar and Concrete Placement, Concrete Cask, MAGNASTOR	8
71160-571	Details, Neutron Absorber, Retainer, MAGNASTOR – 37 PWR	8
71160-572	Details, Neutron Absorber, Retainer, MAGNASTOR – 87 BWR	8NP*
71160-574	Basket Support Weldments, MAGNASTOR – 37 PWR	6
71160-575	Basket Assembly, MAGNASTOR – 37 PWR	11NP*
71160-581	Shell Weldment, TSC, MAGNASTOR	5
71160-584	Details, TSC, MAGNASTOR	8
71160-585	TSC Assembly, MAGNASTOR	11
71160-590	Loaded Concrete Cask, MAGNASTOR	7
71160-591	Fuel Tube Assembly, MAGNASTOR – 87 BWR	8NP*
71160-598	Basket Support Weldments, MAGNASTOR – 87 BWR	7NP*
71160-599	Basket Assembly, MAGNASTOR – 87 BWR	8NP*
71160-600	Basket Assembly, MAGNASTOR – 82 BWR	5NP*
71160-601	Damaged Fuel Can (DFC), Assembly, MAGNASTOR	0
71160-602	Damaged Fuel Can (DFC), Details, MAGNASTOR	1
71160-671	Details, Neutron Absorber, Retainer, For DF Corner Weldment, MAGNASTOR – 37 PWR	0
71160-673	Damaged Fuel Can (DFC), Spacer, MAGNASTOR	0
71160-674	DF Corner Weldment, MAGNASTOR	3NP*
71160-675	DF Basket Assembly, 37 Assembly PWR, MAGNASTOR	3NP*
71160-681	DF, Shell Weldment, TSC, MAGNASTOR	1
71160-684	Details, DF Closure Lid, MAGNASTOR	2
71160-685	DF, TSC Assembly, MAGNASTOR	5

* Proprietary drawing replaced by nonproprietary version.

Security-Related Information Figure Withheld Under 10 CFR 2.390.

R-219542

REV	CHANGE
0	INITIAL ISSUE
1	INC DWG 1A
2	INC DWG 2A
3	INC DWG 3A
4	INC DWG 4A
5	INC DWG 5A
6	INC DWG 6A
7	INC DWG 7A
8	INC DWG 7A, 7B, 7C & 7D
9	INC DWG 9A
10	INC DWG 10A

NAC INTERNATIONAL

FUEL TUBE ASSEMBLY, MAGNASTOR – 37 PWR

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
PROPOSED		9.8.12
DRAWN		9.8.12
DESIGN ENGINEER		8/21/12
REVIEWED		8/21/12
VERIFIED		8/22/12
APPROVED		8/22/12

NEXT ASSEMBLY 71160-575/675

DRAWING TYPE LICENSE

PROJECT 71160

DRAWING 551

SH 1 OF 3

REV 10NF

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

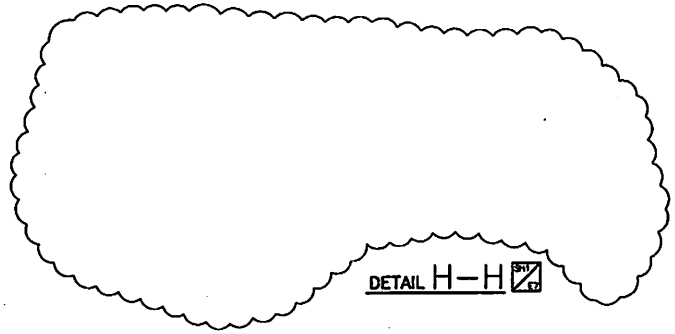
PROPRIETARY INFORMATION REMOVED

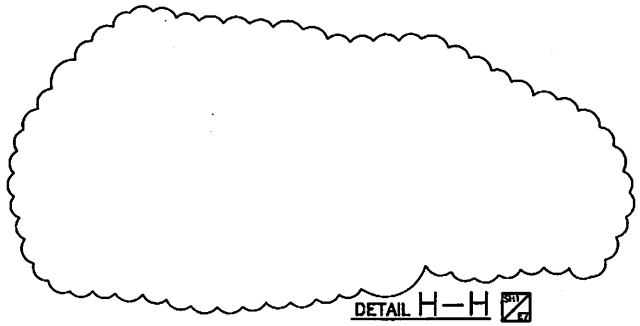
NAC INTERNATIONAL

FUEL TUBE ASSEMBLY,
MAGNASTOR – 37 PWR

PROJECT 71160		DRAWING 551	REV 0ONP
		SH 2 OF 3	

Security-Related Information Figure
Withheld Under 10 CFR 2.390.





NAC INTERNATIONAL

FUEL TUBE ASSEMBLY,
MAGNASTOR – 37 PWR

PROJECT 71160 | DRAWING 551 | REV 0.0HP | SH 3 OF 3

R-228762

REV	CHANGE
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2	INC DCR 1A, 1B, 1C
3	INC DCR 2A
4	INC DCR 3A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
TOLERANCE AND TOLERANCING SHALL BE ASME Y14.5M-94
ALL TUBULAR WEPTH CHAMFERS ARE TO BE CONSIDERED AS A 45° DEPTH OF PERFECT TANGARD.

ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO 63 $\sqrt{}$ OR BETTER
NOT ASSEMBLY N/A
DRAWING TYPE LICENSE

GROUP	NAME	DATE
PREPARED	[illegible]	6-17-15
CHECKED	[illegible]	6-17-15
PROJECT ENGINEER	[illegible]	6-18-15
DESIGN ENGINEER	[illegible]	6-17-15
APPROVED	[illegible]	6/19/15
RELEASED	[illegible]	6/19/15

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160 | DRAWING 556 | REV 4 | SH 1 OF 6 | 6-17-2015

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160 | DRAWING 556 | REV 4 | SH 2 OF 6

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160 | DRAWING 556 | REV 4 | SH 3 OF 6

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160 | DRAWING 556 | REV 4 | SH 4 OF 5

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160 | DRAWING 556 | REV 4

SH 5 OF 6

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY,
MAGNASTOR TRANSFER
CASK (MTC),
STAINLESS STEEL

PROJECT 71160

DRAWING 556 REV 4

SH 6 OF 6

R-228763

REV	CHANGE
0	INITIAL ISSUE
1	INC DCN 0A
2	INC DCN 1A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY, STANDARD TRANSFER CASK, MAGNASTOR

GROUP	NAME	DATE
PREPARED		6-17-15
CHECKED		6-17-15
PROJECT MANAGER		6-18-15
ENGINEERING		6-17-15
LICENSING		6/19/15
QA/QC		6/19/15

UNLESS OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES TO BE 125 OR BETTER

NCSI ASSEMBLY: N/A

DRAWING TYPE: LICENSE

PROJECT 71160 | DRAWING 560 | REV 2 | SH 1 OF 4

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY, STANDARD
TRANSFER CASK,
MAGNASTOR

PROJECT 71160

DRAWING 560 REV 2

SH 2 OF 4

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY, STANDARD TRANSFER CASK, MAGNASTOR

PROJECT 71160

DRAWING 560 REV 2

SH 3 OF 4

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

ASSEMBLY, STANDARD
TRANSFER CASK,
MAGNASTOR

PROJECT 71160

DRAWING 560 REV 2

SH 4 OF 4

RT226822

REV	CHANGE
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2	INC DCR 1A
3	INC DCR 4A
4	INC DCR 5A
5	INC DCR 4A & 4B
6	INC DCR 4A, 5B, 5C, 5D
7	INC DCR 6A, 6B
8	INC DCR 7A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY	ASSY	ASSY	ASSY	ASSY	ASSY	PARK	ASSY	ASSY	ASSY
QUANTITY											

UNLESS OTHERWISE STATED
DIMENSIONS AND TOLERANCES SHALL BE PER ASME Y14.5M-94
ALL THREAD SIZES ON CALLOUTS ARE NO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO BE 125 RA OR BETTER
NEXT ASSEMBLY: 71160-562
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARED	[illegible]	11/14/14
CHECKED	[illegible]	11-14-14
PROJECT MANAGER	[illegible]	11/20/14
DISCIPLINE	[illegible]	11-14-14
LEAD PROJ	[illegible]	11/20/14
SUPERV	[illegible]	11-21-14

NAC INTERNATIONAL

STRUCTURE, WELDMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160 | DRAWING 561 | REV 8 | SH 1 OF 5 | A SIZE 10x30-2015

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

STRUCTURE, WELDMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160

DRAWING 561

REV B

SH 2 OF 5

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

STRUCTURE, WELDMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160

DRAWING 561 REV 8

SH 3 OF 5

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

STRUCTURE, WELDMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160

DRAWING 561

REV 8

SHEET 4 OF 5

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

STRUCTURE, WELDMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160

DRAWING 561

REV 8

SH 5 OF 5

R-221955

REV	CHANGE
0	INITIAL ISSUE
1	INC DCN VA
2	INC DCN VA
3	INC DCN VA
4	INC DCN VA
5	INC DCN VA
6	INC DCN VA SH. 5&7
7	INC DCN VA
8	INC DCN VA

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY	ASSY	ASSY	ASSY
QUANTITY					

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
PREPARED		4/10/13
REVIEWED		4-10-13
CHECKED		4/10/13
APPROVED		4-10-13
APPROVED		4/11/13
APPROVED		4/11/13

ALL DIMENSIONS ARE IN INCHES

FIRST ASSEMBLY 71160-590

DRAWING TYPE LICENSE

NAC INTERNATIONAL

REINFORCING BAR AND CONCRETE PLACEMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160 | DRAWING 562 | REV 8 | SH 1 OF 2

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

REINFORCING BAR AND CONCRETE PLACEMENT, CONCRETE CASK, MAGNASTOR

PROJECT 71160 | DRAWING 562 | REV 8

SHEET 2 OF 2

R-219526

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 0A
2	INC. DCR 1A
3	INC. DCR 2A
4	INC. DCR 3A
5	INC. DCR 4A
6	INC. DCR 5A
7	INC. DCR 6A
8	INC. DCR 7A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONS AND TOLERANCES SHALL BE PER ASME Y14.5M-94.
ALL THREAD DEPTH CALLOUTS ARE TO BE DIMENSIONED AS 1 DIA. DEPTH OF PERFECT THREADS.
ALL DIMENSIONS ARE IN INCHES.
MACHINED SURFACES TO BE 125 OR BETTER
NEXT ASSEMBLY: 71160-551
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PROJECT	Lynda Zgoncena	4.02.12
DESIGN	[illegible]	4/13/12
PROJECT ENGINEER	[illegible]	4/19/12
ENGINEERING	[illegible]	5/7/12
LICENSING	Amy L. Pattle	5/22/12
QA/QP	Roger Bass	5/28/12

NAC INTERNATIONAL

DETAILS,
NEUTRON ABSORBER, RETAINER,
MAGNASTOR - 37 PWR

PROJECT: 71160
DRAWING: 571
REV: 8
SH 1 OF 1

K-219479

REV	CHANGE
0	INITIAL ISSUE
1	ISSUE ECN 7A
2	ISSUE ECN 7A
3	ISSUE ECN 7A
4	ISSUE ECN 7A
5	ISSUE ECN 7A
6	ISSUE ECN 7A
7	ISSUE ECN 7A
8	ISSUE ECN 7A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

: PROPRIETARY INFORMATION REMOVED

NAC INTERNATIONAL

UNLESS OTHERWISE STATED DIMENSIONS FOR MACHINED PARTS TO BE FOR JOINT VALIDATION

ALL SHADED SURFACE FINISHES TO BE 125 OR SMOOTHER AS A MIN. EXCEPT OF PERFECT ENGINE.

ALL DIMENSIONS ARE IN INCHES

SHADED SURFACE TO BE 125 OR SMOOTHER

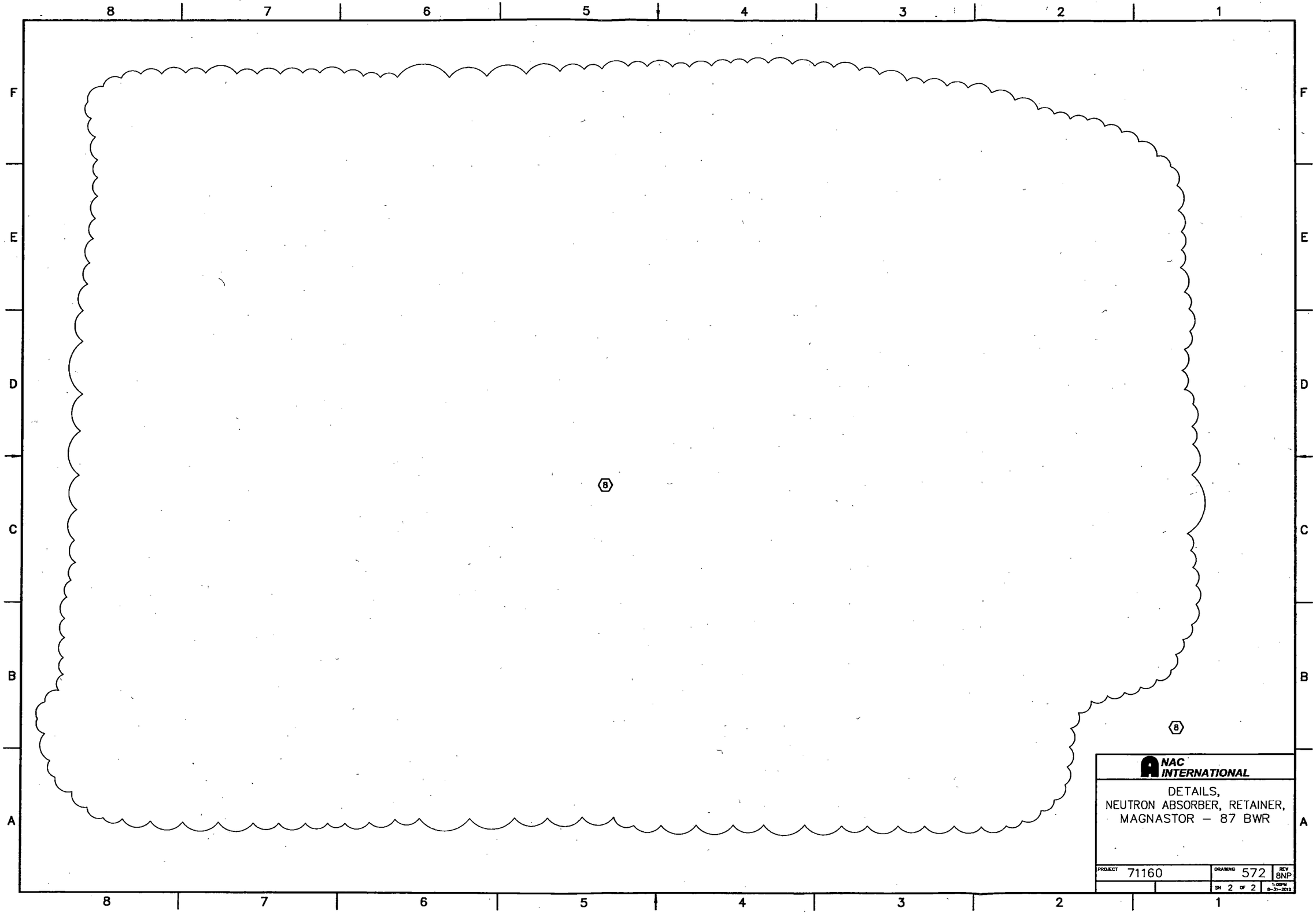
NEXT ASSEMBLY: 71160-591

DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARED	[illegible]	9/6/12
CHECKED	[illegible]	9-6-12
ENGINEERING	[illegible]	9/6/12
ENGINEERING	[illegible]	9/6/12
CHECKED	[illegible]	9/7/12
APPROVED	[illegible]	9-10-12

DETAILS,
NEUTRON ABSORBER, RETAINER,
MAGNASTOR – 87 BWR

PROJECT 71160 | DRAWING 572 | REV 0 | SHEET 1 OF 3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NAC INTERNATIONAL
DETAILS,
NEUTRON ABSORBER, RETAINER,
MAGNASTOR – 87 BWR
PROJECT 71160
DRAWING 572
REV 8NP
SH 2 OF 2
1:00PM 8-31-2012

R-219529

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A & 3B
5	INC DCR 4A
6	INC DCR 5A, 5B

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET SUPPORT WELDMENTS, MAGNASTOR - 37 PWR

	GROUP	NAME	DATE
	PREPARED		3.09.12
	CHECKED		4-13-12
	PROJECT ENGINEER		4/18/12
	MANAGER		5/10/12
	VERIFIER		5/23/12
	QA/QC		5/28/12

UNLESS OTHERWISE STATED

NEXT ASSEMBLY 71160-575

DRAWING TYPE LICENSE

PROJECT 71160

DRAWING 574 REV 6

SH 1 OF 2

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET SUPPORT WELDMENTS, MAGNASTOR – 37 PWR

71160 | 574 | 6

2 of 2

R-219545

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 9A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A
6	INC DCR 5A
7	INC DCR 6A
8	INC DCR 7A
9	INC DCR 8A, 8B, 8C
10	INC DCR 9A
11	INC DCR 10A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

(11) : PROPRIETARY INFORMATION REMOVED (11)

NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR – 37 PWR

UNLESS OTHERWISE STATED

	GROUP	NAME	DATE
			8-10-12
			8-10-12
			8/12/12
			8/10/12
			8/10/12
			8/20/12

NEXT ASSEMBLY 71160-585

DRAWING TYPE LICENSE

PROJECT 71160

DRAWING 575

REV 11NP

SH 1 OF 4

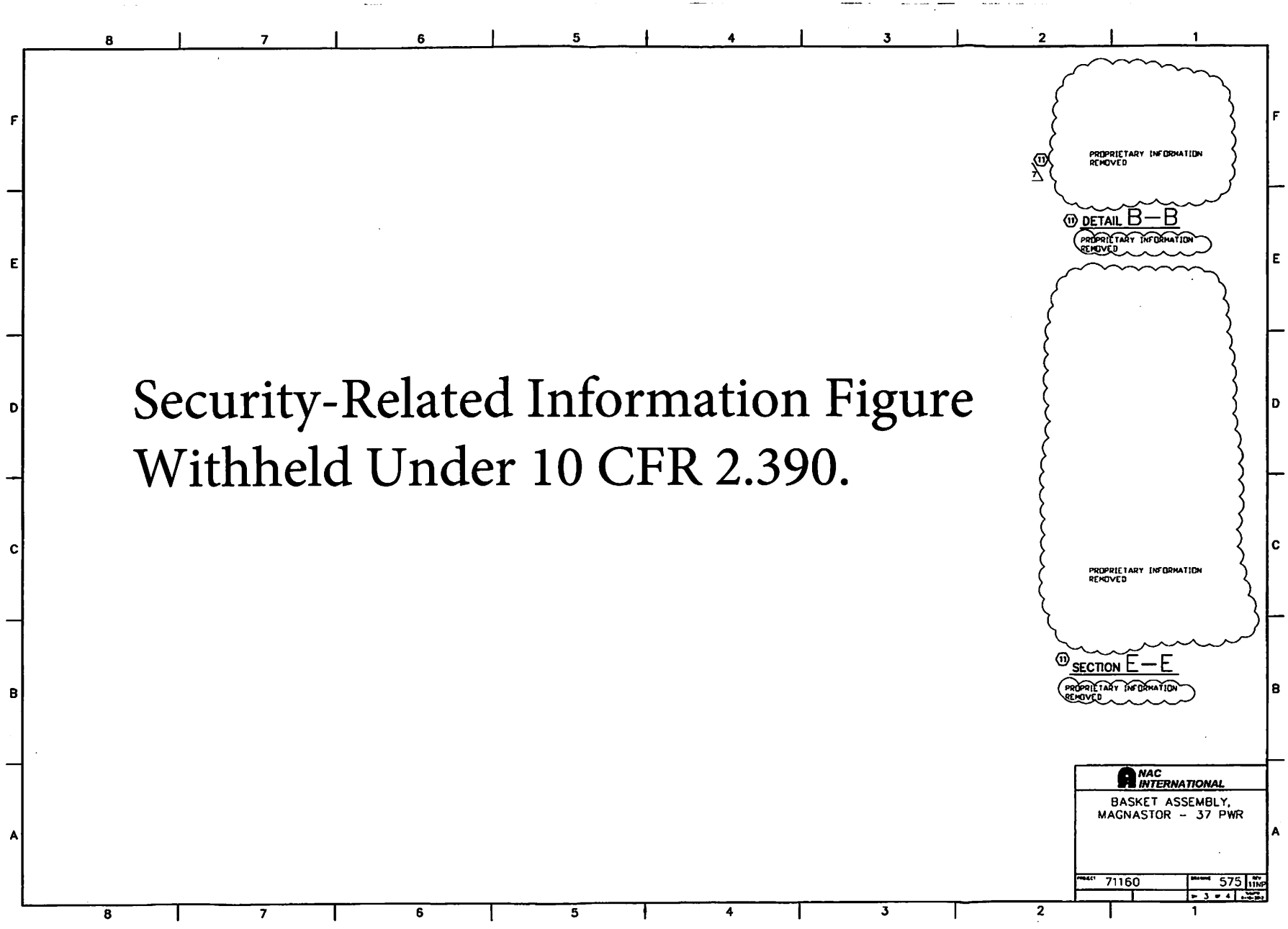
Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR - 37 PWR

PROJECT 71160 | DRAWING 575 | REV 11NP | SH. 2 OF 4

Security-Related Information Figure Withheld Under 10 CFR 2.390.



Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR - 37 PWR

PROJECT 71160		DRAWING 575	REV 11NP
		Sh 4 of 4	

R-22876.4

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY	ASSY
COUNTRY			

UNLESS OTHERWISE STATED
TOLERANCES FOR ESTIMATING BASIS
AS PER ASME Y14.5M-94
ALL THREAD DEPTH CALCULATE ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS.
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO BE 125 RMS REFER
NEXT ASSEMBLY: 71160-585
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARED	[illegible]	6-17-15
DESIGN	[illegible]	6-17-15
CHANGE MANAGER	[illegible]	6-17-15
ENGINEERING	[illegible]	6-17-15
LICENSING	[illegible]	6/19/15
QA/QC	Craig V. Bass	6/19/15

NAC INTERNATIONAL

SHELL WELDMENT,
TSC,
MAGNASTOR

PROJECT 71160 | DRAWING 581 | REV 5 | SH 1 OF 2

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

SHELL WELDMENT,
TSC,
MAGNASTOR

PROJECT 71160

DRAWING 581

REV 5

SH 2 OF 2

R-219954

REV	CHANGE
0	INITIAL ISSUE
1	INC DCN 0A
2	INC DCN 1A
3	INC DCN 2A
4	INC DCN 3A, 3B
5	INC DCN 4A, 4B
6	INC DCN 5A
7	INC DCN 6A
8	INC DCN 7A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DETAILS, TSC, MAGNASTOR

	GROUP	NAME	DATE
UNLESS OTHERWISE STATED			
			10/2/12
			10-3-12
			10/3/12
			10/3/12
			10/3/12
			10/5/12

NEXT ASSY: 71160-585

DRAWING TYPE: LICENSE

PROJECT 71160

DRAWING 584 REV 8

SH 1 OF 2

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DETAILS,
TSC,
MAGNASTOR

PROJECT 71160 | DRAWING 584 | REV B

SH 2 OF 2

R-226559

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A
6	INC DCR 5A
7	INC DCR 6A
8	INC DCR 7A, 7B
9	INC DCR 8A
10	INC DCR 9A
11	INC DCR 10A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

GROUP	NAME	DATE
PREPARED		10/29/14
CHECKED		10/29/14
STRUCTURAL		10-29-14
MANUFACTURING		10-29-14
MATERIALS		10/29/14
SAFETY		10-30-14

UNLESS OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES TO BE 125 RMS OR BETTER

NOT1 NEXTONIX 71160-590/500

DRAWING TYPE LICENSE

PROJECT 71160 | DRAWING 585 | REV 11 | SH 1 of 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

PROJECT 71160

DRAWING 585

REV 11

SHEET 2 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

PROJECT 71160

DRAWING 585

REV 11

SH 3 OF 3

R-219151

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A
6	INC DCR 5A
7	INC DCR 6A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

LOADED CONCRETE CASK, MAGNASTOR

UNLESS OTHERWISE STATED

ALL TAPPED REPAIR CHAMFER ARE TO BE CONFORMED AS A MIN. REPAIR OF POINTED SHAPE.

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES TO BE 125 OR BETTER

NOT ANNEALED N/A

DRAWING TYPE LICENSE

GROUP	NAME	DATE
DRAWN		7/16/12
CHECKED		7/30/12
STRESS CHECKED		8/8/12
APPROVED		8/7/12
APPROVED		8/8/12
QA		8/10/12

PROJECT 71160

DRAWING 590 REV 7

SH 1 OF 2

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

LOADED CONCRETE CASK, MAGNASTOR

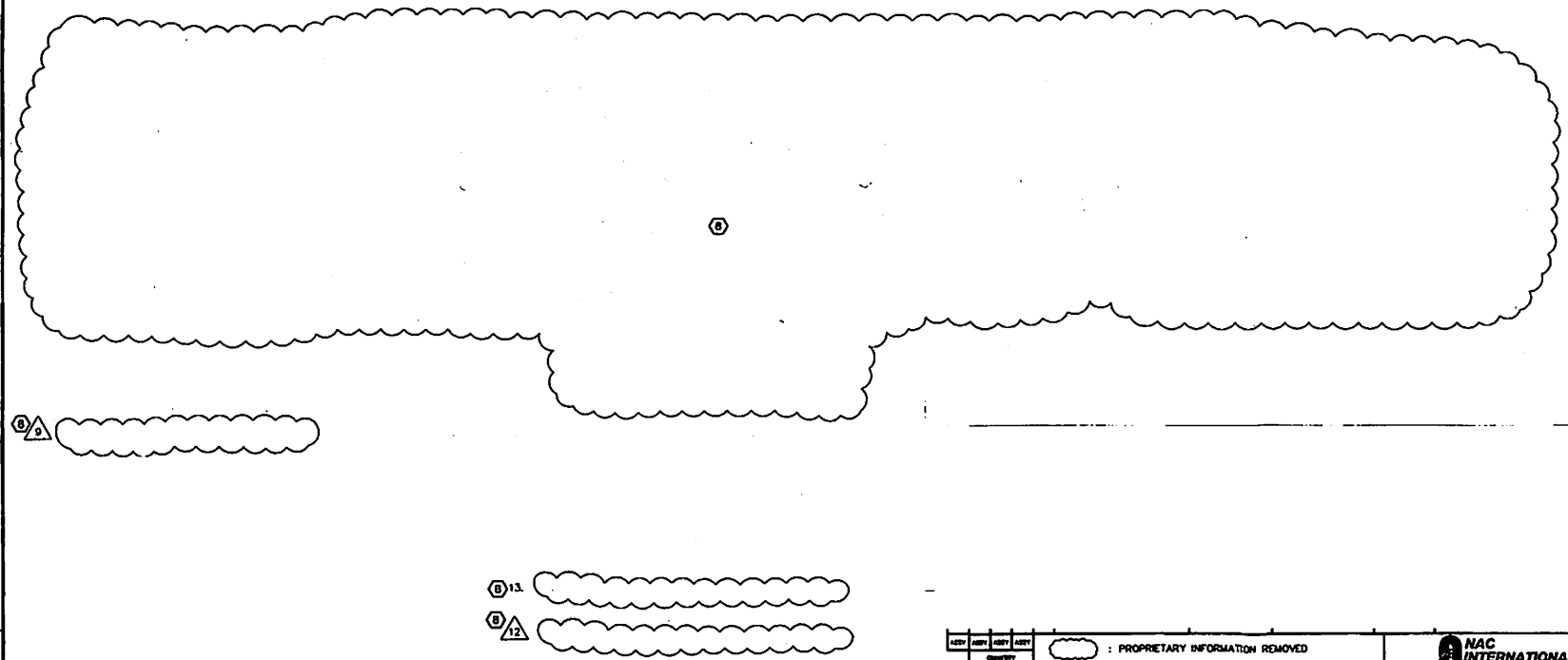
PROJECT 71160

DRAWING 590 REV 7

SH 2 OF 2

R-221317

Security-Related Information Figure Withheld Under 10 CFR 2.390.



REV	CHANGE
0	INITIAL ISSUE
1	INC DOC 1A
2	INC DOC 1A
3	INC DOC 1A
4	INC DOC 3A
5	INC DOC 4A
6	INC DOC 5A
7NP	INC DOC 6NPA
8NP	INC DOC 7NPA

: PROPRIETARY INFORMATION REMOVED

NAC INTERNATIONAL

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
PROJECT		2/5/13
ENGINEERING		2-6-13
PROJECT ENGINEER		2/11/13
QA ENGINEERING		2/6/13
MANUFACTURING		2/8/13
QUALITY		2.12.13

NEXT ASSEMBLY: 71160-599/600

DRAWING TYPE: LICENSE

FUEL TUBE ASSEMBLY, MAGNASTOR – 87 BWR

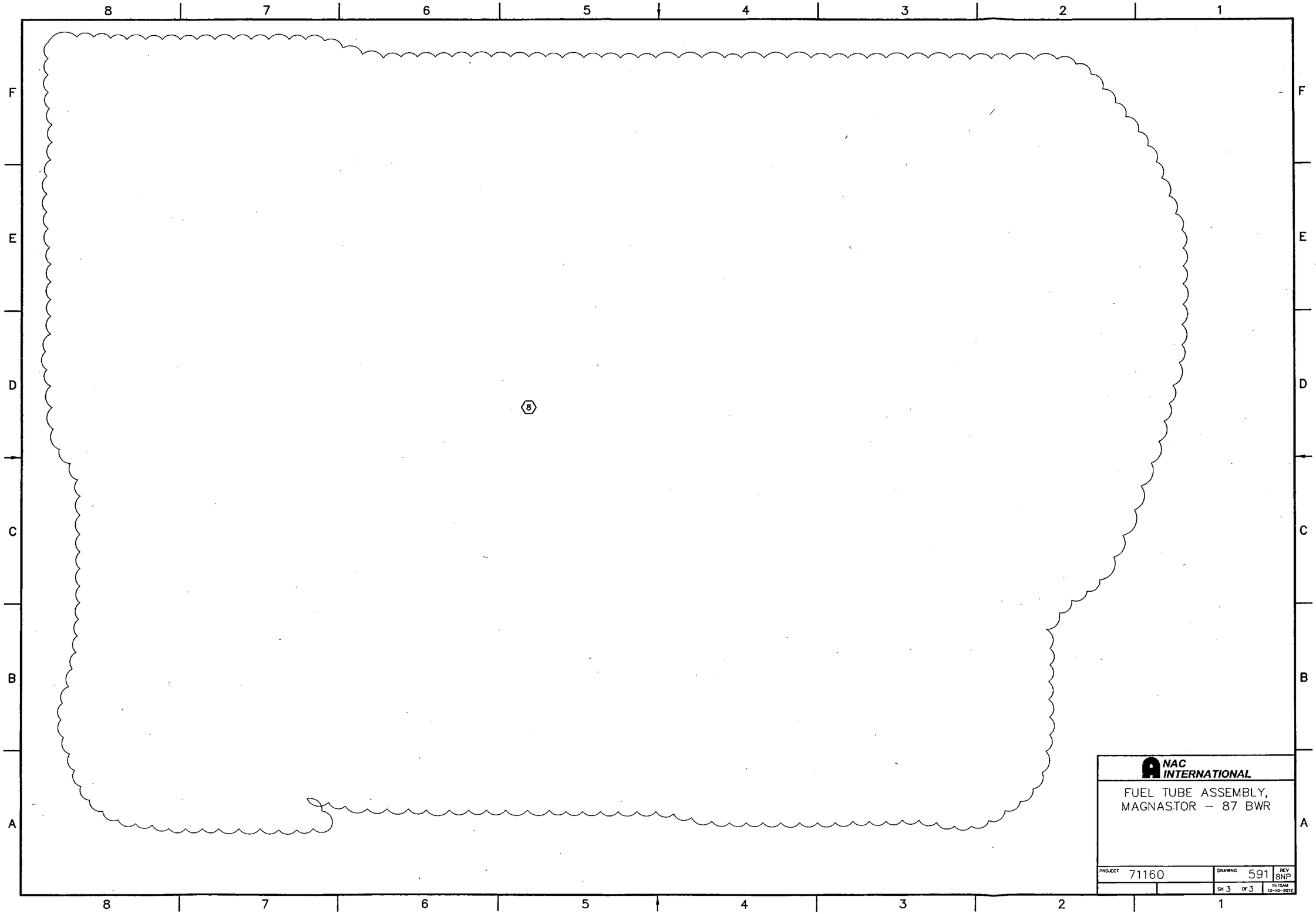
PROJECT 71160 | DRAWING 591 | REV 8NP | SH 1 OF 3

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

FUEL TUBE ASSEMBLY,
MAGNASTOR – 87 BWR

PROJECT 71160 | DRAWING 591 | REV BNP | SHEET 2 OF 3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NAC INTERNATIONAL
FUEL TUBE ASSEMBLY,
MAGNASTOR – 87 BWR
PROJECT 71160
DRAWING 591
REV 8NP
SH 3 OF 3
11:15AM 10-10-2012

R-221319

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5NP	INC DCR 4A
6NP	INC DCR 5NPA
7NP	INC DCR 6NPA

Security-Related Information Figure Withheld Under 10 CFR 2.390.

7

: PROPRIETARY INFORMATION REMOVED

NAC INTERNATIONAL

BASKET SUPPORT WELDMENTS, MAGNASTOR – 87 BWR

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PROPERTY		1/22/13
	DESIGN		2-6-13
	DRAWN		2/11/13
	CHECKED		2/6/13
	VERIFIED		2/8/13
	APPROVED		2.12.13

ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO BE 125 RMS OR BETTER
NCIT ASSOCIATE: 71160-599/600
DRAWING TYPE: LICENSE

PROJECT 71160 | DRAWING 598 | REV 7NP | SH 1 OF 3

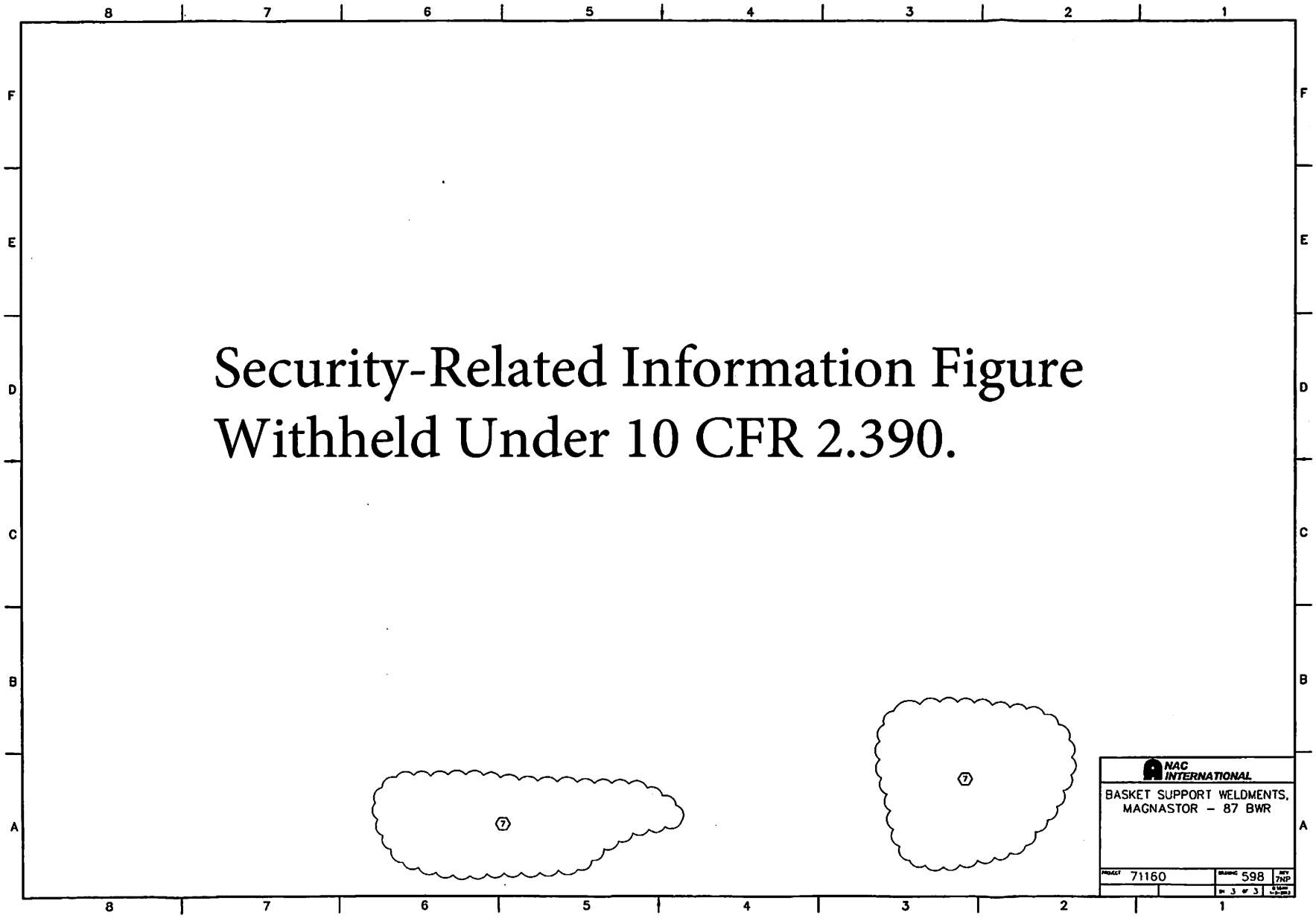
Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET SUPPORT WELDMENTS, MAGNASTOR – 87 BWR

PROJECT 71160	DRAWING 598	REV 7NP
	SH. 2 of 3	

Security-Related Information Figure Withheld Under 10 CFR 2.390.



R-221321

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 1AA
2	INC. DCR 1A
3	INC. DCR 2A
4	INC. DCR 3A
5	INC. DCR 4A
6NP	INC. DCR 5A
7NP	INC. DCR 6NPA
8NP	INC. DCR 7NPA

Security-Related Information Figure Withheld Under 10 CFR 2.390.

: PROPRIETARY INFORMATION REMOVED

NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR – 87 BWR

GROUP	NAME	DATE
PROJECT	Matt	1/22/13
DESIGN		2-6-13
PROJECT ENGINEER		2/11/13
ANALYSIS		2/6/13
LICENSING		2/8/13
QA/QC		2.13.13

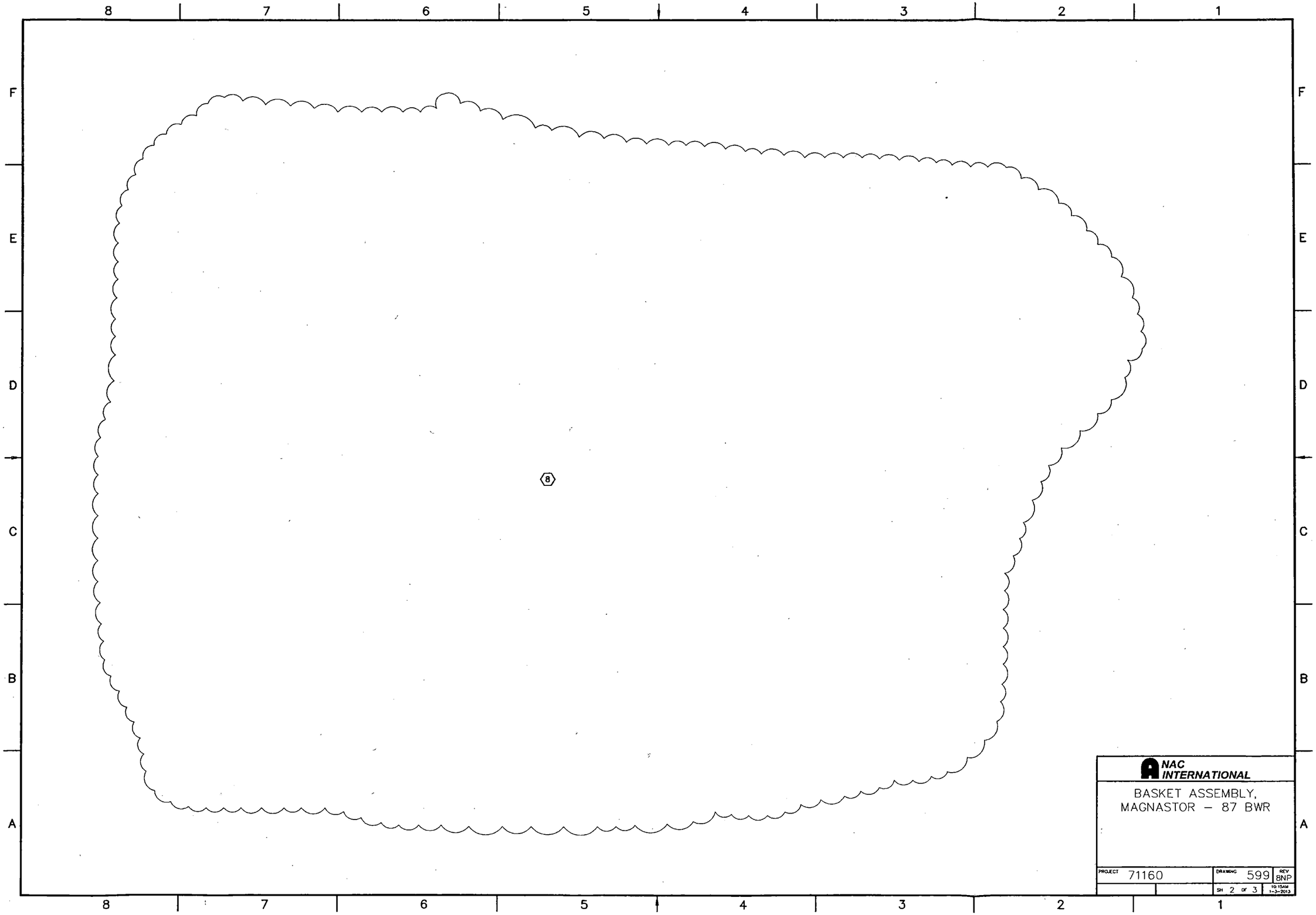
UNLESS OTHERWISE STATED DIMENSIONS AND TOLERANCES SHALL BE PER ASME Y14.5M-94. ALL BOLTED DEPTH CALLOUTS ARE TO BE CONSIDERED AS A DIA. DEPTH OF PERFECT THREADS.

ALL DIMENSIONS ARE IN INCHES. MACHINED SURFACES TO BE 125 OR BETTER.

NEXT ASSEMBLY: 71160-585

DRAWING TYPE: LICENSE

PROJECT: 71160 | DRAWING: 599 | REV: 6NP | SH: 1 OF 3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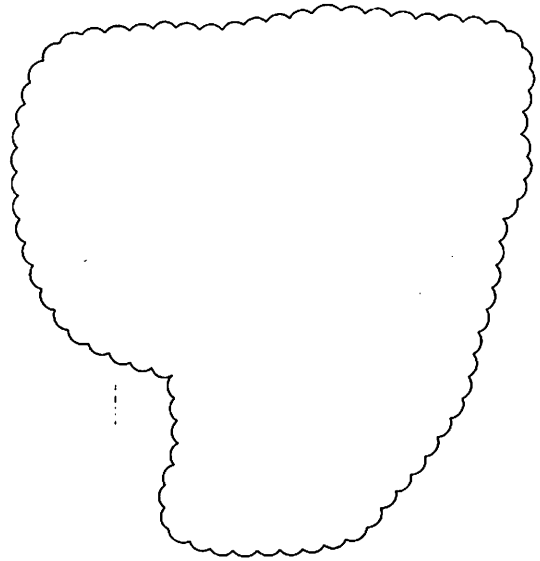
NAC INTERNATIONAL
BASKET ASSEMBLY,
MAGNASTOR – 87 BWR
PROJECT 71160
DRAWING 599
REV. 8NP
SH 2 OF 3
10:15AM 1-3-2013



Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET ASSEMBLY,
MAGNASTOR - 87 BWR

PROJECT 71160 | DRAWING 599 | REV 0 | SHEET 3 OF 3

R-221323

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4NP	INC DCR 3A
5NP	INC DCR 3NPA

Security-Related Information Figure Withheld Under 10 CFR 2.390.

: PROPRIETARY INFORMATION REMOVED

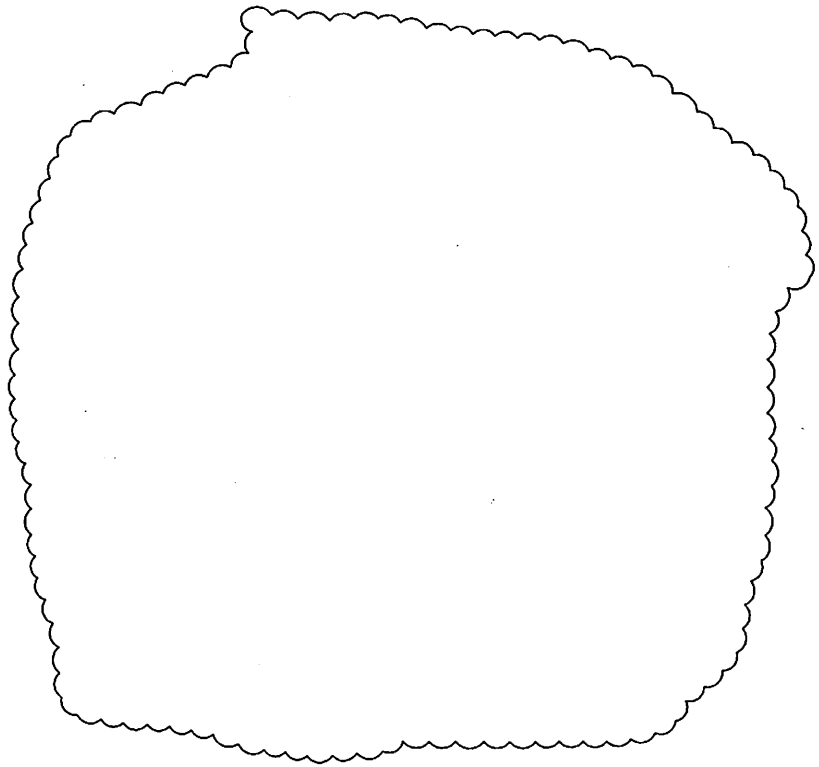
NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR – 82 BWR

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	APPROVED		1/22/13
	CHECKED		2-6-13
	PROJECT MANAGER		2/11/13
	ENGINEERING		2/6/13
	APPROVED		2/8/13
	DRAWN		2.18.13

ALL DIMENSIONS ARE IN INCHES
DIMENSIONS SURVEYED TO BE 0/64 BETWEEN
NEXT ASSEMBLY: 71160-585
DRAWING TYPE: LICENSE

PROJECT: 71160 | DRAWING: 600 | REV: 5NP | SH 1 OF 3



Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET ASSEMBLY,
MAGNASTOR - 82 BWR

PROJECT 71160		DRAWING 600	REV SNP
		SH 2 OF 3	

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

BASKET ASSEMBLY, MAGNASTOR – 82 BWR

PROJECT 71160

DRAWING 600

SHEET 3 OF 3

R-211771

REV	CHANGE
0	INITIAL ISSUE

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DAMAGED FUEL CAN (DFC), ASSEMBLY, MAGNASTOR

GROUP	NAME	DATE
PROPOSED		12.16.09
		12-16-09
		3-24-10
		3/24/10
		3/24/10
		3/25/10

LIMITED OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

NEXT ASSEMBLY: N/A

DRAWING TYPE: LICENSE

PROJECT 71160

DRAWING 601 REV 0

SH 1 OF 1

R- 220765

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

ASSY	ASSY	ASSY	ASSY
QUANTITY			

UNLESS OTHERWISE STATED
TOLERANCE AND TRADEMARK BASIC
BE PER ASME Y14.5M-94
ALL TRIAD SUPPLY CHAINED ARE TO BE CONSIDERED AS A BIG SUPPLY OF PERFECT DIAGRAM.

ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO BE 125 OR BETTER
NEXT ASSEMBLY 71160-601
DRAWING TYPE LICENSE

GROUP	NAME	DATE
PREPARED	[illegible]	5-17-15
CHECKED	[illegible]	6-17-15
PROJECT ENGINEER	[illegible]	6-18-15
ENGINEERING	[illegible]	6-17-15
QUALITY	[illegible]	6/19/15
COMPANY	Ray W. Bass	6/19/15

NAC INTERNATIONAL

DAMAGED FUEL CAN (DFC), DETAILS, MAGNASTOR

PROJECT 71160 | DRAWING 602 | REV 1 | SH 1 OF 2

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DAMAGED FUEL CAN (DFC), DETAILS, MAGNASTOR

PROJECT 71160

DRAWING 602 REV 1

SHEET 2 OF 2

R-212296

REV	CHANGE
0	INITIAL ISSUE

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DETAILS, NEUTRON ABSORBER, RETAINER, FOR DF CORNER WELDMENT, MAGNASTOR – 37 PWR.

PROJECT	71160	DRAWING 671 REV 0
		SH 1 OF 1

UNLESS OTHERWISE STATED DIMENSIONS AND TOLERANCES SHALL BE PER ASME Y14.5M-94

ALL TRIANGLE SHAPE CALLOUTS ARE TO BE CONSIDERED AS A SEL. APPR. OF PERFECT TRIANGLE

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES 125 RMS OR BETTER

NEXT ASSEMBLY 71160-674

DRAWING TYPE LICENSE

GROUP	NAME	DATE
DRAWN	[illegible]	7.19.10
CHECKED	[illegible]	7-19-10
ENGINEERING	[illegible]	7-19-10
MANUFACTURING	[illegible]	7/19/10
APPROVED	[illegible]	7/19/10
QA	[illegible]	7/20/10

R-216038

REV	CHANGE
0	INITIAL ISSUE
1	TRC DOC 5170A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

		2	1	PLATE A	304 ST. STL.	ASME SA240	PLATE
97	98	99	PCN	NAME	MATERIAL	SPEC	DRAWING No. / DESCRIPTION
ASSY	ASSY	ASSY					
QUANTITY							

NAC INTERNATIONAL

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
PREPARED		9/27/11
CHECKED		9-27-11
PROJECT MANAGER		9/27/11
ENGINEERING		9/27/11
LICENSING		9/28/11
QUALITY		9/29/11

71160-685

LICENSE

DAMAGED FUEL CAN (DFC), SPACER, MAGNASTOR

PROJECT 71160 | DRAWING 673 | REV 1

Sh 1 OF 1 | 9/27/2011

R-219940

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PROPRIETARY INFORMATION REMOVED

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VIEW A-A

PROPRIETARY INFORMATION REMOVED

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NOTE:

1. PROPRIETARY INFORMATION REMOVED

REV	CHANGE
ORIG	INITIAL ISSUE
1ASP	INC DCN 1APA
2ASP	INC DCN 1APA
3ASP	INC DCN 2APA

: PROPRIETARY INFORMATION REMOVED

NAC INTERNATIONAL

DF CORNER WELDMENT, MAGNASTOR

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	DRAWER		9/25/12
	CHECKER		9-25-12
	PROJECT MANAGER		10/1/12
	ENGINEERING		10/1/12
	LICENSING		10/1/12
	QUALITY		10/3/12

MATERIAL: 71160-675

LICENSE

PROJECT 71160 DRAWING 674 REV ORIGIN

SH 1 OF 3 9/25/2012

PROPRIETARY INFORMATION REMOVED

SH1/F6 SECTION D-D

PROPRIETARY INFORMATION REMOVED

SH1/F4 SECTION F-F

PROPRIETARY INFORMATION REMOVED

SH1/F1 SECTION H-H

PROPRIETARY INFORMATION REMOVED

DETAIL E-E

PROPRIETARY INFORMATION REMOVED

DETAIL G-G

PROPRIETARY INFORMATION REMOVED

DETAIL K-K

PROPRIETARY INFORMATION REMOVED

DETAIL K-K

NAC INTERNATIONAL

DF CORNER WELDMENT, MAGNASTOR

PROJECT 71160		DRAWING 674	REV 3NP
		SH 2 OF 3	9/19/2012

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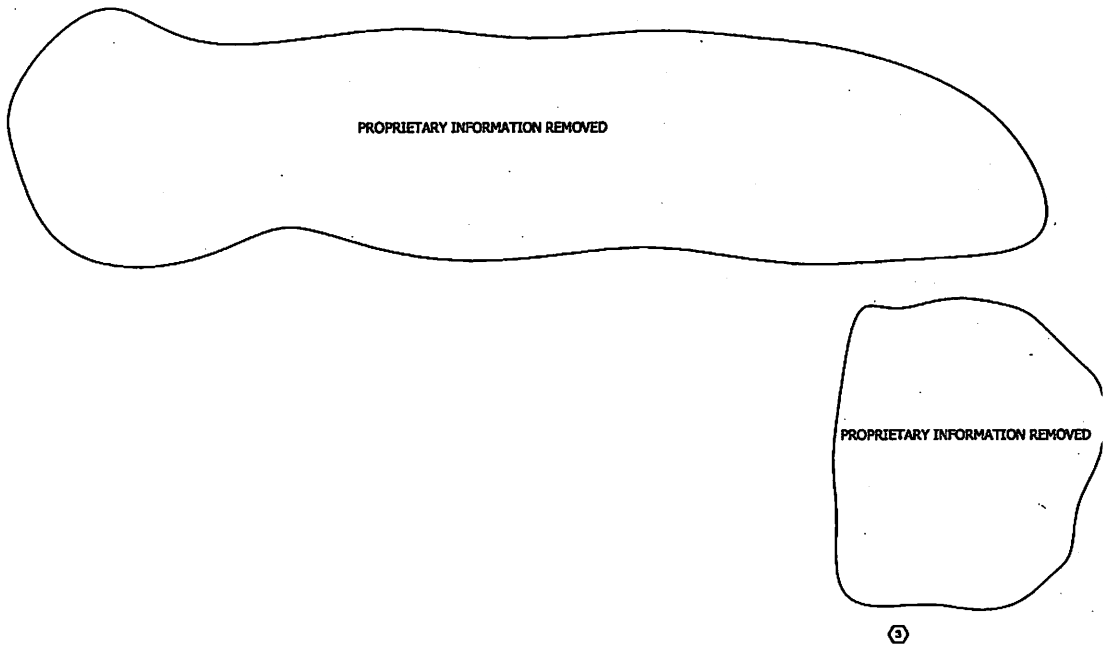

NAC INTERNATIONAL

DF CORNER WELDMENT, MAGNASTOR

PROJECT 71160

DRAWING 674

SH 3 OF 3

R-219847

REV	CHANGE
ORIG	INITIAL ISSUE
1/NP	INC DCR 0004
2/NP	INC DCR 1164
3/NP	INC DCR 1484

Security-Related Information Figure Withheld Under 10 CFR 2.390.

REV	REV	REV
QUANTITY		

PROPRIETARY INFORMATION REMOVED (3)

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GROUP	NAME	DATE
PREPARED	[illegible]	8-27-12
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PROJECT MANAGER	[illegible]	9/4/12
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LICENSING	[illegible]	9/30/12
QUALITY	[illegible]	9/10/12

HEAT ASSEMBLY: 71160-625

DRAWING TYPE: LICENSE

NAC INTERNATIONAL

DF BASKET ASSEMBLY, 37 ASSEMBLY PWR MAGNASTOR

FACILITY 71160 | DRAWING 675 | REV 3/NP | SH 1 OF 5 | 07/10/2012

Security-Related Information Figure Withheld Under 10 CFR 2.390.

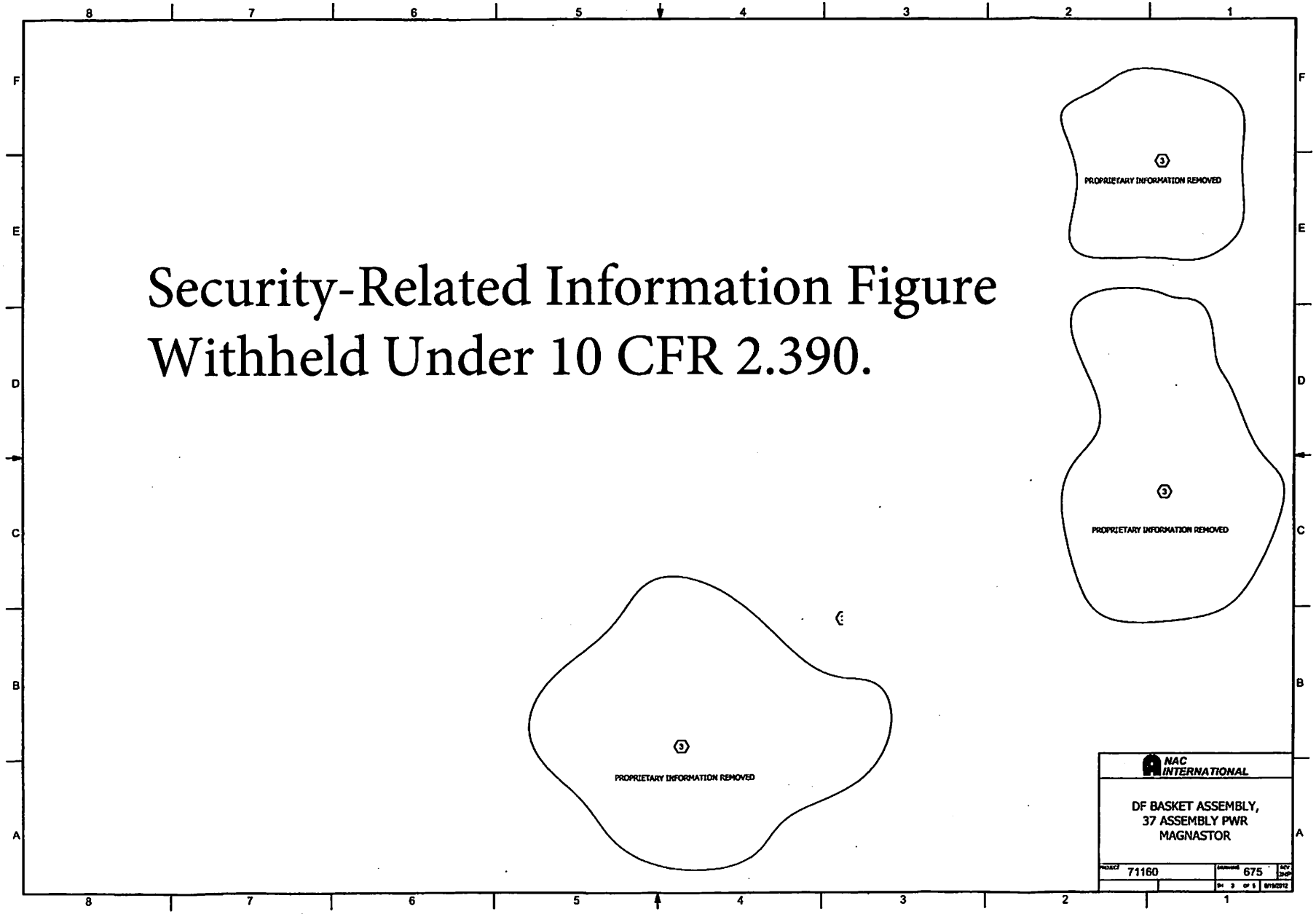
NAC INTERNATIONAL

DF BASKET ASSEMBLY,
37 ASSEMBLY PWR
MAGNASTOR

PROJECT 71160 | DRAWING 675 | REV 3NP

SH 2 OF 5 | 8/19/2012

Security-Related Information Figure Withheld Under 10 CFR 2.390.



Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF BASKET ASSEMBLY, 37 ASSEMBLY PWR MAGNASTOR

PROJECT 71160

DRAWING 675

REV

SH 4 OF 5

07/13/2012

Security-Related Information Figure
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NAC INTERNATIONAL

DF BASKET ASSEMBLY,
37 ASSEMBLY PWR
MAGNASTOR

PROJECT 71160 | DRAWING 675 | REV SHEET | SH 5 OF 5 | 6/18/2012

R-228766

REV	CHANGE
0	INITIAL ISSUE
1	NRC DCR 0A

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NAC INTERNATIONAL

DF, SHELL WELDMENT, TSC, MAGNASTOR

	NAME	DATE
DRAWN		6-17-15
CHECKED		6-17-15
PROJECT ENGINEER		6-18-15
APPROVED		6-17-15
CUSTOMER		6/18/15
QA/QC		6/18/15

UNLESS OTHERWISE STATED FABRICATION AND TOLERANCING SHALL BE PER ASME Y14.5M-94

ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS.

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES TO 125 μin OR BETTER

NEXT ASSEMBLY: 71160-685

DRAWING TYPE: LICENSE

PROJECT: 71160

DRAWING: 681 REV 1

SH 1 OF 2

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF, SHELL WELDMENT,
TSC,
MAGNASTOR

PROJECT 71160	DRAWING 681	REV 1
	SH 2 OF 2	

R-213604

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 0A
2	INC. DCR 1A

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DETAILS, DF CLOSURE LID, MAGNASTOR

GROUP	NAME	DATE
		12/15/10
		12/15/10
		12/19/10
		12/20/10
		12/17/10
		12/20/10

UNLESS OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

MODEL NUMBER 71160-685

DRAWING TYPE LICENSE

PROJECT 71160

DRAWING 684 REV 2

SH 1 OF 2

Security-Related Information Figure
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NAC INTERNATIONAL

DETAILS, DF
CLOSURE LID,
MAGNASTOR

PROJECT 71160

DRAWING 684 REV 2

SH 2 OF 2

R-226600

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A

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ASSY	ASSY	ASSY	ASSY	ASSY	ASSY	ASSY
				QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONS AND TOLERANCES SHALL BE PER ASME Y14.5M-94
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN DEPTH OF PERFECT THREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES TO BE 125 RMS OR BETTER
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DRAWING TYPE: LICENSE

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CHECKED	[illegible]	10-30-14
PROJECT ENGINEER	[illegible]	11-3-14
ENGINEERING	[illegible]	10-30-14
LICENSING	[illegible]	10/30/14
DRAWN	Ray W. Cass	11/4/14

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160 | DRAWING 685 | REV 5 | SH 1 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160 | DRAWING 685 | REV 3

SH 2 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160

DRAWING 685 REV 3

SH 3 OF 3

Chapter 2
Principal Design Criteria

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2 PRINCIPAL DESIGN CRITERIA

MAGNASTOR® is a canister-based spent fuel dry storage cask system designed in accordance with the requirements of 10 CFR 72 [10], Subpart L, Approval of Spent Fuel Storage Casks. It is designed to store a variety of undamaged and damaged PWR fuel assemblies and undamaged BWR fuel assemblies. This chapter presents the principal design criteria for the MAGNASTOR components.

2.1 MAGNASTOR System Design Criteria

The design of MAGNASTOR ensures that the stored spent fuel is maintained subcritical in an inert environment, within allowable temperature limits, and is retrievable. The acceptance testing and maintenance program specified in Chapter 10 ensures that the system is, and remains, suitable for the intended purpose. The MAGNASTOR design criteria appear in Table 2.1-1.

Approved alternatives to the ASME Code for the design procurement, fabrication, inspection, and testing of MAGNASTOR TSCs, fuel baskets, and damaged fuel cans are listed in Table 2.1-2.

Proposed alternatives to ASME Code, Section III, 2001 Edition with Addenda through 2003, including alternatives listed in Table 2.1-2, may be used when authorized by the Director of the Office of Nuclear Material Safety and Safeguards or designee. The request for such alternatives should demonstrate the following.

- The proposed alternatives would provide an acceptable level of quality and safety, or compliance with the specified requirements of ASME Code, Section III, Subsections NB and NG, 2001 Edition with Addenda through 2003, would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.
- Requests for alternatives shall be submitted in accordance with 10 CFR 72.

Table 2.1-1 MAGNASTOR System Design Criteria

Parameter	Criteria
Design Life	50 years
Design Code – Confinement	
TSC	ASME Code, Section III, Subsection NB [1] for confinement boundary
TSC Cavity Atmosphere	Helium
Gas Pressure	7.0 atmospheres gauge (103 psig)
Design Code - Nonconfinement	
Fuel Basket	ASME Code, Section III, Subsection NG [2] and NUREG/CR-6322 [3]
Concrete Cask	ACI-349 [4], ACI-318 [5]
Transfer Cask	ANSI N14.6 [6], NUREG-0612 [15]
Thermal	
Maximum Fuel Cladding Temperature	752°F (400°C) for Normal and Transfer [7] 1058°F (570°C) for Off-Normal and Accident [8]
Ambient Temperature	
Normal (average annual ambient)	76°F
Off-Normal (extreme cold; extreme hot)	-40°F; 106°F
Accident	133°F
Concrete Temperature	
Normal Conditions	≤150°F (bulk) [4]; ≤ 200°F (local) [9]
Off-Normal/Accident Conditions	≤ 350°F local/ surface [4]
Radiation Protection/Shielding	
Owner-Controlled Area Boundary Dose [10]	
Normal/Off-Normal Conditions	25 mrem (Annual Whole Body) [10]
Accident Whole Body Dose	5 rem (Whole Body) [10]

Table 2.1-2 ASME Code Alternatives for MAGNASTOR Components

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification and Compensatory Measures
TSC and Fuel Basket	NCA-1000, NCA-2000, NCA-3000, NCA-4000, NCA-5000, NCA-8000, NB-1110, and NG-1110	Requirements for Code stamping of NB components and preparation of Code Design Specifications, Design Reports, Overpressure Protection Report (TSC only), and Data Reports, and Quality Assurance requirements in accordance with Code requirements.	Code stamping is not required for the TSC, fuel basket or damaged fuel can. Code Design Specifications, Design Reports, Overpressure Protection Report, and Data Reports are not required. The TSC, Fuel Basket and Damaged Fuel Can are designed, procured, fabricated, inspected and tested in accordance with a QA Program meeting 10 CFR 72, Subpart G. Authorized Nuclear Inspection Agency Services are not required.
TSC Pressure-Retaining Materials	NB-2000	Pressure-retaining material to be provided by ASME-approved Material Organization.	Materials will be supplied with Certified Material Test Reports by NAC approved suppliers.
TSC Closure Lid-to-Shell Weld	NB-4243	Full penetration welds required for Category C joints.	The closure lid-to-shell weld is not a full penetration weld. The design and analysis of the closure lid weld utilizes a 0.8 stress reduction factor in accordance with ISG-15 [23].
Port Cover-to-Closure Lid Weld	NB-5230	Radiographic (RT) examination required.	Final surface liquid penetrant examination to be performed per ASME Code Section V, Articles 6 and 24. PT acceptance criteria is to be in accordance with NB-5350.
TSC Closure Lid-to-Shell Weld	NB-5230	Radiographic (RT) examination required.	In accordance with ISG-15, the TSC closure lid-to-shell weld is to be inspected by progressive surface liquid penetrant (PT) examination of the root, midplane and final surface layers. The progressive PT examination of the weld will be performed in accordance with ASME Code, Section V, Articles 6 and 24, and acceptance criteria per NB-5350.

Table 2.1-2 ASME Code Alternatives for MAGNASTOR Components

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification and Compensatory Measures
TSC Closure Ring-to-TSC Shell & TSC Closure Ring-to-Closure Lid	NB-5230	Radiographic (RT) examination required.	Final surface liquid penetrant examination to be performed per ASME Code Section V, Article 6 and 24. PT acceptance criteria is to be in accordance with NB-5350.
TSC	NB-6111	All completed pressure retaining systems shall be pressure tested.	Following closure lid to TSC shell welding, each TSC shall be hydrostatically pressure tested to 125% of MNOP. No observable pressure drop or water leakage from the closure lid to TSC shell weld is allowed. Since the shell welds of the TSC cannot be checked for leakage during this pressure test, as required by the Code, the shop helium leakage test to 2×10^{-7} cm^3/sec (as described in Section 10.1.3) provides reasonable assurance of the leak tightness of the TSC shell weldment.
TSC	NB-7000	Pressure vessels shall be protected from the consequences of pressure conditions exceeding design pressure.	No overpressure protection is provided. The function of the TSC is to confine radioactive contents without release under normal conditions, or off-normal and accident events of storage. The TSC is designed to withstand the maximum internal pressure considering 100% fuel rod failure and maximum accident condition temperatures.
TSC	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The TSC is marked and identified to ensure proper identification of the contents. Code stamping is not required.
Fuel Basket Assembly & Damaged Fuel Can Structural Materials	NG-2000	Core support structural materials are to be provided by an ASME approved Material Organization.	Fuel basket and damaged fuel can structural materials with Certified Material Test Reports to be supplied by NAC approved suppliers.

Table 2.1-2 ASME Code Alternatives for MAGNASTOR Components

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification and Compensatory Measures
Fuel Basket Assembly & Damaged Fuel Can Structural Components	NG-8000	Requirements for nameplates, stamping and reports per NCA-8000.	The fuel basket structural assembly and the damaged fuel cans are marked and identified to ensure component traceability in accordance with NAC's QA Program.

2.2 Spent Fuel To Be Stored

MAGNASTOR is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

The fuel assemblies are assigned to two groups of PWR and two groups of BWR fuel assemblies on the basis of fuel assembly length. Refer to Chapter 1 for the fuel assembly length groupings.

PWR and BWR fuel assemblies having parameters as shown in Table 2.2-1 and Table 2.2-2, respectively, may be stored in MAGNASTOR. PWR fuel assemblies may be stored with nonfuel hardware. Undamaged or damaged fuel assemblies or PWR fuel debris may be stored in a damaged fuel can. PWR fuel assemblies loaded into a DFC shall not contain nonfuel hardware, with the exception of instrument tube tie components and steel inserts.

The minimum initial enrichment limits are shown in Table 2.2-1 and Table 2.2-2 for PWR and BWR fuel, respectively, and exclude the loading of fuel assemblies enriched to less than 1.3 wt% ^{235}U, including unenriched fuel assemblies. Fuel assemblies with low enriched, unenriched, and/or annular axial end-blankets may be loaded into MAGNASTOR.

2.2.1 PWR Fuel Evaluation

MAGNASTOR evaluations are based on bounding PWR fuel assembly parameters that maximize the source terms for the shielding evaluations, the reactivity for criticality evaluations, the decay heat load for the thermal evaluations, and the fuel weight for the structural evaluations. These bounding parameters are selected from the various spent fuel assemblies that are candidates for storage in MAGNASTOR. The bounding fuel assembly values are established based primarily on how the principal parameters are combined, and on the loading conditions (or restrictions) established for a group of fuel assemblies based on its parameters.

The limiting parameters of the PWR fuel assemblies authorized for loading in MAGNASTOR are shown in Table 2.2-1. The maximum initial enrichments listed are based on a minimum effective neutron absorber sheet areal density of 0.036 ^{10}B g/cm^2 and soluble boron concentration of 2,500 ppm in the spent fuel pool water. Lower absorber sheet areal densities and/or soluble boron concentrations are allowed in the spent fuel pool water for fuel assemblies with lower

maximum enrichments. The maximum initial enrichment authorized represents the peak fuel rod enrichment for variably enriched PWR fuel assemblies. The PWR fuel assembly characteristics are summarized by fuel assembly type in Table 6.4.3-1, with maximum initial enrichment/ minimum soluble boron content as a function of absorber sheet loading listed in Table 6.4.3-2. Table 2.2-1 assembly physical information is limited to the criticality analysis input of fuel mass, array configuration, and number of fuel rods. These analysis values are key inputs to the shielding and criticality evaluations in Chapters 5 and 6. Lattice parameters dictating system reactivity are detailed in Chapter 6. Enrichment limits are set for each fuel type to produce reactivities at the upper subcritical limit (USL).

The maximum TSC decay heat load for the storage of PWR fuel assemblies is 35.5 kW. Uniform and preferential loading patterns are allowed in the PWR basket and in the DF Basket Assembly. The uniform loading pattern permits assemblies with a maximum heat load of 0.96 kW/assembly. The preferential loading pattern permits peak heat loads of 1.20 kW, as indicated in the zone description in Figure 2.2-1. The fuel basket configuration for PWR fuel with damaged fuel cans is shown in Figure 2.2-3. The bounding thermal evaluations are based on the Westinghouse 17×17 fuel assembly. The minimum cool times are determined based on the maximum decay heat load of the contents. The fuel assemblies and source terms that produce the maximum storage and transfer cask dose rates are summarized in Table 5.1.3-3 and Table 5.1.3-6 for MTC1 and MTC2, respectively.

A bounding weight of 1,680 pounds, as shown in Table 2.2-1, based on a B&W 15×15 fuel assembly with control components inserted, has been structurally evaluated in each location of the PWR fuel basket. A bounding weight of 1,814 pounds is evaluated for each loaded damaged fuel can in the damaged fuel configuration of the PWR DF fuel basket.

As noted in Table 2.2-1, the evaluation of PWR fuel assemblies includes nonfuel hardware. Empty fuel rod positions are filled with a solid filler rod or a solid neutron absorber rod that displaces a volume not less than that of the original fuel rod. PWR fuel assemblies loaded in a DFC shall not contain nonfuel hardware, with the exception of instrument tube tie components and steel inserts.

2.2.2 BWR Fuel Evaluation

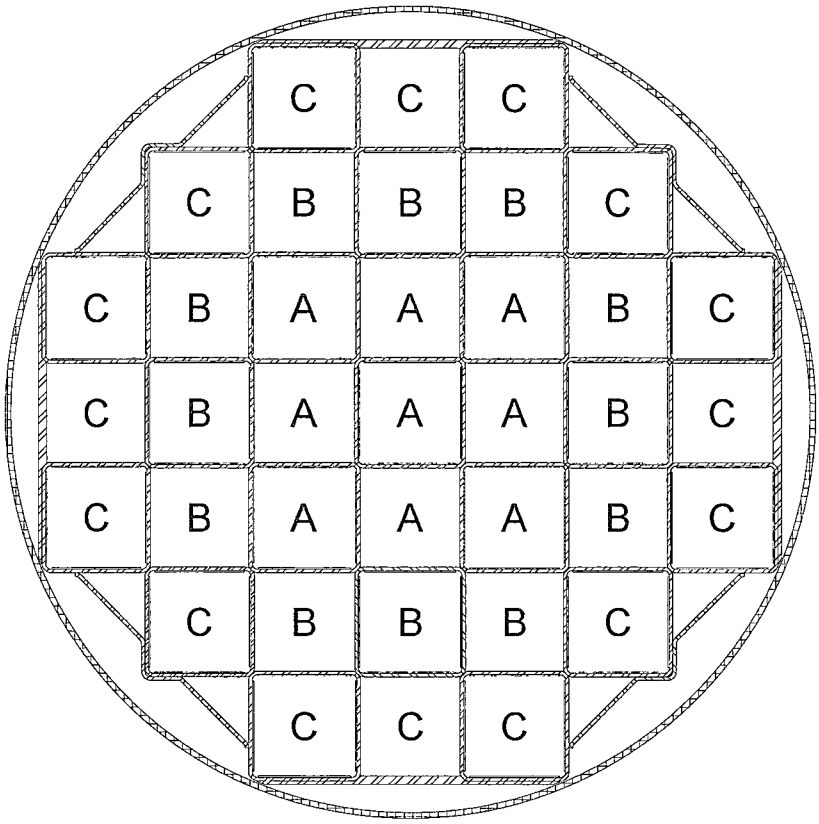
MAGNASTOR evaluations are based on bounding BWR fuel assembly parameters that maximize the source terms for the shielding evaluations, the reactivity for the criticality evaluations, the decay heat load for the thermal evaluations, and the fuel weight for the structural evaluations. These bounding parameters are selected from the various spent fuel assemblies that are candidates for storage in MAGNASTOR. The bounding fuel assembly values are established

based primarily on how the principal parameters are combined, and on the loading conditions or restrictions established for a group of fuel assemblies based on its parameters. Each TSC may contain up to 87 undamaged BWR fuel assemblies. To increase allowed assembly enrichments over those determined for the 87-assembly basket configuration, an optional 82-assembly loading pattern may be used. The required fuel assembly locations in the 82-assembly pattern are shown in Figure 2.2-2.

The limiting parameters of the BWR fuel assemblies authorized for loading in MAGNASTOR are shown in Table 2.2-2. The maximum initial enrichment represents the peak planar-average enrichment. The BWR fuel assembly characteristics are summarized by fuel type in Table 6.4.3-3, with maximum initial enrichment as a function of absorber sheet loading listed in Table 6.4.3-4. Table 2.2-2 assembly physical information is limited to the critical analysis input of fuel mass, array configuration, and number of fuel rods. These analysis values are key inputs to the shielding and criticality evaluations in Chapters 5 and 6. Lattice parameters dictating system reactivity are detailed in Chapter 6. Enrichment limits are set for each fuel type to produce reactivities at the USL. The maximum decay heat load per TSC for the storage of BWR fuel assemblies is 33.0 kW (average of 0.379 kW/assembly). Only uniform loading is permitted for BWR fuel assemblies. The bounding thermal evaluations are based on the GE 10×10 fuel assembly. The minimum cooling times are determined based on the maximum decay heat load of the contents. The fuel assemblies and source terms that produce the maximum storage and transfer cask dose rates are summarized in Table 5.1.3-3 and Table 5.1.3-6 for MTC1 and MTC2, respectively. A bounding weight of 704 pounds, as shown in Table 2.2-2, is based on the maximum weight of GE 7×7 and 8×8 assemblies with channels; this weight has been structurally evaluated in each storage location of the BWR basket.

As noted in Table 2.2-2, the evaluation of BWR fuel envelops unchanneled assemblies and assemblies with channels up to 120 mils thick. Empty fuel rod positions are filled with a solid filler rod or a solid neutron absorber rod that displaces a volume not less than that of the original fuel rod.

Figure 2.2-1 PWR Fuel Preferential Loading Zones



Zone Description	Designator	Heat Load (W/assy)	# Assemblies
Inner Ring	A	922	9
Middle Ring	B	1,200	12
Outer Ring	C	800	16

Figure 2.2-2 82-Assembly-BWR Basket Pattern

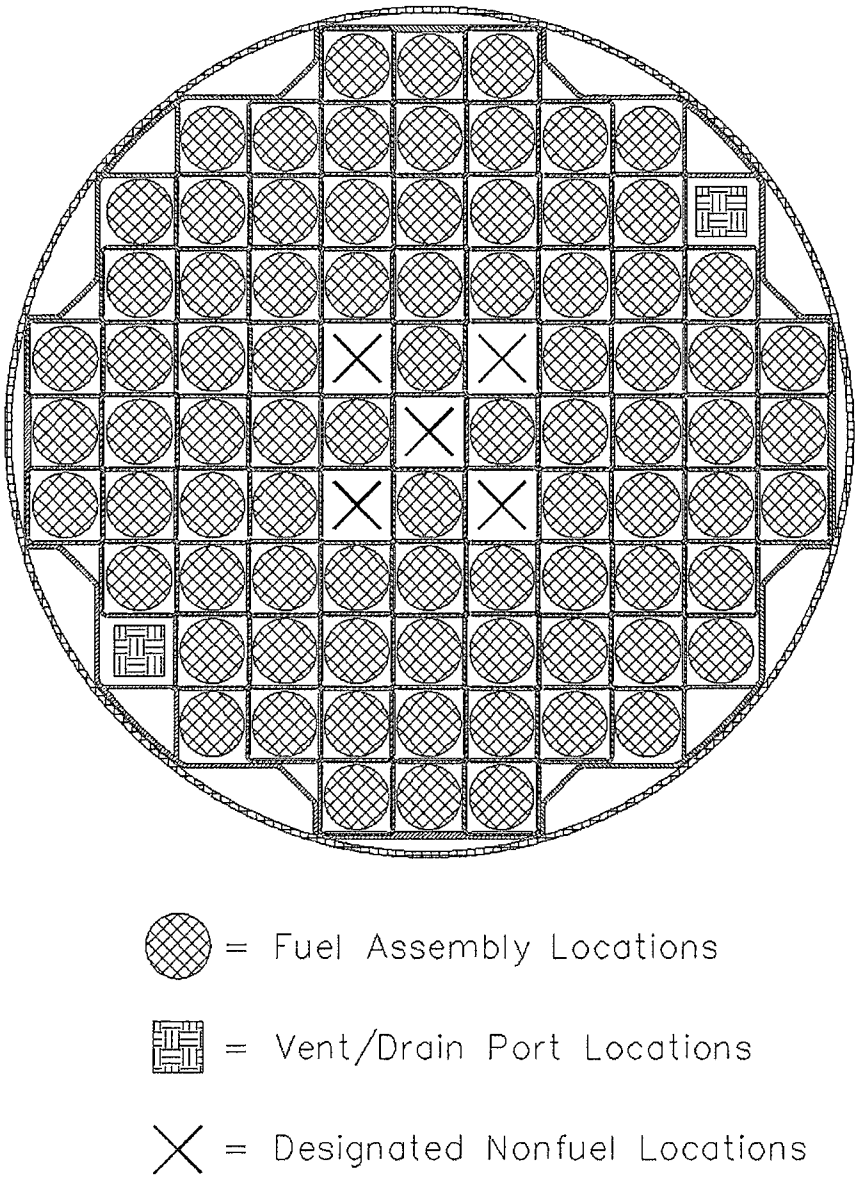
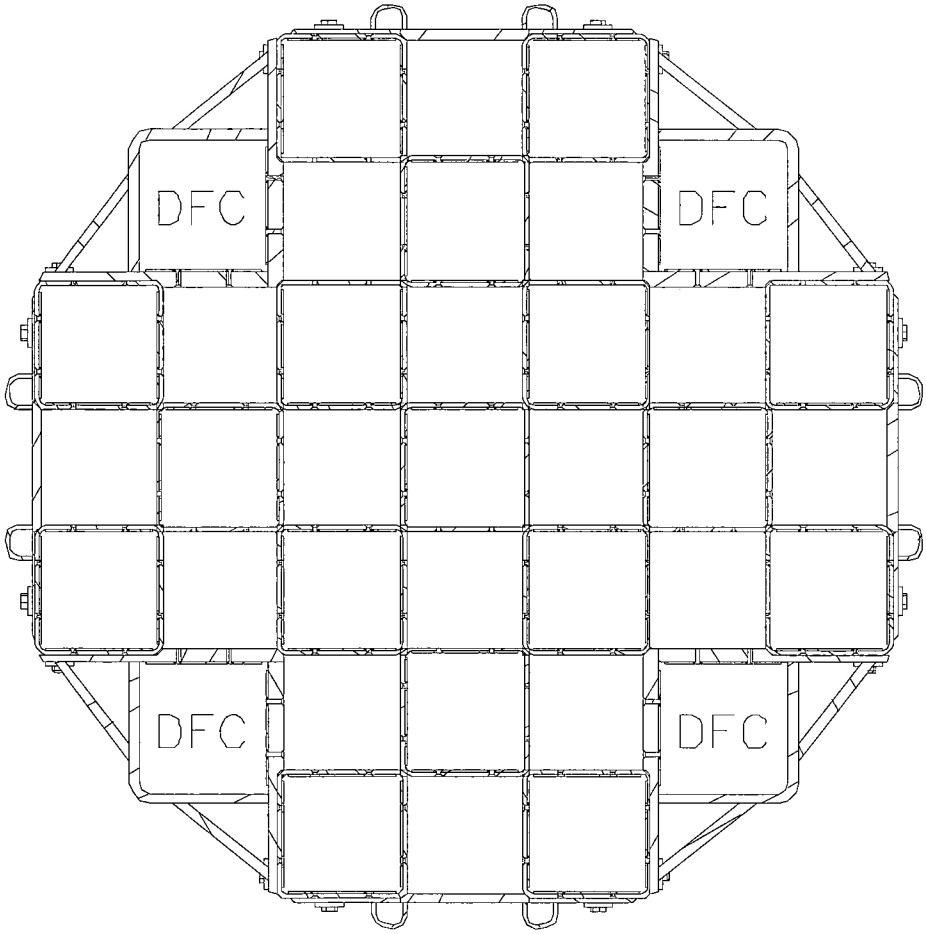


Figure 2.2-3 DF Basket Assembly Configuration for PWR Fuel with Damaged Fuel Can Locations



DFC designated locations may contain a loaded DFC or an undamaged PWR fuel assembly

Table 2.2-1 PWR Fuel Assembly Characteristics

Characteristic	Fuel Class					
	14×14	14×14	15×15	15×15	16×16	17×17
Base Fuel Type[a]	CE, SPC	W, SPC	W, SPC	BW, FCF	CE	BW, SPC, W, FCF
Max Initial Enrichment (wt% ^{235}U)	5.0	5.0	5.0	5.0	5.0	5.0
Min Initial Enrichment (wt% ^{235}U)	1.3	1.3	1.3	1.3	1.3	1.3
Number of Fuel Rods	176	179	204	208	236	264
Max Assembly Average Burnup (MWd/MTU)	60,000	60,000	60,000	60,000	60,000	60,000
Min Cool Time (years)	4	4	4	4	4	4
Max Weight (lb) per Storage Location	1,680	1,680	1,680	1,680	1,680	1,680
Max Decay Heat (Watts) per Preferential Storage Location	1,200	1,200	1,200	1,200	1,200	1,200

- Fuel cladding is a zirconium-based alloy.
- All reported enrichment values are nominal preirradiation fabrication values.
- Weight includes the weight of nonfuel-bearing components.
- Assemblies may contain nonfuel hardware and/or fuel replacement rods (also referred to as filler rods). Filler rods are considered to be a component of spent nuclear fuel assemblies and not nonfuel hardware. Filler rods may be burnable absorber rods, stainless steel rods or zirconium alloy rods.
- Required soluble boron content is fuel type and enrichment specific. Minimum soluble boron content varies between 1,500 and 2,500 ppm. Maximum initial enrichment represents the peak fuel rod enrichment for variably-enriched fuel assemblies.
- Spacers may be used to axially position fuel assemblies to facilitate handling.
- Maximum uniform heat load is 959 watts per storage location.

[a] Indicates assembly and/or nuclear steam supply system (NSSS) vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor provided that the fuel assembly meets the limits listed in Table 6.4.3-1. Table 6.2.1-1 contains vendor information by fuel rod array. Abbreviations are as follows: Westinghouse (W), Combustion Engineering (CE), Siemens Power Corporation (SPC), Babcock and Wilcox (BW), and Framatome Cogema Fuels (FCF).

Table 2.2-2 BWR Fuel Assembly Characteristics

Characteristic	Fuel Class			
	7×7	8×8	9×9	10×10
Base Fuel Type[a]	SPC, GE	SPC, GE	SPC, GE	SPC, GE, ABB
Max Initial Enrichment (wt% ^{235}U)	4.5	4.5	4.5	4.5
Number of Fuel Rods	48 49	59 60 61 62 63 64[b]	72 74[c] 76 79 80	91[c] 92[c] 96[c,d] 100[d]
Max Assembly Average Burnup (MWd/MTU)	60,000	60,000	60,000	60,000
Min Cool Time (years)	4	4	4	4
Min Average Enrichment (wt% ^{235}U)	1.3	1.3	1.3	1.3
Max Weight (lb) per Storage Location	704	704	704	704
Max Decay Heat (Watts) per Storage Location	379	379	379	379

- Each BWR fuel assembly may have a zirconium-based alloy channel up to 120 mil thick.
- Assembly weight includes the weight of the channel.
- Maximum initial enrichment is the peak planar-average enrichment.
- Water rods may occupy more than one fuel lattice location. Fuel assembly to contain nominal number of water rods for the specific assembly design.
- All enrichment values are nominal preirradiation fabrication values.
- Spacers may be used to axially position fuel assemblies to facilitate handling.

[a] Indicates assembly vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor/type provided that the fuel assembly meets the limits listed in Table 6.4.3-2. Table 6.2.1-2 contains vendor information by fuel rod array. Abbreviations are as follows: General Electric/Global Nuclear Fuels (GE), Exxon/Advanced Nuclear Fuels/Siemens Power Corporation (SPC), and ASEA Brown Boveri (ABB).

[b] May be composed of four subchannel clusters.

[c] Assemblies may contain partial-length fuel rods.

[d] Composed of four subchannel clusters.

2.3 Design Criteria for Environmental Conditions and Natural Phenomena

This section presents the design criteria for site environmental conditions and natural phenomena applied in the design basis analyses of MAGNASTOR. Analyses to demonstrate that the design basis system meets the design criteria defined in this section are presented in the appropriate chapters.

The use of MAGNASTOR at a specific site requires that the site either meet the design criteria of this section or be separately evaluated against the site-specific conditions to ensure the acceptable performance of the system.

2.3.1 Tornado Missiles and Wind Loadings

The concrete casks are typically placed outdoors on an unsheltered reinforced concrete storage pad at an ISFSI site. This storage condition exposes the casks to tornado and wind loading.

2.3.1.1 Applicable Design Parameters

The design basis tornado and wind loading is defined based on Regulatory Guide 1.76 [11], Region 1, and NUREG-0800 [12]. The tornado and wind loading criteria are as follows.

Tornado and Wind Condition	Limit
Rotational Wind Speed, mph	290
Translational Wind Speed, mph	70
Maximum Wind Speed, mph	360
Radius of Maximum Wind Speed, ft	150
Pressure Drop, psi	3.0
Rate of Pressure Drop, psi/sec	2.0

2.3.1.2 Determination of Forces on Structures

Tornado wind forces on the concrete cask 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 cask is demonstrated to remain stable under design basis tornado wind loading in conjunction with impact from a high-energy tornado missile.

2.3.1.3 Tornado Missiles

The design basis tornado missile impacts are defined in Paragraph 4, Subsection III, Section 3.5.1.4 of NUREG-0800 [12]. The design basis tornado is considered to generate three types of missiles that impact the cask at normal incidence.

Massive Missile – (deformable w/high kinetic energy)	Weight = 4,000 lb Frontal Area = 20 sq ft
Penetration Missile – (rigid hardened steel)	Weight = 280 lb Diameter = 8.0 in
Protective Barrier Missile – (solid steel sphere)	Weight = 0.15 lb Diameter = 1.0 in

Each missile is assumed to impact the concrete cask at a velocity of 126 miles per hour, horizontal to the ground, which is 35% 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 analysis of the loaded concrete cask for missile impacts applies the laws of conservation of momentum and conservation of energy to determine the rigid body response of the concrete cask. Each missile impact is evaluated, and all missiles are assumed to impact in a manner that produces the maximum damage to the cask.

2.3.2 Water Level (Flood) Design

The loaded concrete cask 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 specific site characteristics.

2.3.2.1 Flood Elevations

The concrete cask design basis is a maximum floodwater depth of 50 feet above the base of the cask and a floodwater velocity of 15 ft per second. Under design basis flood conditions, the cask does not move or tip on the storage pad and the confinement function is maintained.

2.3.2.2 Phenomena Considered in Design Load Calculations

The occurrence of flooding at an ISFSI site is dependent upon the specific site location and the surrounding natural and man-made geographical features. Some possible sources of a flood at an ISFSI site are: overflow from a river or stream due to unusually heavy rain, snow-melt runoff, or a dam or major water supply line break caused by a seismic event (earthquake); high tides

produced by a hurricane; and a tsunami (tidal wave) caused by an underwater earthquake or volcanic eruption.

Flooding at 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.

2.3.2.3 Flood Force Application

The evaluation of the concrete cask for a flood condition determines a maximum permissible floodwater current velocity and a maximum permissible floodwater depth. The criteria employed in the determination of the maximum permissible values are that a cask tip-over will not occur, and that the TSC material yield strength is not exceeded.

The force of the floodwater current on the concrete cask is calculated as a function of the velocity, which is a factor comprised of the dynamic water pressure, the frontal area of the cask that is normal to the direction of the current, and a drag coefficient dependent on the Reynold's number. The maximum permissible force of the floodwater current is determined such that the overturning moment on the cask will be less than that required to tip the cask over.

During a flood condition, the force of the floodwater exerts a hydrostatic pressure on the canister shell. This pressure is based on the design basis flood: floodwater depth of 50 ft and floodwater velocity of 15 ft per second. Therefore, the force exerted on the canister shell is 22 psi. The analysis of the canister shell will demonstrate that there is no containment malfunction or impairment of the ability to retrieve fuel from the canister.

2.3.2.4 Flood Protection

The inherent strength of the reinforced concrete cask 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 cask are necessary. For the design basis flood, the allowable stresses in the TSC are not exceeded.

2.3.3 Seismic Design

An ISFSI site may be subject to seismic events (earthquakes) during its lifetime. The seismic response spectra experienced by the concrete cask depends upon the geographical location of the specific site and the distance from the epicenter of the earthquake. The possible significant effect of a beyond-design-basis seismic event on the concrete cask would be a tip-over; however, the loaded concrete cask does not tip over during the design-basis seismic event. Although it is a nonmechanistic event, the loaded concrete cask design basis includes consideration of the consequences of a hypothetical cask tip-over event.

The TSC is analyzed for loads induced by the application of a 0.37g seismic acceleration to the concrete cask at the top surface of the ISFSI pad.

2.3.4 Snow and Ice Loadings

The criterion for determining design snow loads is based on ANSI/ASCE 7-93 [13], Section 7.0. Flat roof snow loads apply and the design basis snow and ice load are calculated from the following formula.

$$p_f = 0.7C_eC_tIp_g$$
$$= 100.8 \text{ psf}$$

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 1, 18, 19, and 20 and Figure 7, respectively, of ANSI/ASCE 7-93.

The exposure factor, C_e, accounts for wind effects. The exposure factor of the concrete cask is assumed to be 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, C_t, accounts for the importance of buildings and structures in relation to public health and safety. The concrete cask is conservatively classified as a Category III building or other structure. 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 lb per square ft is assumed.

The design basis snow and ice load is bounded by the weight of the loaded transfer cask on the top of the concrete cask shell and by the tornado missile loading on the concrete cask lid. The snow load is considered in the load combinations evaluations of the concrete cask.

2.3.5 Combined Load Criteria

Each normal condition and off-normal and accident event has a combination of load cases that defines the total combined loading for that condition/event. 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 [10] and ANSI/ANS-57.9 [14].

2.3.5.1 Load Combinations and Design Strength - Concrete Cask

Refer to Table 2.3-1 for the load combinations for the concrete cask. The live loads are considered to vary from 0% to 100% to ensure that the worst-case condition is evaluated. In each case, use of 100% of the live load produces the maximum load condition. The steel liner of the concrete cask is a stay-in-place form that also provides radiation shielding. The concrete cask is designed to the requirements of ACI 349 [4].

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

2.3.5.2 Load Combinations and Design Strength – TSC and Fuel Basket

The TSC is designed in accordance with the ASME Code, Section III, Subsection NB [1]. The basket and damaged fuel can (DFC) are designed in accordance with the ASME Code, Section III, Subsection NG [2]. Structural buckling of the basket is evaluated in accordance with NUREG/CR-6322 [3].

Refer to Table 2.3-2 for the load combinations for all normal conditions and off-normal or accident events and the corresponding ASME service levels. Levels A and D service limits represent normal conditions and accident events, respectively. Levels B and C service limits are used for off-normal events. The analysis criteria of the ASME Code, Section III, Subsection NB are employed. Stress intensities produced by pressure, temperature, and mechanical loads are combined before comparison to the ASME Code allowable criteria. For components used in the TSC, refer to the allowable criteria in Table 2.3-3.

The load combinations considered for the fuel basket for normal conditions and off-normal or accident events are the same as those identified for the TSC in Table 2.3-2, except that there are no internal pressure loads. The analysis criteria of the ASME Code, Section III, Subsection NG are employed. For the fuel basket components, refer to the allowable criteria in Table 2.3-3.

2.3.5.3 Design Strength - Transfer Cask

The transfer cask is a special lifting device. It is designed, fabricated, and load tested to meet the requirements of ANSI N14.6 [6] for the handling of vertical loads defined in NUREG 0612 [15]. The design criteria are as follows.

- The combined shear stress or maximum tensile stress during the lift (with 10% dynamic load factor) shall be $\leq S_y/6$ and $S_u/10$.

- For off-normal (Level C) conditions, membrane stresses shall be less than $1.2S_m$ and membrane plus bending stresses shall be the lesser of $1.8S_m$ and $1.5S_y$.
- 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.

Refer to Chapter 10 for information on load testing of the transfer cask.

2.3.6 Environmental Temperatures

A temperature of 76°F is defined as the design base normal operations temperature for MAGNASTOR in storage. This temperature conservatively bounds the maximum average annual temperature in the 48 contiguous United States, specifically, Miami, FL, at 75.6°F [16] and meets the normal condition thermal boundary defined in NUREG-1536 [25]. Use of this design base establishes a bounding condition for existing and potential ISFSI sites in the United States. Refer to Chapter 4 for the evaluation of this environmental condition along with the thermal analysis models. Refer to Chapter 3 for the thermal stress evaluation for the normal operating conditions. Normal temperature fluctuations are bounded by the severe ambient temperature cases that are evaluated as off-normal and accident events.

Off-normal, severe environmental events are defined as -40°F with no solar loads and 106°F with solar loads. An extreme environmental condition of 133°F with maximum solar loads is evaluated as an accident case to show compliance with the maximum heat load case required by ANSI/ANS-57.9. Thermal performance is also evaluated assuming both the half blockage of the concrete cask air inlets and the complete blockage of the air inlets.

The design basis temperatures used in the concrete cask analysis follow. Solar insolation is as specified in 10 CFR 71.71 [17] and Regulatory Guide 7.8 [18].

Condition	Ambient Temperature	Solar Insolation
Normal	76°F	yes
Off-Normal - Severe Heat	106°F	yes
Off-Normal - Severe Cold	-40°F	no
Accident - Extreme Heat	133°F	yes

Table 2.3-1 Load Combinations for the 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 and 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/ANS-57.9 [14] and ACI 349 [4]. Where:

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

Table 2.3-2 Load Combinations for the TSC

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	TSC w/ fuel	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Thermal	Inside concrete cask: 76°F ambient	X		X				X		X	X	X	X	X	
	Inside transfer cask: 76°F ambient		X		X		X								X
	Inside concrete cask: -40°F or 106°F ambient					X			X						
Internal Pressure	Normal	X	X	X			X	X	X	X	X	X	X		
	Off-Normal				X	X									
	Accident (fire)													X	X
Handling Load	Normal (1.1g)		X	X	X										
	Off-Normal						X	X	X						
Drop/Impact	24-in drop, < 60g									X					
Seismic	Tip-over and complete burial										X				
Flood	50-ft water head											X			
Tornado	Pressure drop of 3.0 psi												X		

Table 2.3-3 Structural Design Criteria for Components Used in the TSC

	Component	Criteria
1.	Normal Operations: Service Level A TSC: ASME Section III, Subsection NB [1] Basket: ASME Section III, Subsection NG [2]	$P_m \leq S_m$ $P_L + P_b \leq 1.5\ S_m$ $P_L + P_b + Q \leq 3S_m$ $P_s < 0.6\ S_m$
2.	Off-Normal Operations: Service Level B TSC: ASME Section III, Subsection NB	$P_m < 1.1\ S_m$ $P_L + P_b < 1.65\ S_m$ $P_s < 0.6\ S_m$
3.	Off-Normal Operations: Service Level C TSC: ASME Section III, Subsection NB Basket: ASME Section III, Subsection NG	Subsection NB Criteria: $P_m < 1.2\ S_m$ or S_y (whichever is greater) $P_L + P_b < 1.8\ S_m$ or $1.5\ S_y$ (whichever is lesser) $P_s < 0.6\ S_m$ Subsection NG Criteria: $P_m < 1.5S_m$ $P_L + P_b < 2.25S_m$ $P_s < 0.6\ S_m$
4.	Accident Conditions, Service Level D TSC: ASME Section III, Subsection NB Basket: ASME Section III, Appendix F Basket: ASME Section III, Subsection NG	$P_m \leq 2.4\ S_m$ or $0.7\ S_u$ (whichever is lesser) $P_L + P_b \leq 3.6\ S_m$ or $1.0\ S_u$ (whichever is lesser) $P_s < 0.42\ S_u$ Plastic Analysis (Basket): $P_m \leq 0.7S_u$ $P_{int} \leq 0.9S_u$ $P_s < 0.42\ S_u$
5.	Basket Structural Buckling	NUREG/CR-6322 [3]

Symbols:

S_m = material design stress intensity
S_u = material ultimate strength
S_y = material yield strength

P_L = primary local membrane stress
P_m = primary general membrane stress
P_b = primary bending stress
P_{int} = primary stress intensity
P_s = average primary shear across a section loaded in pure shear

2.4 Safety Protection Systems

MAGNASTOR relies upon passive systems to ensure the protection of public health and safety, except in the case of fire or explosion. As previously discussed, 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.

2.4.1 General

MAGNASTOR is designed for safe, long-term storage of spent fuel. The system will withstand all of the evaluated normal conditions and off-normal and postulated accident events without release of radioactive material or excessive radiation exposure to workers or the general public. The major design considerations to assure safe, long-term fuel storage and retrievability for ultimate disposal by the Department of Energy in accordance with the requirements of 10 CFR 72 and ISG-2 [24] are as follows.

- Continued radioactive material confinement in postulated accidents.
- Thick steel and concrete biological shield.
- Passive systems that ensure reliability.
- Pressurized inert helium atmosphere to provide corrosion protection for fuel cladding and enhanced heat transfer for the stored fuel.

Retrievability is defined as: "maintaining spent fuel in substantially the same physical condition as it was when originally loaded into the storage cask, which enables any future transportation, unloading and ultimate disposal activities to be performed using the same general type of equipment and procedures as were used for the initial loading."

Each major component of the system is classified with respect to its function and corresponding potential effect on public safety. In accordance with Regulatory Guide 7.10 [19], each major system component is assigned a safety classification (see Table 2.4-1). The safety classification is based on review of the component's function and the assessment of the consequences of its failure following the guidelines of NUREG/CR-6407 [20]. The safety classification categories are defined in the following list.

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 MAGNASTOR design incorporates features addressing the design considerations described previously to assure safe operation during loading, handling, and storage of spent nuclear fuel.

2.4.2 Confinement Barriers and Systems

The radioactive materials that MAGNASTOR must confine during storage originate from the stored fuel assemblies and residual contamination inside the TSC. The system is designed to safely confine this radioactive material under all storage conditions.

The stainless steel TSC is assembled and closed by welding. All of the field-installed welds are liquid penetrant examined as detailed in Chapter 10 and on the License Drawings. The longitudinal and girth shop welds of the TSC shell are full penetration welds that are radiographically and liquid penetrant examined during fabrication. The TSC bottom-plate-to-shell shop weld joint is ultrasonically and liquid penetrant examined during fabrication.

The TSC vessel provides a leaktight boundary precluding the release of solid, volatile, and gaseous radioactive material. There are no evaluated normal conditions or off-normal or accident events that result in damage to the TSC producing a breach in the confinement boundary. Neither normal conditions of operation or off-normal events preclude retrieval of the TSC for transport and ultimate disposal. The TSC is designed to withstand accident conditions, including a 24-inch end drop in the concrete cask and a tip-over of the concrete cask, without precluding the subsequent removal of the fuel (i.e., the fuel tubes do not deform such that they bind the fuel assemblies).

Operator radiation exposure during handling and closure of the TSC is minimized by the following.

- Minimizing the number of operations required to complete the TSC loading and sealing process.
- Placing the closure lid on the TSC while the transfer cask and TSC are under water in the fuel pool.
- Using temporary shielding, including a weld shield plate as the mounting component of the weld machine.
- Using the retaining blocks or bolted retaining ring on the transfer cask to ensure that the TSC is not raised out of the transfer cask.

2.4.3 Concrete Cask Cooling

The loaded concrete cask is passively cooled. Ambient air enters at the bottom of the concrete cask through four air inlets and heated air exits through the four air outlets at the top of the cask due to natural convection heat transfer. Radiant heat transfer also occurs from the TSC to the concrete cask liner. Consequently, the liner also heats the convective airflow. This natural circulation of air inside the concrete cask, in conjunction with radiation from the TSC surface, maintains the fuel cladding and concrete cask component temperatures below their design limits. Conduction does not play a substantial role in heat removal from the TSC surface. Refer to Chapter 4 for details on the concrete cask thermal analyses.

2.4.4 Protection by Equipment

There is no important-to-safety equipment required for the safe storage operation of MAGNASTOR. The important-to-safety equipment employed in the handling of MAGNASTOR is the lifting yoke and the crane hook extension (where required) used to lift the transfer cask. The lifting yoke and the crane hook extension are designed, fabricated and tested in accordance with ANSI N14.6 as a special lifting device as defined in NUREG-0612. The lifting yoke and the crane hook extension are proof load tested to 300% or 150% (for facilities not requiring a single failure-proof criteria) of its design load when fabricated. Following the load test, the bolted connections are disassembled, and the components are inspected for deformation. Permanent deformation of components is not acceptable. Engagement pins are examined by dye penetrant examination. The transfer cask, lifting yoke and crane hook extension are inspected for visible defects prior to each use. Transfer cask annual maintenance requirements are defined in Chapter 10.

2.4.5 Protection by Instrumentation

No instrumentation is required for the safe storage operations of MAGNASTOR.

A remote temperature-monitoring system may be used to measure the outlet air temperature of the concrete casks in long-term storage. The outlet temperature can be monitored daily as a check of the continuing thermal performance of the concrete cask. Alternately, a daily visual inspection for blockage of the air inlet and air outlet screens of all concrete casks may be performed. Following any natural phenomena event, such as an earthquake or tornado, the concrete casks shall be inspected for damage and air inlet and air outlet blockage.

2.4.6 Nuclear Criticality Safety

MAGNASTOR design includes features to ensure that nuclear criticality safety is maintained (i.e., the cask remains subcritical under normal conditions and off-normal and accident events). The design of the TSC and fuel basket is such that, under all conditions, the highest neutron multiplication factor (k_{eff}) is less than 0.95.

2.4.6.1 Control Methods for Prevention of Criticality

The principal design criterion is that k_{eff} remain less than 0.95 for all conditions. Criticality control for PWR spent fuel is achieved using neutron absorber material fixed in the basket and by maintaining a minimum boron concentration in the TSC during fuel loading. The fixed neutron absorber captures thermal neutrons that are moderated in the water surrounding the fuel. Fast, high-energy neutrons escape the system. The minimum effective loading for neutron absorber sheets is 0.036, 0.030 or 0.027 ^{10}B g/cm^2 for PWR fuel baskets and 0.027. 0.0225 or 0.020 ^{10}B g/cm^2 for BWR fuel baskets. The required minimum boron loading in a neutron absorber sheet is determined based on the assumed boron effectiveness used in the criticality analysis, i.e., 75% for Boral (registered trademark of Ceradyne, Inc.) and 90% for borated aluminum alloys and for borated metal matrix composites (MMCs). Neutron absorber sheets are mechanically attached to the fuel tube structure to ensure that the neutron absorber remains in place during the design basis normal conditions and off-normal and accident events.

The basket designs ensure that there is sufficient absorption of moderated neutrons by the neutron absorber (and by boron in the cavity water in some cases) to maintain criticality control in the basket ($k_{eff} < 0.95$). See Chapter 6 for the detailed criticality analyses.

2.4.6.2 Error Contingency Criteria

The standards and regulations of criticality safety require that k_{eff}, including uncertainties, be less than 0.95. The bias and 95/95 uncertainty are applied to the calculation using an upper subcritical limit (USL) approach [22]. The $k_{eff} + 2\sigma$ value must be less than the USL. Based on MCNP critical benchmarks, the USL as a function of fission neutron lethargy (eV) is shown as:

$$USL = 0.9364 + 8.4409 \times 10^{-3} \times x$$

where:

x = energy of average neutron lethargy causing fission

2.4.6.3 Verification Analyses

The MCNP criticality analysis code is benchmarked through a series of calculations based on critical experiments. These experiments span a range of fuel enrichments, fuel rod pitches, poison sheet characteristics, shielding materials, and geometries that are typical of light water

reactor fuel in a cask. To achieve accurate results, three-dimensional models, as close to the actual experiment as possible, are used to evaluate the experiments.

2.4.7 Radiological Protection

MAGNASTOR is designed to minimize operator radiological exposure in keeping with the As Low As Reasonably Achievable (ALARA) philosophy.

2.4.7.1 Access Control

Access to MAGNASTOR at an ISFSI site will be controlled by a fence with lockable truck and personnel access gates to meet the requirements of 10 CFR 72, 10 CFR 73, and 10 CFR 20 [21]. Access to the storage area, and its designation as to the level of radiation protection required, will be established by site procedures by the licensee.

2.4.7.2 Shielding

MAGNASTOR is designed to limit the dose rates in accordance with 10 CFR 72.104 and 72.106, which set whole body dose limits for an individual located beyond the controlled area at $\leq$ 25 mrem per year (whole body) during normal operations and $\leq$ 5 rem (5,000 mrem) from any design basis accident. Burnup profile shape should be considered during ALARA and site boundary planning by the system licensee, as it may affect system dose rate profiles.

2.4.7.3 Ventilation Off-Gas

MAGNASTOR is passively cooled by radiation and natural convection heat transfer at the outer surface of the concrete cask and in the TSC-concrete cask annulus. In the TSC-concrete cask annulus, air enters the air inlets, flows up between the TSC and concrete cask liner in the annulus, and exits the air outlets. If the exterior surface of the TSC is excessively contaminated, the possibility exists that contamination could be carried aloft by the airflow. Therefore, during fuel loading, the spent fuel pool water is minimized in the transfer cask/TSC annulus by supplying the annulus with clean or demineralized spent fuel pool water. Water is supplied into the annulus while the transfer cask is submerged. The use of the annulus system minimizes the potential for contamination of the exterior surfaces of the TSC.

After the transfer cask is removed from the pool, removable contamination levels on the TSC exterior are determined. If TSC decontamination is required, clean water can be used to flush the annulus. To facilitate decontamination, the TSC exterior surfaces are smooth.

MAGNASTOR has no radioactive releases during normal conditions or off-normal or accident events of storage. Hence, there are no off-gas system requirements for MAGNASTOR.

2.4.7.4 Radiological Alarm Systems

No radiological alarms are required on MAGNASTOR. Typically, total radiation exposure due to the ISFSI installation is monitored by the use of the licensee's boundary dose monitoring program.

2.4.8 Fire Protection

A major ISFSI fire is not considered credible, since there is very little material near the concrete casks that could contribute to a fire. The concrete cask is largely impervious to incidental thermal events. Administrative controls will be established by the licensee to ensure that the presence of combustibles at the ISFSI is minimized. A hypothetical 1,475°F fire occurring at the base of the cask for eight minutes is evaluated as an accident condition.

2.4.9 Explosion Protection

MAGNASTOR is analyzed to ensure its proper function under an over-pressure event. The TSC is protected from direct over-pressure conditions by the concrete cask. For the same reasons as for the fire condition, a severe explosion on an ISFSI site is not considered credible. The evaluated 20 psig over-pressure condition is considered to bound any explosive over- pressure resulting from an industrial explosion at the boundary of the owner-controlled area.

2.4.10 Auxiliary Structures

The loading, welding, vacuum drying, cooling, helium backfill, transfer, and transport of MAGNASTOR require the use of auxiliary equipment as described in Chapter 9. External transfer of a TSC may require the use of a structure, referred to as a "TSC Handling and Transfer Facility." The TSC Handling and Transfer Facility is a specially designed and engineered structure independent of the 10 CFR 50 facilities at the site.

The design of the TSC Handling and Transfer Facility would meet the requirements for MAGNASTOR described in the Design Features presented in Appendix A of the Technical Specifications, in addition to those requirements established by the licensee.

The design, analysis, fabrication, operation, and maintenance of the TSC Handling and Transfer Facility would be performed in accordance with the quality assurance program requirements of the licensee. The components of the TSC Handling and Transfer Facility would be classified as Important-to-Safety or Not-Important-to-Safety in accordance with the guidelines of NUREG-6407.

Table 2.4-1 Safety Classification of MAGNASTOR Components

Component Description	Reference Drawings	Safety Function	Safety Classification
TSC Assembly Shell and Base Plate Closure Lid Closure Ring Port Covers	71160-581 71160-584 71160-585	Structural and Confinement	A
Fuel Basket Assembly Basket Support Weldments Fuel Tube Assemblies Neutron Absorbers Damaged Fuel Cans	71160-551 71160-571 71160-572 71160-574 71160-575 71160-591 71160-598 71160-599 71160-600 71160-601 71160-602 71160-671 71160-673 71160-674 71160-675 71160-681 71160-684 71160-685	Criticality, Structural and Thermal	A
Transfer Cask Assembly Trunnions Inner and Outer Shells Shield Doors and Rails Lead Gamma Shield Neutron Shield	71160-560 71160-556	Structural, Shielding and Operations	B
Adapter Plate Assembly Base Plate Door Rails Hydraulic Operating System Side Shields	None	Operations and Shielding	NQ
Concrete Cask Assembly Structural Weldments and Base Plate Lid Weldment Lifting Lugs Reinforcing Bars Concrete	71160-561 71160-562 71160-590	Structural, Shielding, Operations and Thermal	B

2.5 Decommissioning Considerations

The principal components of MAGNASTOR are the concrete cask and the TSC. Refer to Chapter 15 for information on decommissioning MAGNASTOR.

Decommissioning of MAGNASTOR involves removing the TSC by offsite transport and disassembling the concrete cask. It is expected that the concrete will be broken up and the steel components segmented to reduce volume. The concrete and carbon steel are not expected to be surface-contaminated and no significant activation is expected.

The TSC is designed and fabricated to ensure its retrievability for use as a component of the waste package for permanent disposal at the Mined Geological Disposal System in accordance with the guidance of ISG-2 [24] and the requirements of 10 CFR 72. Consequently, decommissioning may not be required. If necessary, the TSC could be decommissioned following unloading by decontaminating the inside and segmenting the shell and closure plates. Since the neutron flux rate from the stored fuel is low, only minimal activation of the TSC is expected. The resulting stainless steel could be disposed of, or recycled, in accordance with the appropriate regulatory requirements.

The storage pad, fence, and supporting utility fixtures are not expected to require decontamination as a result of use of MAGNASTOR. Consequently, these items may be reused or disposed of as locally generated clean waste.

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Chapter 3
Structural Evaluation

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3 STRUCTURAL EVALUATION

This chapter describes the design and analysis of the principal structural components of MAGNASTOR®. It demonstrates that MAGNASTOR meets the structural requirements for confinement of contents, criticality control, heat dissipation, radiological shielding, and contents retrievability required by 10 CFR 72 [1] for the design basis normal conditions, and off-normal and accident events.

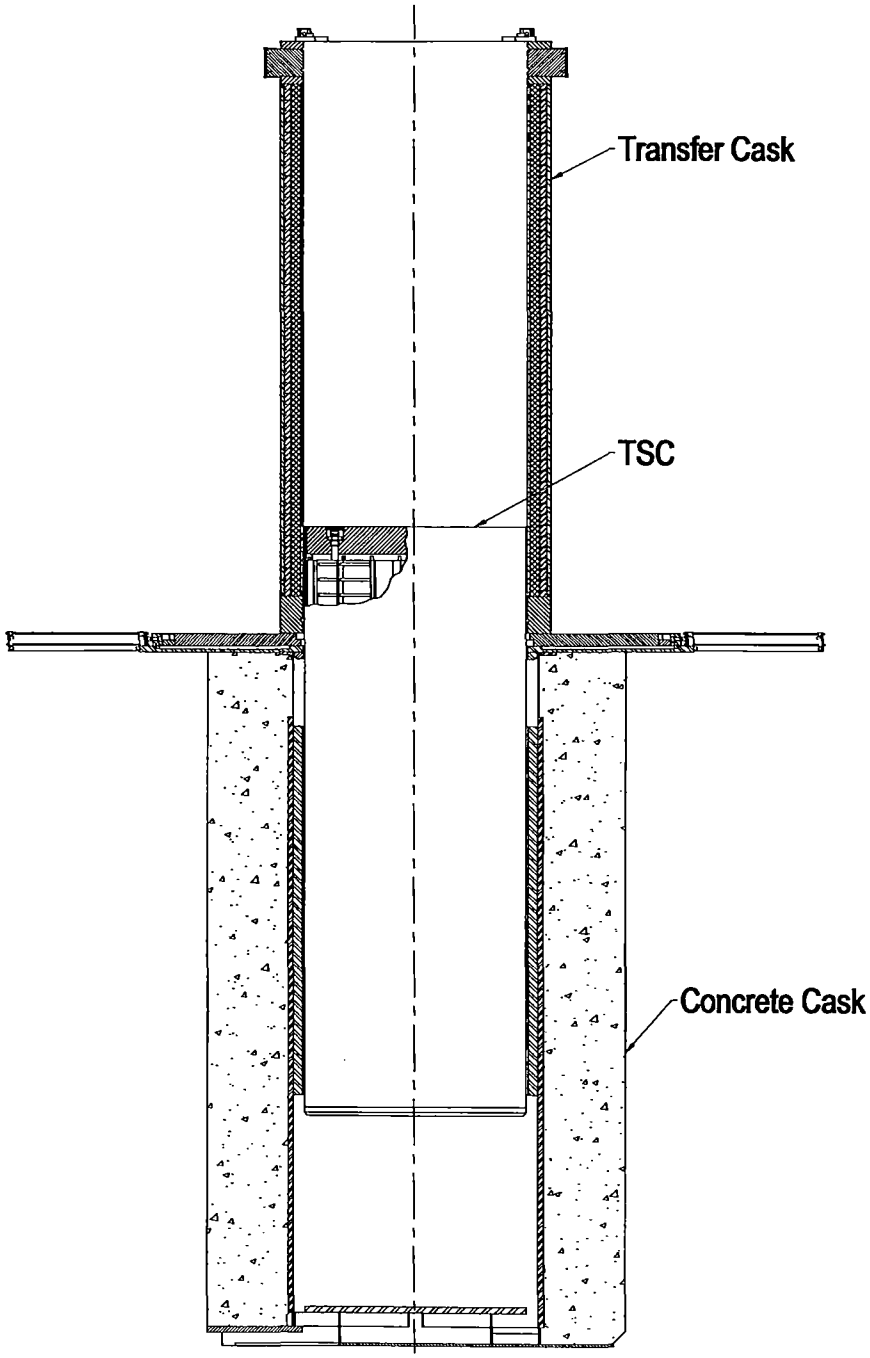
3.1 MAGNASTOR Structural Design

3.1.1 Major Components

The three principal components of MAGNASTOR are the concrete cask, the TSC, and the transfer cask (refer to Figure 3.1.1-1). The following table shows the principal structural components of the three major MAGNASTOR components.

Concrete Cask	TSC	Transfer Cask
Reinforced concrete shell	Closure lid assembly and closure ring	Trunnions
Liner weldment	Shell	Inner and outer steel shells
Bottom weldment	Bottom plate	Shield doors
Lid assembly	Fuel basket assembly (PWR or BWR)	Door support rails
		Lead and NS-4-FR shielding

Figure 3.1.1-1 Principal Components of MAGNASTOR



3.1.2 Discussion of MAGNASTOR

MAGNASTOR has multiple configurations to accommodate all PWR and BWR fuel assemblies. The type (PWR or BWR) and overall length of the fuel assembly determine the basic storage configuration, or group. The TSC is designed in two different lengths to accommodate the four groupings of PWR (2) and BWR (2) fuel assemblies. The concrete cask and transfer cask are also designed in two different lengths. The long concrete cask and transfer cask configurations are designed to accommodate the two TSC lengths, and the short concrete cask and transfer cask configurations are designed to only accommodate the short TSCs. The bounding weights and center of gravity of a loaded concrete cask are presented in Table 3.2.1-1.

The evaluations presented in this chapter are based on the bounding, or limiting, configuration of the components for the condition being evaluated. In most cases, the bounding condition evaluates the heaviest configuration, with either a total weight or bounding weight used as specified in the analysis. Factors of safety greater than ten are generally stated in the analyses as "Large." Numerical values are shown for factors of safety that are less than ten.

Concrete Cask

The concrete cask is provided in four different configurations designated CC1, CC2, CC3 and CC4. The concrete cask is a reinforced concrete cylinder with an outside diameter of 136 inches and an overall height of approximately 225 inches (CC1 and CC2) or 218 inches (CC3 and CC4). The internal cavity of the concrete cask is lined by a carbon steel shell with an inside diameter of 79.5 inches and a thickness of either 1.75 inches (CC1, CC2 and CC4) or 3.0 inches (CC3). There are 24 standoffs (3 × 7½ S-Beam) welded to the inner diameter of the liner. The overall cavity opening in the concrete cask is 73.5 inches. The liner thickness is designed primarily on radiation shielding requirements, but is also related to the need to establish a practical limit for the diameter of the concrete shell. The concrete shell, constructed using Type II Portland Cement, has a nominal density of 145 lb/ft^3 and a compressive strength of 4,000 psi at ambient temperature. Vertical hook bars and horizontal hoop bars form the inner and outer rebar cages. The inner rebar cage is optional for all concrete cask configurations.

A ventilation airflow path is formed by inlets at the bottom of the concrete cask, the annular space between the concrete cask inner shell and the TSC, and outlets in the concrete cask lid assembly. The passive ventilation system operates by natural convection as cool air enters the bottom inlets, is heated by the TSC, and exits from the outlets. Both the air inlets and air outlets are formed with carbon steel in the concrete cask body. For the CC3 and CC4 configuration, a labyrinth of steel bars is included in each inlet vent for enhanced radiation shielding.

The top end of the concrete cask is closed by a lid assembly that is attached by six ∅5/8-inch lid bolts. The lid assembly is composed of a carbon steel top plate and a cylindrical concrete plug

that is encased in 1/4-inch thick carbon steel plate. The lid assembly used with the CC1, CC2 and CC4 configurations has an overall thickness of 6.8 inches and an overall diameter of 88.0 inches. The CC3 lid assembly has a slightly larger overall diameter (91.5 inches) and also includes an additional 6.0 inches of concrete (over a 60.0-inch diameter) for enhanced radiation shielding.

TSC

The TSC consists of a cylindrical shell closed at its top end by a closure lid assembly. The bottom of the TSC is a 2.75-inch thick stainless steel plate that is welded to the TSC shell. The TSC forms the confinement boundary for the PWR or BWR spent fuel that is contained in the fuel basket assembly. The TSC is designed to accommodate both PWR and BWR classes of spent fuel assemblies. The TSC shell is fabricated from dual-certified SA240 Type 304/304L stainless steel. The TSC closure lid is fabricated from Type 304 or 304L stainless steel, with material yield and ultimate strengths equal to, or greater than, those of Type 304. The TSC shell is a 0.5-inch thick plate formed into a 72-inch outer diameter cylinder. The TSC closure lid assembly is provided as either a single-piece 9-inch thick stainless steel plate (i.e., the TSC1 and TSC2 configurations) or a two-piece composite lid assembly (i.e., the TSC3 and TSC4 configurations). The TSC3 and TSC4 composite lid assembly design consists of a 4-inch thick closure lid and a 5-inch thick shield plate. The closure lid forms the TSC confinement boundary and provides radiation shielding. The shield plate, which is fabricated from A36 carbon steel that is coated with electroless nickel plating, provides radiation shielding and structural support for the closure lid. The shield plate is attached to the closure lid by ten 1-½ inch diameter A193, Grade B6 bolts.

The fuel basket assembly is provided in two configurations – one for up to 37 PWR fuel assemblies and one for up to 87 BWR fuel assemblies. The baskets are manufactured from SA537 Class 1 Carbon Steel. For both the PWR basket and BWR basket, the basic components are the same. The baskets are assembled from three major components – fuel tube assemblies, corner support weldments, and side support weldments. The fuel tube assemblies are equipped with neutron absorbers and stainless steel covers on up to four interior surfaces of the fuel tubes. When neutron absorbers are not needed, they may be replaced by aluminum sheets. The geometric integrity of the fuel tube array (21 fuel tubes – PWR, 45 fuel tubes – BWR) is maintained by the corner and side support weldments, which are bolted to the fuel tube array.

The nominal inner dimension of the PWR fuel tubes is 8.86-inches square. The nominal inner dimension of the BWR fuel tubes is 5.86-inches square.

Transfer Cask

The transfer cask, with its lifting yoke, is primarily a shielded lifting device used to handle the TSC. It provides biological shielding for a loaded TSC. The transfer cask is used for the vertical transfer of the TSC between workstations and the concrete cask, or transport cask. The shielding of the cask incorporates a multiwall (steel/lead/NS-4-FR/steel) design. The transfer cask is provided in two different configurations (referred to as MTC1 and MTC2) that differ primarily in the structural materials and overall length. The materials of construction for the transfer cask structural components are carbon steel for the MTC1 configuration and stainless steel for the MTC2 configuration. The length of the MTC1 configuration is sufficient to accommodate both long and short PWR and BWR TSCs. The MTC2 configuration is shorter and lighter than the MTC1 and is designed to only accommodate the short PWR and BWR TSCs. The transfer cask can handle a loaded TSC weighing up to 118,000 pounds. The transfer cask is a heavy lifting device that is designed, fabricated, and load-tested to the requirements of ANSI–N14.6 [2] and NUREG–0612 [3]. Both the MTC1 and MTC2 configurations include TSC retainers that are designed to prevent a loaded TSC from being inadvertently lifted through the top of the transfer cask. The MTC1 TSC retainer consists of three retractable retainer assemblies attached to the top of the transfer cask. The MTC2 TSC retainer consists of an annular plate that is bolted to the transfer cask top ring. The transfer cask has retractable bottom shield doors. During loading operations, the doors are closed and secured by bolts/pins so they cannot inadvertently open. During unloading, the doors are retracted using hydraulic cylinders to allow the TSC to be lowered into the concrete cask or transport cask.

Component Evaluation

The following components are evaluated in this chapter.

- TSC lifting devices
- TSC shell, bottom plate, and closure lid assembly
- Fuel basket assembly
- Transfer cask trunnions, shells, retainer, shield doors, and support rails
- Concrete cask body
- Concrete cask steel components (reinforcement, inner shell, lid assembly, bottom weldment, etc.)

Other MAGNASTOR components shown on the license drawings in Chapter 1 are included as loads in these component evaluations.

The structural evaluations in this chapter demonstrate that MAGNASTOR components meet their respective structural design criteria and are capable of safely storing the design basis PWR or BWR spent fuel assemblies.

3.1.3 Design Criteria Summary

MAGNASTOR structural design criteria are described in Chapter 2. Load combinations for normal, off-normal, and accident loads are evaluated in accordance with ANSI/ANS-57.9 [4] and ACI 349 [5]. The TSC components and welds that form the confinement boundary are evaluated in accordance with ASME Code, Section III, Subsection NB for Class 1 components [6]. The shield plate and its attachment bolts for the TSC3 and TSC4 composite lids are analyzed in accordance with ASME Code, Section III, Subsection NF [31]. The basket is evaluated in accordance with ASME Code, Section III Subsection NG [7] and ASME Code, Section III, Appendix F [8]. The buckling evaluation of the fuel basket is performed in accordance with NUREG/CR-6322 [9]. The transfer cask and lifting yoke are lifting devices that are designed to NUREG-0612 [3] and ANSI N14.6 [2].

3.2 Weights and Centers of Gravity

3.2.1 Calculated Maximum Weights and Centers of Gravity

The maximum calculated weights and centers of gravity (CGs) for MAGNASTOR PWR, PWR with Damaged Fuel Cans, and BWR configurations are presented in Table 3.2.1-1. The weights and CGs presented in this section are calculated based on nominal design dimensions.

The stainless steel TSC assembly holds the fuel basket structure and confines the contents. TSCs are provided in four configurations designated TSC1 through TSC4. The TSC configurations are distinguished by their length and closure lid assembly design, as detailed on the drawings. TSC1 and TSC3 are 191.8 inches long; TSC2 and TSC4 are 184.4 inches long. TSC1 and TSC2 include a 9-in thick solid stainless steel closure lid assembly. TSC3 and TSC4 include a composite closure lid assembly consisting of a 4-in thick stainless steel closure lid and a 5-in thick carbon steel shield plate. The solid stainless steel standard closure lid assembly is heavier than the composite closure lid assembly. Therefore, the bounding weight of the standard closure lid assembly is used for all weight and CG calculations.

The concrete cask is a reinforced concrete structure with a structural steel inner liner and base. The concrete cask may be supplied in four different configurations designated CC1 through CC4. CC1 is the standard 225.27-in high cylinder. CC2 is also 225.27-in high, but is a segmented design. CC1, CC2 and CC4 are equipped with a 1.75-in thick carbon steel liner. CC3 is a 218.3-in high standard design cylinder equipped with a 3-in thick carbon steel liner and additional shielding at the air inlets. CC4 is a 218.3-in high standard design cylinder with inlet shield bars. The shorter length of CC3 and CC4 limit their use to the shorter canisters, i.e., TSC2 and TSC4, while the longer CC1 and CC2 can be used with all canister designs. The top of the concrete cask is closed by a lid assembly. The lid assembly is composed of a carbon steel top plate and a cylindrical concrete plug that is encased in ¼-in thick carbon steel plate. The lid assembly used with the CC1 and CC2 configurations has an overall thickness of 6.8 inches and an overall diameter of 88.0 inches. The CC3 lid assembly has a slightly larger overall diameter (91.5 inches) and also includes an additional 6.0 inches of concrete (over a 60.0-in diameter) for enhanced radiation shielding. The CC4 lid assembly has the same overall diameter as the CC3 lid configuration and the same thickness of the CC1 and CC2 lid configuration.

There are two MAGNASTOR Transfer Casks (MTCs) considered in this calculation, i.e., MTC1 and MTC2. The MTC1 transfer cask is longer and made of carbon steel, while the MTC2 transfer cask is shorter and made of stainless steel.

Table 3.2.1-1 MAGNASTOR Storage Weight and Center of Gravity Summary

Description	CC1 & CC2 / MTC1 [1]						CC3 & CC4 [2] / MTC2 [2]			
	PWR		BWR		DF - PWR		PWR		DF - PWR	
	Weight (lb)[3]	CG (in)[4]	Weight (lb)[3]	CG (in)[4]	Weight (lb)[3]	CG (in)[4]	Weight (lb)[3]	CG (in)[4]	Weight (lb)[3]	CG (in)[4]
Maximum Contents (fuel, DFC and/or spacers, if used)	62,160	-	61,248	-	61,184	-	62,160	-	61,184	-
Basket	20,500	-	22,000	-	24,000	-	19,500	-	24,000	-
TSC w/o Lid	9,500	-	9,500	-	9,500	-	9,500	-	9,500	-
Closure Lid	10,500	-	10,500	-	10,500	-	10,500	-	10,500	-
Loaded TSC (TSC, lid, basket, contents)	102,000	100	103,000	99	104,500	96	101,000	96	104,500	96
Water in TSC and Annulus	17,500	-	16,500	-	16,500	-	17,000	-	16,500	-
Transfer Cask[5] (does not include lifting yoke or transfer adapter)	108,500	-	108,500	-	108,500	-	106,000	-	106,000	-
Lifting Yoke [6] (not included in transfer cask weight)	5,500	-	5,500	-	5,500	-	5,500	-	5,500	-
Concrete Cask [7, 8] (does not include concrete cask lid)	214,500	-	214,500	-	214,500	-	225,000 [12] 210,000 [13]	-	225,000 [12] 210,000 [13]	-
Concrete Cask Lid [8]	4,500	-	4,500	-	4,500	-	6,000 [12] 4,500 [13]	-	6,000 [12] 4,500 [13]	-
Storage Cask Loaded (concrete cask w/ lid, TSC w/ lid, basket, contents)	320,500	113	321,500	113	323,500	112	332,500 [12] 315,000 [13]	108 [12] 109 [13]	335,500 [12] 318,500 [13]	108 [12] 109 [13]
Transfer Cask, TSC w/o Lid, Basket, Lifting Yoke – Empty	143,500	-	145,500	-	146,500	-	140,000	-	144,500	-
Loaded Transfer Cask Wet Weight [9]	228,000	-	228,000	-	229,500	-	223,500	-	226,500	-
Under Hook Wet Weight [10]	233,500	-	233,500	-	234,500	-	228,500	-	232,000	-
Under Hook Dry Weight [11]	216,000	-	217,000	-	218,500	-	212,000	-	216,000	-

See following page for Notes.

Table 3.2.1-1 MAGNASTOR Storage Weight and Center of Gravity Summary (continued)

Notes:

1. Bounding weights and centers of gravity for CC1 and CC2 concrete casks and MTC1 transfer cask with all TSC configurations.
2. Bounding weights and centers of gravity for CC3 and CC4 concrete casks and MTC2 with TSC2 or TSC4.
3. Weights and CGs are maximum calculated values based on nominal component dimensions. All weights rounded to the nearest 500 pounds, except for the maximum contents. Component weights are rounded individually, so total assembly weights may not equal the sum of the component weights.
4. CG is measured from the bottom of each component and CG of TSC contents is assumed to equal the mid-length of the TSC cavity.
5. The MTC1 and MTC2 transfer casks can be used with all three concrete cask configurations (i.e., CC1, CC2, CC3 and CC4). The MTC2 transfer cask can only be used for a short TSC configuration (i.e., TSC2 and TSC4), while MTC1 can be used with any TSC configuration.
6. Transfer cask lifting yoke weight for specific sites may vary from listed weight. The site-specific yoke weight should be used for site-specific applications.
7. Bounding weight with inner rebar cage, which bounds the weight of construction aids used with the no inner rebar cage configuration.
8. Average concrete density is considered to be 148 pcf for conservative weight calculation.
9. Loaded Transfer Cask Wet Weight (transfer cask, TSC, basket, closure lid, contents, water in TSC and transfer cask annulus).
10. Under Hook Wet Weight (transfer cask, TSC, basket, lifting yoke, closure lid, contents, water in TSC and transfer cask annulus).
11. Under Hook Dry Weight (transfer cask, TSC, basket, lifting yoke, closure lid, contents).
12. Value for the CC3 concrete cask configuration
13. Value for the CC4 concrete cask configuration

3.3 Materials

Refer to Chapter 8 for the information on Materials.

3.4 General Standards for Casks

MAGNASTOR is designed for safe, long-term storage of spent fuel. The system will withstand all of the evaluated normal conditions, and off-normal and postulated accident events without release of radioactive material or excessive radiation exposure to workers or to the general public.

3.4.1 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of MAGNASTOR are evaluated in Section 8.10.

3.4.2 Positive Closure

A stainless steel closure lid closes the top end of the TSC. Prior to being welded to the TSC shell, the closure lid assembly is supported by lugs welded on the inside surface of the TSC shell at an elevation that allows for thermal expansion of the canister and fuel basket without contact with the closure lid assembly. The lugs also serve as the handling points for the empty TSC shipping/receiving and placement in the transfer cask. The closure lid includes locations for installing load-tested hoist rings or lifting points that are used to lift and lower the loaded TSC after the closure lid is welded to the TSC shell. The closure lid and its weld to the TSC shell can support the weight of the TSC with a load factor of six on material yield strength and ten on material ultimate strength (ANSI N14.6/NUREG-0612). The TSC has a single 0.5-inch J-groove weld attaching the closure lid to the TSC shell. A closure ring, which provides the double weld redundant sealing of the confinement boundary, is installed in the TSC-to-closure lid groove and welded to both the closure lid and the TSC shell. Two port penetrations through the closure lid are used for water removal/TSC drying/helium backfill. Both have single welded, redundant port covers over them to provide the double weld confinement boundary. The port cover welds and the closure ring welds are field welds, and the final weld surfaces are liquid penetrant (PT) examined. The TSC closure lid weld is a field weld and the root, midplane, and final weld surfaces are liquid penetrant (PT) examined. The progressive inspection requirements for the closure lid weld are based on a critical flaw size of 0.33 inch determined by the critical flaw evaluation.

3.4.3 Lifting Devices

To provide more efficient handling of MAGNASTOR, different methods of lifting are designed for each of the components. The transfer cask, the TSC, and the concrete cask, are handled using trunnions, hoist rings, and lift lugs, respectively.

The design of the MAGNASTOR addresses the concerns identified in NRC Bulletin 96-02, "Movement of Heavy Loads Over Spent Fuel, Over Fuel in the Reactor Core, or Over Safety-Related Equipment" (April 11, 1996) listed as follows.

- The MAGNASTOR lifting and handling components satisfy the requirements of NUREG-0612 and ANSI N14.6 for safety factors on redundant and nonredundant load paths as described in this chapter.
- Transfer cask lifting in the spent fuel pool or cask loading pit, or transfer cask lifting and movement above the spent fuel pool operating floor will be addressed on a plant-specific basis.

3.4.3.1 Concrete Cask Lift

The concrete cask is lifted by means of embedded lift anchor and lug assemblies located in the top of the concrete cask body. Additionally, the CC1 and CC2 concrete cask configurations can be lifted by air pads beneath the cask. It is noted that movement of the concrete cask with air pads uses four load modules, one placed in each cask inlet, developing a minimum lift interface area of 5,760 in^2, (48 in × 30 in × 4) and bearing stress less than 60 psi (340,000/5,760) at the lift module to cask interface. Use of air pads to move the concrete cask produces insignificant stress in the cask body; therefore, further evaluation of the cask movement is focused on the use of a vertical lift transporter. The concrete cask lift is analyzed in accordance with ANSI N14.6 and ACI 349. The concrete cask lid assembly is evaluated for lift conditions related to installation on the concrete cask body.

Lift Lug

A weight of 340,000 lb is conservatively used for the evaluation of the lift lugs, which bounds the maximum weight of a loaded concrete cask. Assuming a 10% dynamic load factor, the design load (P) on each lug is as follows.

$$P = \frac{340{,}000 \times 1.1}{4} = 93{,}500 \text{ lb}$$

The lugs are evaluated for adequate strength using this bounding load. The bearing stresses and loads for lug failure involving bearing, shear-tear-out, or hoop tension are determined using an allowable load coefficient (K). Actual lug failures may involve more than one failure mode, but such interaction effects are accounted for in the values of K [10].

The allowable ultimate bearing load (P_{bruL}) and allowable yield bearing load (P_{bryL}) for the evaluation of lug failure in bearing, shear-tear-out, or hoop tension are as follows.

P_{bruL} = 470 kip

P_{bryL} = 361 kip

These values are determined based on lug geometry and the following material properties.

F_{tu} = 80.0 ksi ---------- Ultimate strength, A537 CL2, at 100°F
F_{ty} = 60.0 ksi ---------- Yield strength, A537 CL2, at 100°F

Using the criteria of minimum factors of safety of 5 on ultimate strength and 3 on yield strength, the factors of safety (FS) for the lugs are shown as follows.

Ultimate Bearing:

$$FS = \frac{P_{bruL}}{P} = \frac{470}{93.5} = 5.03 > 5$$

Yield Bearing:

$$FS = \frac{P_{bryL}}{P} = \frac{361}{93.5} = 3.86 > 3$$

The tensile stress (σ) in the net cross-sectional area of the lug is calculated to be as follows.

$$\sigma = \frac{P}{A} = \frac{93.5}{7.20} = 13.0 \text{ ksi}$$

The factors of safety (FS) are listed as follows.

Ultimate:

$$FS = \frac{80.0}{13.0} = 6.2 > 5$$

Yield:

$$FS = \frac{60.0}{13.0} = 4.6 > 3$$

Lift Anchor

From the previous lug analysis, the maximum load on each embedment plate is 93.5 kip. The ultimate strength (σ) in the plate is calculated as follows.

$$\sigma = \frac{P}{A} = \frac{93.5}{16.0} = 5.84 \text{ ksi}$$

The factors of safety (FS) are as follows.

Ultimate Tensile:

$$FS = \frac{80.0}{5.84} = 13.7 > 5$$

Yield Tensile:

$$FS = \frac{53.0}{5.84} = 9.1 > 3$$

Where the embedment plate material strengths are listed as follows.

F_{tu} = 80.0 ksi ---------- Ultimate strength, A537 CL2, at 200°F
F_{ty} = 53.0 ksi ---------- Yield strength, A537 CL2, at 200°F

Concrete Anchor

The concrete shear area is conservatively assumed to be the perimeter of the bottom plate of the lift anchor. The shear cone in the concrete is conservatively ignored, and the minimum strength of concrete is used for the material temperature of 300°F. The required anchor depth, D, is determined to be as follows.

$$D = \frac{W}{\phi 2P\sqrt{f_c'}} = \frac{187{,}000}{0.85 \times 2 \times 42.2 \times \sqrt{3{,}800}} = 42.3 \text{ inch} \qquad [5]$$

where:

W = 2×93.5 kip = 187,000 lb ---------- Anchor load
ϕ = 0.85 ---------- Shear factor
f_c' = 3,800 psi ---------- Concrete strength at 300°F
P = 42.2 inch ---------- Perimeter of bottom plate

Excluding the bottom anchor plate, the length of the anchor is 65.5 inches for the segmented concrete cask configuration and 70.0 inches for the standard concrete cask configuration; therefore, the minimum factor of safety (FS) is as follows.

$$FS = \frac{65.5}{42.3} = 1.55$$

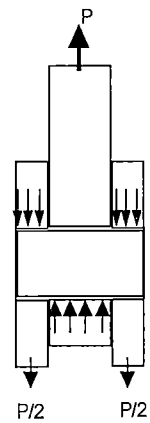
Lift Pin

The lift pin allowable ultimate shear load (P_{usp}) for the symmetrical joint is the double shear strength of the pin.

$$P_{usp} = 1.571 D_p^2 F_{sup} = 678.6 \text{ kip} \qquad [10]$$

where:

D_p = 4.0 inch ---------- Pin diameter
F_{sup} = $0.6S_m = 0.6 \times 45.0$ ksi = 27 ksi
S_m = 45.0 ksi ---------- 17-4PH stainless steel, at 200°F



The load on the pin is twice the lift lug load (P); therefore, the factor of safety (FS) for the pin is as follows.

$$FS = \frac{P_{usp}}{2 \times P} = \frac{678.6}{2 \times 93.5} = 3.63 > 3.0$$

Lift Lug Bolt

Bolt on lift lugs are used for both the CC2 and CC4 concrete cask configurations. The evaluation of the bounding CC2 cask configuration is presented. For the segmented concrete cask (CC2), the eight bolts that attach each set of the lift lugs to the embedded anchor are in tension. The tensile load is the combination of axial loads and the prying action of the lug fitting.

The preload per bolt is

$$P_{pl} = \frac{T}{kd} = \frac{125 \times 12}{(0.158 \times 1.25)} = 7.6 \text{ kip}$$

where:

T = 125 ft-lbs ---------- Maximum lug bolt torque
d = 1.25 in ---------- Lug bolt diameter
k = 0.158 ---------- Torque Coefficient or Nut factor

The load per bolt due to dead weight (with 10% DLF) is

$$P_d = \frac{W_l}{n} = \frac{187}{8} = 23.4 \text{ kip}$$

where:

$W_l = 2 \times 93.50 = 187.0$ kip ---------- Lug lifting load based on a conservative 340 kip cask weight and a 1.1 DLF
$n = 8$ ---------- Number of bolts per lift lug

The tensile load (Q) on the bolt due to prying is calculated to be 2.5 kip [11].

The total load on the bolt (P) is as follows.

$$P = P_d + P_{pl} + Q = 23.4 + 7.6 + 2.5 = 33.5 \text{ kip}$$

The total stress in the bolt shank is

$$S_t = \frac{P}{A_t} = \frac{33.5}{0.9524} = 35.2 \text{ ksi}$$

where:

$$A_t = \pi\left(\frac{E_{smin}}{2} - \frac{0.16238}{n}\right)^2 = 0.9524 \text{ inch}^2 \text{. Tensile area of 1-1/4–7 UNC 2A}$$

The bolts are designed to meet a factor of safety of three on yield strength and five on ultimate strength consistent with the ANSI N14.6 specifications for a non-critical lift.

The factor of safety against bolt failure

$$FS = \frac{S_y}{S_t} = \frac{144.0}{35.2} = 4.09 > 3$$

where:

S_y =144.0 ksi.....Yield Strength, SB-637 Grade N07718, 200°F

$$FS = \frac{S_u}{S_t} = \frac{177.6}{35.2} = 5.05 > 5$$

where:

S_u = 177.6 ksi.....Ultimate strength, SB-637 Grade N07718, 200°F

The bolts are threaded into the top plate of the lift anchor. The plate material is SA-537 Class 2 carbon steel, which has lower yield and ultimate strength compared to the bolt material is SB-637 Grade N07718. As a result, the internal threads of the SA-537 Class 2 plate provide the limiting stress condition of the bolted joint.

The shear stress in the internal threads is

$$\tau = \frac{P}{A_n} = \frac{33.5}{5.005} = 6.69 \text{ ksi}$$

where:

P = 33.5 kip..... The maximum bolt load

$$A_n = 3.1416 n L_e D_{smin}\left[\frac{1}{2n} + 0.57735\left(D_{smin} - E_{n\,max}\right)\right]$$

= 5.005 inch^2..... Shear area of 1-1/4–7 UNC 2A internal thread

L_e = 1.7 in..... Thread length of engagement

Converting the thread shear stress to a von Mises stress (S_v) provides

$$S_v = \sqrt{3}\tau = \sqrt{3}(6.69) = 11.59$$

The bolts are designed to meet a factor of safety of three on yield strength and five on ultimate strength consistent with the ANSI N14.6 specifications for a non-critical lift.

The factor of safety against thread shear is

$$FS = \frac{S_y}{S_v} = \frac{53.0}{11.59} = 4.57 > 3$$

where:

S_y = 53.0 ksi .....Yield Strength, SA-537 Class 2, 200°F

$$FS = \frac{S_u}{S_v} = \frac{80.0}{11.59} = 6.90 > 5$$

where:

S_u = 80.0 ksi Ultimate strength, SA-537 Class 2, 200°F

Concrete Cask Lid Assembly Lift

The lid assembly of the concrete cask is lifted using three 7/8-9 UNC 2A threaded bolts with a ¾-inch thread engagement in the A36 carbon steel lid. A weight of 6,000 lb is conservatively used for the evaluation of the cask lid assembly lift, which bounds the maximum weight of the lid assembly. The load per bolt (P), including dynamic load factor of 10%, is as follows.

$$P = \frac{6{,}000 \times 1.1}{3} = 2{,}200 \text{ lb}$$

The required length of engagement is calculated to be as shown in the following.

$$L_e = \frac{2A_t}{3.1416(K_{n\,max})\left[\frac{1}{2} + 0.57735(n)(E_{s\,min} - K_{n\,max})\right]} = 0.645 \text{ inch [12]}$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.75}{0.645} = 1.16$$

Pedestal Structural Evaluation

This section presents the structural evaluation of the pedestal during a concrete cask top-end lift. The ANSYS finite element model, presented in Section 3.10.4, is used to evaluate the concrete cask pedestal. The critical loading is during the concrete cask lift operations using the concrete cask lift anchors mounted on top of the concrete cask body.

Component Stresses

From the finite element model, the maximum stresses in the pedestal stand occur in the support rails. The critical section is the unsupported region between the pedestal stand and the inlet top. The maximum membrane stress is 16.7 ksi. The maximum membrane plus bending stress is 25.3 ksi. The factors of safety (FS) are shown as follows.

Membrane

$$FS = \frac{S_m}{\sigma_m} = \frac{19.3}{16.7} = 1.16$$

Membrane plus bending

$$FS = \frac{1.5S_m}{\sigma_{m+b}} = \frac{28.95}{25.3} = 1.14$$

where:

S_m = 19.3 ksi ---------- Design stress intensity, A-36 carbon steel, at 300°F

Pedestal Welds

The pedestal is a welded assembly. The structural welds in the pedestal are evaluated using an allowable stress of $0.6S_m$. The weld forces (F_x, F_y, and F_z) are obtained from the pedestal finite element analysis results. The total weld load (F_w) is obtained by using the square root of the sum of the squares method of the weld forces.

Support Rail to Inlet Top Weld

The support rails are welded to the inlet top with a ⅝-inch fillet weld. The stress in the weld (σ) is as follows.

$$\sigma = \frac{F_w}{A} = 9.1 \text{ ksi}$$

where:

F_w = 36,077 lb ---------- Total weld load
F_x = 3,248 lb ---------- Weld force, X-direction
F_y = 32,351 lb ---------- Weld force, Y-direction
F_z = -15,633 lb ---------- Weld force, Z-direction
A = 3.95 inch^2 ---------- Area
l_w = 8.95 inches ---------- Weld length
t_w = ⅝-inch ---------- Weld size

The factor of Safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\sigma} = 1.27$$

where:

S_m = 19.3 ksi ---------- Design stress intensity, A-36 carbon steel, 300°F

Inlet Top to Inlet Side Weld

The inlet top is welded to the inlet side with a ⅛-inch fillet weld plus a ¼-inch groove weld. The stress in the weld is as follows.

$$\sigma = \frac{F_w}{A} = \frac{34{,}099}{8.03} = 4.2 \text{ ksi}$$

where:

F_w = 34,099 lb ---------- Total weld load
F_x = 10,437 lb ---------- Weld force, X-direction
F_y = -32,351 lb ---------- Weld force, Y-direction
F_z = -2,685 lb ---------- Weld force, Z-direction
A = $l_w \times t_w$ = 8.03 inch^2 ---------- Area
l_w = 30.9 inches ---------- Weld length
tw = $((0.125 + 0.25) \times .707) = 0.26$ inch ---- Weld size

The factor of Safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\sigma} = \frac{0.6 \times 19.3}{4.2} = 2.76$$

where:

S_m = 19.3 ksi ---------- Design stress intensity, A-36 carbon steel, at 300°F

Inlet Side to Base Plate Weld

The critical section of the inlet side to base plate weld is the 8.25-inch segment at the inner end of the inlet. The weld is a ¼-inch groove weld. The stress in the weld is as follows.

$$\sigma = \frac{F_w}{A} = 9.9 \text{ ksi}$$

where:

$F_w = \sqrt{F_x^2 + F_y^2 + F_z^2} = 20{,}484$ lb

F_x = 270 lb ---------- Weld force, X-direction

F_y = 20,459 lb ---------- Weld force, Y-direction

F_z = -971 lb ---------- Weld force, Z-direction

$A = l_w \times t_w = 2.06 \text{ inch}^2$

l_w = 8.25 inches ---------- Weld length

tw = 0.25 inch ---------- Weld size

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\sigma} = \frac{0.6 \times 19.3}{9.9} = 1.17$$

where:

S_m = 19.3 ksi ---------- Design stress intensity, A-36 carbon steel, at 300°F

Support Rail Gusset to Support Rail Weld

The rail gusset weld is a ⅝-inch fillet weld. The stress in the weld is as follows.

$$\sigma = \frac{F_w}{A} = 2.5 \text{ ksi}$$

where:

$F_w = \sqrt{F_x^2 + F_y^2 + F_z^2} = 4{,}915$ lb

F_x = 2,224 lb ---------- Weld force, X-direction

F_y = -1,636 lb ---------- Weld force, Y-direction

F_z = -4,066 lb ---------- Weld force, Z-direction

$A = l_w \times (t_w \times 0.707) = 1.97 \text{ inch}^2$

l_w = 4.45 inches ---------- Weld length

tw = ⅝-inch ---------- Weld size

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\sigma} = 4.63$$

where:

S_m = 19.3 ksi ---------- Design stress intensity, A-36 carbon steel, at 300°F

Nelson Studs

During a top-end concrete cask lift, the Nelson studs transmit the weight of a loaded TSC to the concrete cask. The liner is not directly attached to the pedestal. The ability of the Nelson studs to transfer load to the concrete cask is based upon the compressive strength of the concrete. Using ACI 349-85 [5], the maximum pullout strength of the concrete is defined by the equation

$$P_d = 4 \times \phi \times \sqrt{f_c'} \times A_{cd}$$

where:

ϕ = 0.85 ---------- Strength reduction factor
f_c' = 3,800 psi ---------- Concrete compression strength, 300°F
A_{cd} = Projected cone area of Nelson stud less head area

The projected area of a single Nelson stud is calculated by creating a cone that projects 45° from the head of the Nelson stud and omits the projected area of the Nelson stud head.

For a 0.75-inch diameter, 6.0-inch long Nelson stud, the projected area is as follows.

$$A_{cd} = \pi(l_e(l_e + d_h)) = 116.6 \text{ inch}^2$$

where:

l_e = 5.5 inches ---------- Bolt length
d_h = 1.25 inches ---------- Head diameter

For a single Nelson stud, the allowable concrete pullout strength is as follows.

$$P_d = 4 \times 0.85 \times \sqrt{3800} \times 116.6 = 24{,}438 \text{ lb}$$

The maximum load on a Nelson stud is 17,145 lb; therefore, the factor of safety (FS) is as follows.

$$FS = \frac{P_d}{F} = \frac{24{,}438}{17{,}145} = 1.43$$

The geometry of the four Nelson studs on the inlet top plate is such that the projected cones intersect each other. The combined projected area (A_{cd}) is 332 inches^2. The total load on the four Nelson studs is 18,817 pounds. The allowable concrete pullout strength (P_{cd}) is as follows.

$$P_{cd} = 4 \times 0.85 \times \sqrt{3800} \times 332.0 = 69{,}584 \text{ lb}$$

The factor of safety (FS) is as follows.

$$FS = \frac{P_{cd}}{F} = \frac{69{,}584}{18{,}817} = 3.70$$

The maximum stress in a Nelson stud is as follows.

$$\sigma = \frac{F}{A_s} = 39.0 \text{ ksi}$$

where:

$$A_s = \frac{\pi}{4} D^2 = 0.44 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{S_u}{\sigma} = \frac{58.0}{39.0} = 1.49$$

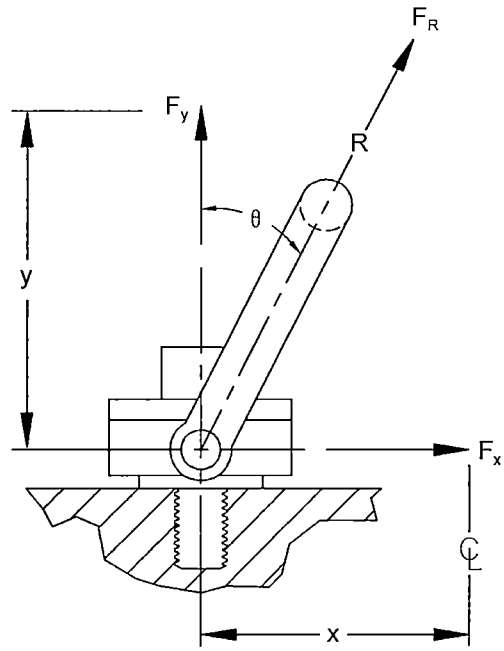
where:

S_u = 58.0 ksi ---------- Ultimate strength, A-36 carbon steel, at 300°F

3.4.3.2 TSC Lift

The adequacy of the TSC lifting components is demonstrated by evaluating the hoist rings, the TSC closure lid, and the weld that joins the closure lid to the TSC shell against the criteria in NUREG-0612 [3] and ANSI N14.6 [2]. The lifting configuration for the TSC consists of six hoist rings threaded into the closure lid assembly at equally spaced angular intervals. The hoist rings are analyzed as a redundant system with two three-legged lifting slings. For redundant lifting systems, ANSI N14.6 requires that load-bearing members be capable of lifting three times the load without exceeding the yield strength of the material and five times the load without exceeding the ultimate strength of the material. The closure lid is evaluated for lift conditions as a redundant system that demonstrates a factor of safety greater than three based on yield strength and a factor of safety greater than five based on ultimate strength. The TSC lift analysis is based on a load of 120,000 lb, which bounds the weight of the heaviest loaded TSC configuration. A dynamic load factor of 10% is considered in the analysis.

Hoist Ring and Sling Evaluation



The TSC lift configuration is shown in the accompanying sketch.

The vertical component force on the hoist ring, assuming a 10% dynamic load factor, is as follows.

$$F_y = \frac{120{,}000 \text{ lb} \times 1.1}{3 \text{ lift points}} = 44{,}000 \text{ lb}$$

As shown in the sketch, x is the distance from the TSC centerline to the hoist ring centerline (20.5 inch); F_x is the horizontal component of force on the hoist ring; R is the sling length; F_R is the maximum allowable force on the hoist ring; and the angle θ is the angle from vertical to the sling.

The hoist rings are rated at 50,000 lb with a safety factor of five on ultimate strength. Calculating the maximum angle (θ) that will limit F_R to 50,000 pounds is as follows.

$$\theta = \cos^{-1}\left(\frac{F_y}{F_R}\right) = \cos^{-1}\left(\frac{44{,}000}{50{,}000}\right) = 28.4°$$

The minimum sling length, R, is as follows.

$$R = \frac{x}{\sin\theta} = \frac{20.5}{\sin 28.4} = 43.1 \text{ inches}$$

A 50-inch sling places the lift hook about 44 inches above the top of the TSC (y = R cos θ = 50 cos 28.4° = 44 inches).

Bolt Shear

From the Machinery's Handbook [12], the shear stress (τ) in the hoist ring hole threads (2½-4-UNC) in the closure lid is calculated as follows.

$$\tau = \frac{F_y}{A_n} = \frac{44{,}000 \text{ lb}}{12.148 \text{ in}^2} = 3{,}622 \text{ psi}$$

where:

A_n = 12.148 inch^2 ---------- Shear area of the closure lid assembly threads based on a length of engagement of 2.0 inches.

The limiting case for the TSC closure lid allowable stress values corresponds to the TSC1/TSC2 closure lid fabricated from the optional SA336, Type 304 stainless steel material. Using shear allowables of 0.6 S_y and 0.5 S_u at a temperature of 300°F, the shear stress factors of safety are as follows.

Yield:

$$FS_y = \frac{0.6 \times 22{,}400 \text{ psi}}{3{,}622 \text{ psi}} = 3.7 > 3$$

Ultimate:

$$FS_u = \frac{0.5 \times 61{,}800 \text{ psi}}{3{,}622 \text{ psi}} = 8.5 > 5$$

The criteria of NUREG-0612 and ANSI N14.6 for redundant systems are met and the minimum thread engagement length of 2.0 inches is adequate.

The weight of the heaviest loaded transfer cask is less than 230,000 pounds. Three times the bounding weight of the loaded TSC is (3 × 120,000) 360,000 lb, which is greater than the weight of the heaviest transfer cask plus the weight of the loaded TSC (108,500 + 102,500 lb). Consequently, the preceding analysis bounds the inadvertent lift of the transfer cask during the handling of the TSC.

TSC Lift Evaluation

The structural adequacy of the TSC closure lid assembly and closure weld are evaluated using the finite element models described in Section 3.10.3. Bounding analyses are performed for the TSC configurations with a single-piece closure lid assembly (i.e., TSC1 and TSC2) and a composite closure lid assembly (i.e., TSC3 and TSC4). During a TSC lift, the acceleration due to gravity, with a dynamic load factor of 10%, is applied to the fully loaded TSC in the vertical direction. The maximum stress intensities in the TSC lid and closure weld resulting from a three-point lift, which all occur in the TSC3 and TSC4 configurations, are as follows:

Component Description	Stress Intensity (psi)
TSC Shell (below Closure Lid Weld)	3,919
Closure Lid Weld	1,501

The TSC3/TSC4 shell and closure lid have a yield strength of 18,000 psi and an ultimate strength of 63,400 psi. These are conservatively evaluated at a temperature of 650°F. The strength of the weld joint is taken as the same as the strength of the base material. Thus, when compared to the yield and ultimate strengths, the maximum nodal stress intensity of 3,919 psi produces the following factors of safety for a three-point lift.

Yield:

$$FS_y = \frac{\text{yield strength}}{\text{maximum stress intensity}} = \frac{18{,}000\ \text{psi}}{3{,}919\ \text{psi}} = 4.59 > 3$$

Ultimate:

$$FS_u = \frac{\text{ultimate strength}}{\text{maximum stress intensity}} = \frac{63{,}400\ \text{psi}}{3{,}919\ \text{psi}} = 16.2 > 5$$

The criteria of NUREG-0612 and ANSI N14.6 for redundant systems are met. Thus, the TSC shell and closure lid are adequate.

3.4.3.3 Transfer Cask Lift

The MAGNASTOR transfer casks are analyzed for loads associated with the heavy lift requirements specified in ANSI N14.6 [2] and NUREG–0612 [3]. All load path components of the casks are evaluated for structural adequacy. The transfer casks are analyzed for loads associated with the vertical lift of the transfer casks. The transfer cask is not designed for redundant lifting; therefore, factors of safety of six on material yield strength and ten on material ultimate strength are required for the lifting trunnions.

The analysis of the fully loaded transfer cask consists of a finite element analysis using the ANSYS program to calculate the stress in the transfer cask forgings, shells, and the trunnion region for the operational vertical lift condition. Additionally, the ANSYS program was used to evaluate stress in the retaining ring of the MTC2 cask for the inadvertent lift condition. Details of the ANSYS finite element model*s* are presented in Section 3.10.5. The structural evaluations of the rail, the shield door, and the rail welds are performed using standard engineering equations. The analysis of the carbon steel transfer cask, MTC1, is presented in Section 3.4.3.3.1, while the stainless steel transfer cask, MTC2, analysis is presented in Section 3.4.3.3.2.

3.4.3.3.1 Transfer Cask Lift: MTC1

The MTC1 transfer cask is analyzed in the following section. The design weight of the transfer cask is 230,000 pounds. A bounding weight of the transfer cask of 240,000 lb is considered in the evaluation. A conservative load of 264,000 lb (240,000 × 1.1 dynamic load factor) is used in the finite element analysis.

Transfer Cask Body

Table 3.4.3-1 provides the summaries of the stress intensities for the seven cross-sectional locations of the trunnion and top ring. Table 3.4.3-2 provides the stress summaries for the inner and outer shells and bottom ring. The maximum primary membrane stress intensity, P_m, and the maximum primary membrane plus bending stress intensity, $P_m + P_b$, is compared with the allowable stress criteria.

The cross-section of the trunnion is circular. Two cross-sectional areas are examined as shown in Figure 3.4.3-1. The maximum bending stress occurs at the cross-section (x = 43.9 inches) at the intersection of the trunnions with the outer diameter of the top forging ring. The maximum stress occurs at the trunnion surface. The maximum stress in the trunnion is 3.8 ksi. Comparing the stress to the material (A350 Grade LF 2) allowable yield and ultimate strength, the factors of safety are 8.1 (>6) for material yield strength and 18.5 (>10) for material ultimate strength.

For the top ring, the five cross-sectional areas selected for stress examination are shown in Figure 3.4.3-1. The maximum bending plus membrane stress occurs at the radial cross-section (topring-A1) above the trunnion. The bending stress through this cross-sectional area is 4.9 ksi. Comparing the stress to the material (A516 Gr 70) allowable yield and ultimate strength, the factors of safety are 6.6 (>6) and 14.2 (>10) for yield and ultimate material strengths, respectively.

For the inner shell, the maximum stress intensity occurs at the location of "θ = 10°, z = -7.0 inches", which is outside the intersection just below the trunnion. The maximum bending plus membrane stress through the shell is 2.3 ksi. Comparing the stress to the material (A588) allowable yield and ultimate strengths, the factors of safety are 18.6 (>6) and 30.2 (>10), respectively.

For the outer shell, the maximum stress intensity occurs at the location of "θ = 10°, z = -7.0 inches", which is outside the intersection just below the trunnion. The maximum bending plus membrane stress in the shell thickness is 3.5 ksi. Comparing the stress to the material (A588) allowable yield and ultimate strengths, the factors of safety are12.3 (>6) and 20 (>10), respectively.

For the bottom ring the maximum stress intensity occurs at the nodal location of "θ = 90°, z = -173.5 inches", which is just below the inner and outer shells. The maximum membrane plus bending stress in the ring thickness is 0.7 ksi. Comparing this stress to the material (A588) allowable yield and ultimate strengths, the factors of safety are 58 (>6) and 94 (>10) for yield and ultimate strength, respectively.

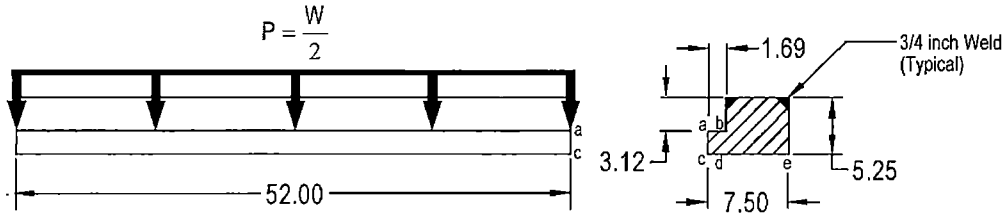
Transfer Cask Shield Door Rails and Welds

This section demonstrates the adequacy of the transfer cask shield doors, door rails, and welds in accordance with NUREG-0612 and ANSI N14.6, which require safety factors of six and ten on material yield strength and ultimate strength, respectively, for nonredundant lift systems. The transfer cask shield doors and door rails are designed to retain and support the maximum loaded TSC weight of 118,000 lb, which includes the weight of basket, fuel, and water. The shield doors are 5-inch thick plates that slide on the door rails. The rails are 7.50-inches wide × 52-inches long and are welded to the bottom ring of the transfer cask. The doors and the rails are constructed of A-588 and SA-350 Grade LF 2 low alloy steel, respectively.

A weight of 143,000 lb (>118,000 × 1.1) is conservatively used for the evaluation of the rails. This weight bounds the weight of the heaviest loaded TSC, the weight of the water in the TSC, and the weight of the shield doors and rails. The 10% dynamic load factor is included to ensure that the evaluation bounds all normal operating conditions. Allowable stress for the component materials are taken at 400°F, which bounds the maximum temperature at the bottom of the transfer cask under normal conditions.

Stress Evaluation for Door Rail

Each rail is assumed to carry one-half of the load.



All Dimensions in Inches

The shear stress (τ) in each door rail bottom plate (section b-d) due to the applied load is as follows.

$$\tau = \frac{P}{A} = \frac{143.0/2}{110.8} = 0.65 \text{ ksi}$$

where:

$A = (5.25 - 3.12) \times 52 = 110.8 \text{ inch}^2$ ------- Shear area

The bending stress (σ_b) in each rail bottom section b-d due to the applied load, P, is as follows.

$$\sigma_b = \frac{6M}{Lt_{a\text{-}c}^{\ 2}} = 3.1 \text{ ksi}$$

where:

$M = P \times L_{a\text{-}b} = 120.8$ inch-kip
$L_{a\text{-}b} = 1.69$ inches ---------- Applied load moment arm
$L = 52$ inches ---------- Length of the rail
$t_{a\text{-}c} = 2.13$ inches ---------- Thickness of the rail

The maximum stress (σ) intensity in the bottom section of the rail is as follows.

$$\sigma = \sqrt{(\sigma_b)^2 + 4\tau^2} = 3.4 \text{ ksi}$$

The factor of safety (FS) based on the material yield strength is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{30.8 \text{ ksi}}{3.4 \text{ ksi}} = 9.1 > 6$$

where:

S_y=30.8 ksi ---------- Yield strength for A350 Grade LF 2, at 400°F

The factor of safety (FS) based on the material ultimate strength is as follows.

$$FS = \frac{S_u}{\sigma} = \frac{70 \text{ ksi}}{3.4 \text{ ksi}} = 20.6 > 10$$

where:

$S_u = 70.0$ ksi ---------- Ultimate strength A-350 Grade LF 2, at 400°F

Stress Evaluation for the Shield Doors

The shield doors are 5-inches thick at the center and step down to 2.94-inches thick at the edges, where they rest on the rails. The stepped edges of the two door leaves are designed to interlock at the center. Therefore, the doors are analyzed as single simply supported plates. The engagement length of the door with the rail is 52 inches. The shear stress (τ) at the edge of the shield door where the door contacts the rail is as follows.

$$\tau = \frac{P}{A_S} = 0.47 \text{ ksi}$$

where:

$A_S = t_d \times L = 152.9$ inch^2 ---------- Total shear area
$t_d = 5.0 - 2.06 = 2.94$ inches ---------- Thickness of the door at edge
$L = 52$ inches ---------- Length of door and rail engagement

The maximum bending stress (σ_b) at the center of the doors is as follows.

$$\sigma_b = \frac{Mc}{I} = 4.0 \text{ ksi}$$

where:

$$M = \frac{WL}{8} = 1.36 \times 10^6 \text{ inch-lb}$$

W = 143,000 lb ---------- Total weight

$$c = \frac{h}{2} = 2.5 \text{ inches}$$ ---------- Distance to surface

$$I = \frac{bh^3}{12} = 855 \text{ inch}^4$$ ---------- Cross-sectional moment of inertia

L = 76 inches ---------- Span length

The maximum stress intensity (σ) in the door is as follows.

$$\sigma = \sqrt{(\sigma_b)^2 + 4\tau^2} = 4.1 \text{ ksi}$$

The factor of safety (FS) based on the yield strength is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{43 \text{ ksi}}{4.1 \text{ksi}} = 10.5 > 6$$

where:

S_y = 43 ksi ---------- Yield strength for A-588, at 400°F

The factor of safety (FS) based on the ultimate strength is as follows.

$$FS = \frac{S_u}{\sigma} = \frac{70 \text{ ksi}}{4.1 \text{ksi}} = 17.1 > 10$$

where:

S_u = 70.0 ksi ---------- Ultimate strength for A-588, at 400°F

Door Rail Weld Evaluation

The door rails are attached to the bottom forging of the transfer cask by 0.75-inch partial penetration bevel groove welds that extend the full length of the inside and outside of each rail. The loaded TSC weight is conservatively assumed to act at a point on the inside edge of the rail. Since the base metal is the limiting strength of the welded section, the ultimate strength on the inner weld is evaluated. Summing moments about the edge of outer weld are as follows.

$$\Sigma M = 0 = P \times L_{c\text{-}e} - F_w \times \left(L_{d-e} - \frac{L_w}{2} \right) \Rightarrow F_w = 91 \text{ kip}$$

where:

$P = \frac{W}{2} = 71.5$ kip ---------- Load on a single rail

$L_w = 0.75$ inch ---------- Weld length

$L_{d\text{-}e} = 7.5 - 1.69 = 5.81$ ---------- Distance from edge of inner weld to edge of outer weld

$L_{c\text{-}e} = 7.5$ inches ---------- Width of the rail

The maximum stress (σ) in the base metal attached by the inner weld is as follows.

$$\sigma = \frac{F_w}{A_w} = 2.3 \text{ ksi}$$

where:

$Aw = 0.75 \times 52 = 39$ inch^2 ---------- Area on the base metal supporting inner weld

The factor of safety (FS) based on the yield strength is as follows.

$$FS = \frac{43 \text{ ksi}}{2.3 \text{ ksi}} = 18.7 > 6$$

The factor of safety (FS) based on the ultimate strength is as follows.

$$FS = \frac{70 \text{ ksi}}{2.3 \text{ ksi}} = 30.4 > 10$$

Trunnion Bearing Stress Evaluation

During a vertical lifting load case, the transfer cask is being lifted by the trunnions.

The load on each trunnion is 132 kips (240 × 1.1/2). The minimum trunnion bearing engagement depth is 7.5-inches, but only 50% of this is used in the evaluation. The diameter of the trunnion is 9 inches. The bearing stress on the trunnion (σ_b) is as follows.

$$\sigma_{brg} = \frac{W_{VL}}{A_{brg}} = \frac{132}{33.75} = 3.92 \text{ ksi}$$

The factor of safety (FS) is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{30.8}{3.92} = 7.85$$

where:

S_y = 30.8 ksi ---------- Yield strength, SA-350 LF2, at 400°F

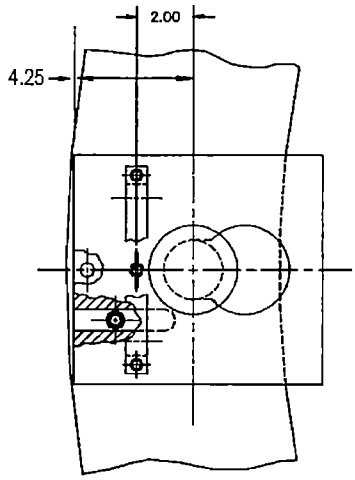
Inadvertent Lift of Transfer Cask by TSC

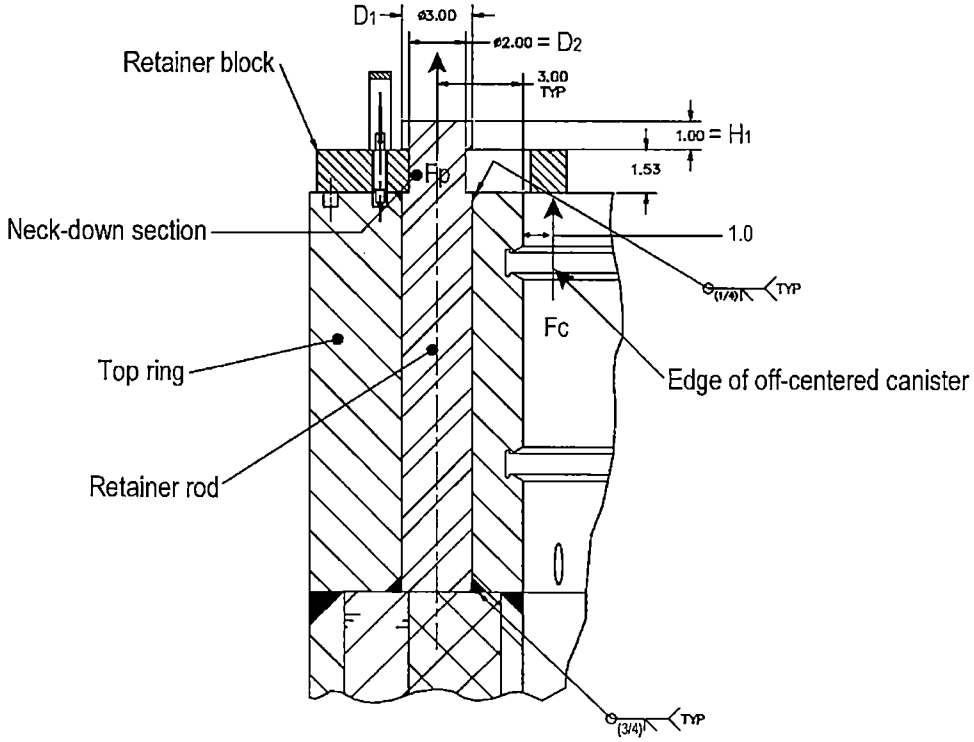
The inadvertent lift of the transfer cask by the TSC is considered an off-normal event. The stresses associated with this condition are required to satisfy allowable stress limits for ASME Boiler and Pressure Vessel Code, Service Level C condition. The temperature of the cask at the top is assumed to be 300°F.

In the event the transfer cask is lifted by the TSC during handling operations, instead of by the transfer cask trunnions, the weight of the transfer cask is supported by the three retaining blocks mounted on top of the transfer cask top ring. In this case, the retaining blocks must have sufficient strength to support the weight of the transfer cask. The three retaining blocks on the top-forging ring are spaced 120° apart.

Retainer Rod Evaluation

During an inadvertent lift of the transfer cask, the retainer rod is subjected to a tensile load, F_P, due to the prying action of the retaining block. The top view and the side view of the retaining block are shown in the following sketches.





A conservative weight of 110,000 lb is used for this evaluation. This weight bounds the maximum weight of the transfer cask. The dynamic load factor, DLF, is 1.1. The maximum uplifting force applied by the TSC to the retainer block, F_c, is 110 kip (1.1)/3 = 40.3 kip. When the TSC is off-center, the maximum distance between the TSC outer edge and the inner edge of the transfer cask is one inch. The prying force applied to the retainer rod (Fp) is as follows.

$$Fp = \frac{40.3 \times (1+3+4.25)}{4.25} = 78.2 \text{ kip}$$

Effective Stress Areas of Retainer Rod

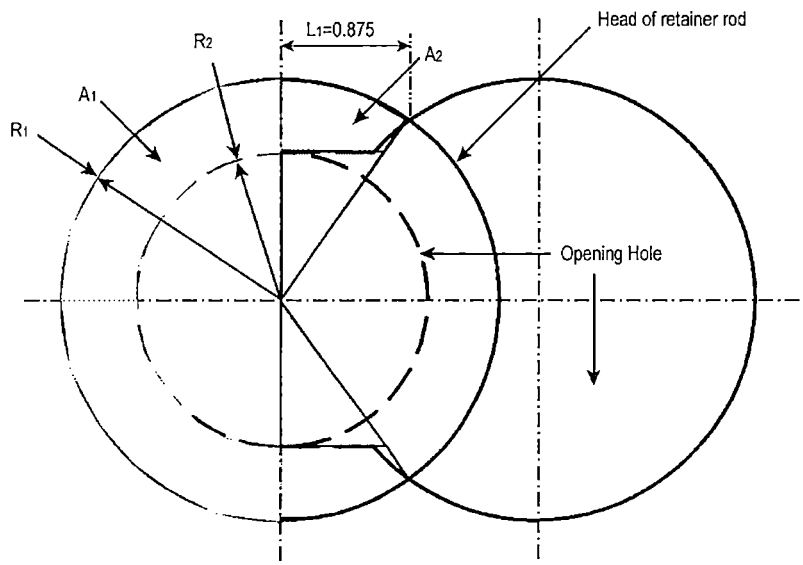
Referring to the previous sketch, the cross-sectional areas for the retainer rod evaluation are as follows.

$A_t = \frac{\pi}{4} D_2^2 = 3.14 \text{ inch}^2$ ---------- Tensile area (neck down area)

$A_{ws} = \pi D_1 H_w = 7.07 \text{ inch}^2$ ---------- Weld shear area

$A_{sh} = \pi D_2 H_1 = 6.28 \text{ inch}^2$ ---------- Head shear area (through head thickness)

The bearing area in the retainer rod just above the neck-down area is the hatched area as shown in the following sketch.



The total bearing area (A_{brg}) is as follows.

$$A_{brg} = 2(A_1 + A_2) = 2(0.982 + 0.342) = 2.648 \text{ inch}^2$$

Retainer Rod Load Capacity:

The load capabilities of the retainer rod are calculated in the following.

$F_{tensile}$ = $(A_t)(S_M)$= (3.14)(33.6) = 105.5 kip -------- Load capability at D2
F_{ws} = $(A_{ws})(S_S)$ = (7.07)(19.08) = 134.9 kip -------- Shear capability of weld
F_{brg} = $(A_{brg})(S_{brg})$ = (2.648)(33.6) = 88.9 kip -------- Bearing capability of rod head
F_{sh} = $(A_{sh})(S_S)$ = (6.28)(20.16) = 126.6 kip -------- Shear capability under rod head

where:

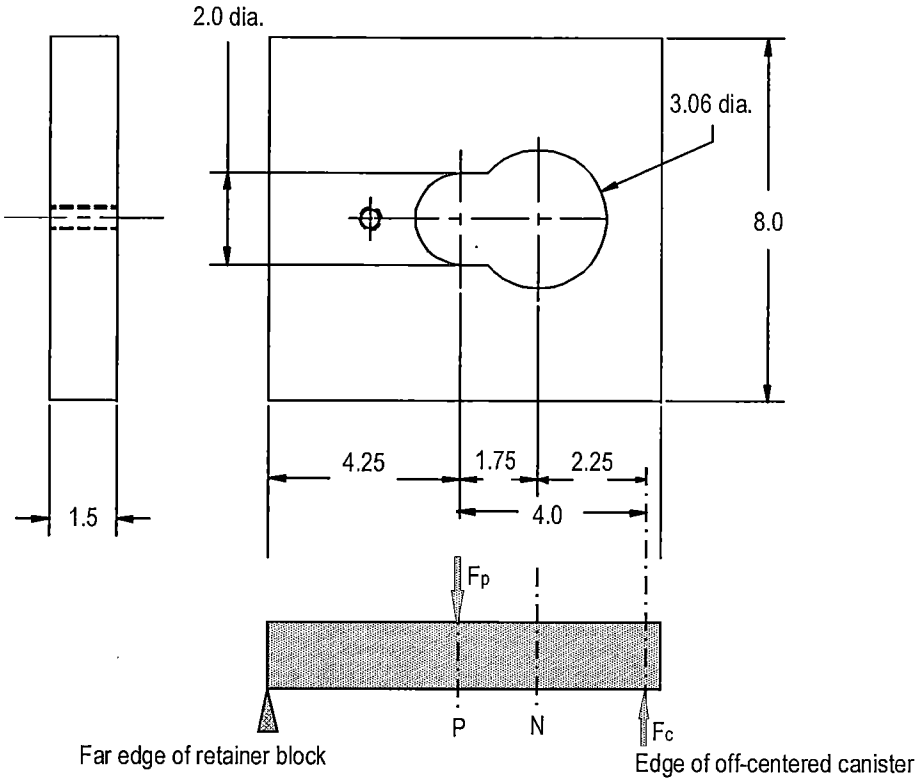
S_M = 1.5 S_m = 1.5 (22.4) = 33.6 ksi
S_S = 1.5(0.6) S_m = 0.9 (22.4) = 20.16 ksi
S_{Sw} = 1.5(0.6) S_{m350} = 0.9 (21.2) = 19.08 ksi
S_{brg} = S_y = 33.6 ksi
S_y = 33.6 ksi ---------- Yield strength, A-516 Grade 70 at 300°F
S_m = 22.4 ksi ---------- Design stress intensity, A-516 Grade 70 at 300°F
S_{m350} = 21.2 ksi ---------- Design stress intensity, A350 Grade LF 2 at 300°F

The minimum factor of safety (FS) is as follows.

$$FS = \frac{F_{brg}}{F_p} = \frac{88.9}{78.2} = 1.14$$

Retainer Block Evaluation

The retainer block and the force-loading diagram are shown in the following sketch.



Point P is where the headed retainer rod is loaded under prying force F_p. The maximum bending stress (σ_b) in the retainer block is as follows.

$$\sigma_b = \frac{Mc}{I} = 71.6 \text{ ksi}$$

where:

$M = F_c(4) = 161.2$ kip-inch
$F_c = 40.3$ kip
$I = \frac{bh^3}{12} = 1.688 \text{ inch}^4$
$C = 0.75$ inch

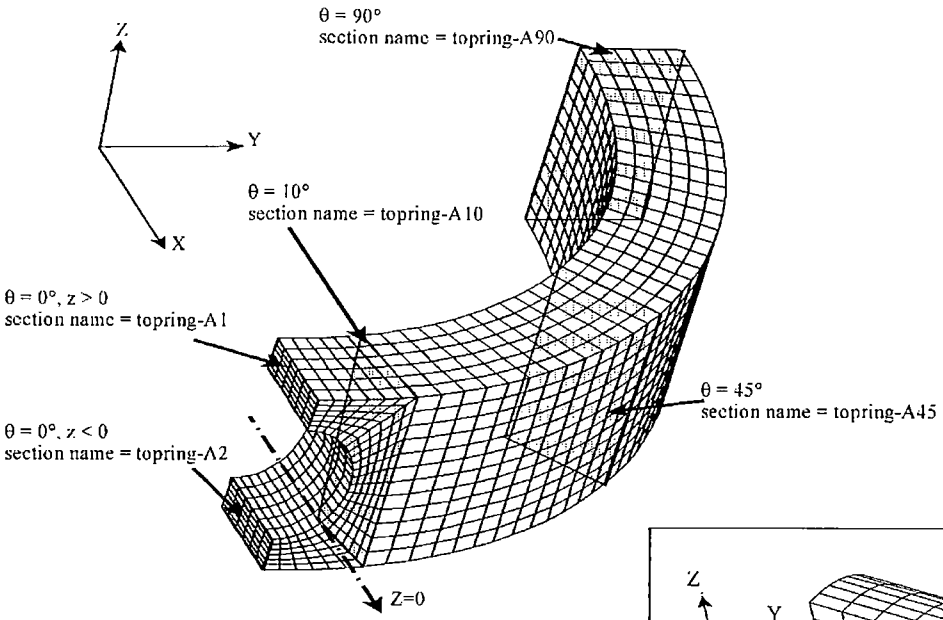
The factor of safety (FS) is as follows.

$$FS = \frac{2.25S_m}{\sigma_b} = 1.41$$

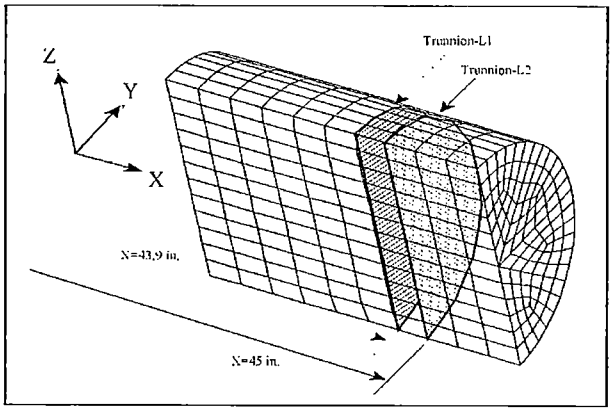
where:

S_m = 45.0 ksi ---------- Yield strength, 17-4 PH at 300°F

Figure 3.4.3-1 Top Ring Section Cuts



Top Ring Section without Trunnion



Trunnion (enlarged)

Table 3.4.3-1 Stress Intensity for MTC1 Trunnions and Top Ring

Location [a]	Position [a]	P_m [b] ksi	P_b [b] ksi	$P_m + P_b$ [b] ksi	Material	S_{yield} ksi	$S_{ultimate}$ ksi	FS_{Yield}	$FS_{Ultimate}$
Trunnion-L1	x =43.9 inch	0.04	3.75	3.79	SA350	30.8	70.0	8.1	Large
Trunnion-L2	x = 45 inch	0.00	2.05	2.05	SA350	30.8	70.0	Large	Large
TopRing-A1	θ = 0°, z > 0	2.37	2.57	4.93	SA516	32.5	70.0	6.6	Large
TopRing-A2	θ = 0°, z < 0	0.33	1.29	1.63	SA516	32.5	70.0	Large	Large
TopRing-A10	θ = 10°	0.07	1.02	1.09	SA516	32.5	70.0	Large	Large
TopRing-A45	θ = 45°	0.11	0.84	0.95	SA516	32.5	70.0	Large	Large
TopRing-A90	θ = 90°	0.11	0.75	0.86	SA516	32.5	70.0	Large	Large

Table 3.4.3-2 Stress Intensity for MTC1 Shells and Bottom Ring

Location [c]	Position[c]	$P_m + P_b$ [d] ksi	Material	S_{yield} ksi	$S_{ultimate}$ ksi	FS_{Yield}	$FS_{Ultimate}$
Inner Shell	θ = 10°, z=-7 inch	2.32	A588	43.0	70.0	Large	Large
Outer Shell	θ = 10°, z=-7 inch	3.50	A588	43.0	70.0	Large	Large
Bottom Ring	θ = 90°, z=-173.5	0.74	A588	43.0	70.0	Large	Large

[a] The locations and positions are defined in Figure 3.4.3-1.
[b] P_m = primary membrane stress intensity; P_b = primary bending stress intensity; $P_m + P_b$ = primary membrane + bending stress intensity.
[c] The locations and positions correspond to the axis shown in Figure 3.10.5-1, Section 3.10.5.
[d] $P_m + P_b$ = primary membrane + bending stress intensity.

3.4.3.3.2 Transfer Cask Lift: MTC2

The MTC2 transfer cask is analyzed in the following section. A bounding weight of the transfer cask of 228,000 lb is considered in the evaluation. A conservative load of 250,800 lb (228,000 × 1.1 dynamic load factor) is used in the finite element analysis.

Transfer Cask Body

Table 3.4.3-3 provides the summaries of the stress intensities for the seven cross-sectional locations of the trunnion and top ring. Table 3.4.3-4 provides the stress summaries for the inner and outer shells and bottom ring. The maximum primary membrane stress intensity, P_m, and the maximum primary membrane plus bending stress intensity, $P_m + P_b$, are compared with the allowable stress criteria.

The cross-section of the trunnion is circular. Two cross-sectional areas are examined as shown in Figure 3.4.3-1. The MTC2 and MTC1 transfer cask models are similar. As such, the locations depicted in Figure 3.4.3-1 correspond to the same locations used for the MTC2 analysis. The maximum bending stress occurs at the cross-section (× = 43.9 inches) at the intersection of the trunnions with the outer diameter of the top forging ring. The maximum stress occurs at the trunnion surface. The maximum stress in the trunnion is 3.62 ksi. Comparing the stress to the material (SA182 F304) allowable yield and ultimate strength, the factors of safety are 6.9 (>6) for material yield strength and 18.3 (>10) for material ultimate strength.

For the top ring, the five cross-sectional areas selected for stress examination are shown for the MTC1 transfer cask in Figure 3.4.3-1. The MTC2 and MTC1 transfer cask models are similar. As such, the locations depicted in Figure 3.4.3-1 correspond to same locations used for the MTC2 analysis. The maximum bending plus membrane stress occurs at the radial cross-section (topring-A1) above the trunnion. The bending stress through this cross-sectional area is 4.14 ksi. Comparing the stress to the material (SA182 F304 or SA336 F304) allowable yield and ultimate strength, the factors of safety are 6.04 (>6) and 16.01 (>10) for yield and ultimate material strengths, respectively.

For the inner shell, the maximum stress intensity occurs at the location of "$\theta = 0°$, $z = -5.625$ inches," which is outside the intersection just below the trunnion. The maximum bending plus membrane stress through the shell is 1.37 ksi. Comparing the stress to the material (SA240 304) allowable yield and ultimate strengths, the factors of safety are 18.2 (>6) and 51.8 (>10), respectively.

For the outer shell, the maximum stress intensity occurs at the location of "θ = 8.3°, z = -5.625 inches," which is outside the intersection just below the trunnion. The maximum bending plus membrane stress through the shell thickness is 3.27 ksi. Comparing the stress to the material (SA240 304) allowable yield and ultimate strengths, the factors of safety are 7.6 (>6) and 21.7 (>10), respectively.

For the bottom ring, the maximum stress intensity occurs at the nodal location of "θ = 90°, z = -165.125 inches," which is just below the inner and outer shells. The maximum membrane plus bending stress through the ring thickness is 0.34 ksi. Comparing this stress to the material (SA182 F304 or SA336 F304) allowable yield and ultimate strengths, the factors of safety are 73.5 (>6) and 195 (>10) for yield and ultimate strength, respectively.

Stress Evaluation for Door Rail and Shield Doors

The shield doors and door rails of the MTC2 transfer cask are similar in geometry, but differ in material from those of the MTC1 transfer cask, which are evaluated in Section 3.4.3.3.1. The loading conditions analyzed in the Section 3.4.3.3.1 analysis are bounding for the MTC2 transfer cask. Therefore, the stresses provided in Section 3.4.3.3.1 are bounding for the shield doors and door rails of the MTC2 transfer cask. Factors of safety are calculated for the MTC2 transfer cask shield doors and door rails using the Section 3.4.3.3.1 stresses and the appropriate stress allowables.

Door Rail

The factor of safety (FS) for the door rail, based on the material yield strength, is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{25.0\text{ ksi}}{3.4\text{ ksi}} = 7.4 > 6$$

where:

S_y = 25.0 ksi ---------- Yield strength for SA182 F304, at 200°F

σ = 3.4 ksi ---------- The maximum stress (σ) intensity in the bottom section of the rail (Section 3.4.3.3.1)

The factor of safety (FS) for the door rail, based on the material ultimate strength, is as follows.

$$FS = \frac{S_u}{\sigma} = \frac{66.3\text{ ksi}}{3.4\text{ ksi}} = 19.5 > 10$$

where:

S_u = 66.3 ksi ---------- Ultimate strength for SA182 F304, at 200°F

σ = 3.4 ksi ---------- The maximum stress (σ) intensity in the bottom section of the rail (Section 3.4.3.3.1)

Shield Doors

The factor of safety (FS) for the shield door, based on the material yield strength, is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{25.0\,\text{ksi}}{4.1\,\text{ksi}} = 6.1 > 6$$

where:

S_y = 25.0 ksi ---------- Yield strength for SA182 F304, at 200°F

σ = 4.1 ksi ---------- The maximum stress (σ) intensity in the door (Section 3.4.3.3.1)

The factor of safety (FS) for the shield door, based on the material ultimate strength, is as follows.

$$FS = \frac{S_u}{\sigma} = \frac{66.3\,\text{ksi}}{4.1\,\text{ksi}} = 16.2 > 10$$

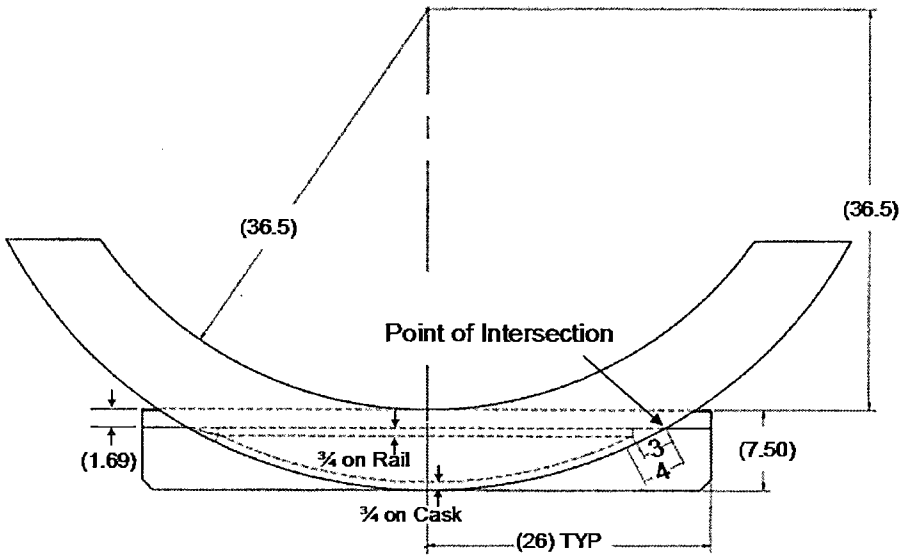
where:

S_u = 66.3 ksi ---------- Ultimate strength for SA182 F304, at 200°F

σ = 4.1 ksi ---------- The maximum stress (σ) intensity in the door (Section 3.4.3.3.1)

Door Rail Weld

The door rails are attached to the bottom forging of the transfer cask by 3/4-inch partial penetration bevel groove welds along the rail inner surface and at the outer surface of the cask, as shown in the figure below. As a minimum the weld is to extend within 3.5 inches from the intersection of the inner surface of the rail and outer surface of the cask.



Key Parameters:

P = 71.5 kip ---------- Load in a single rail

D = 88.0 in ---------- Bottom ring outer diameter

t = 0.75 in ---------- Weld thickness

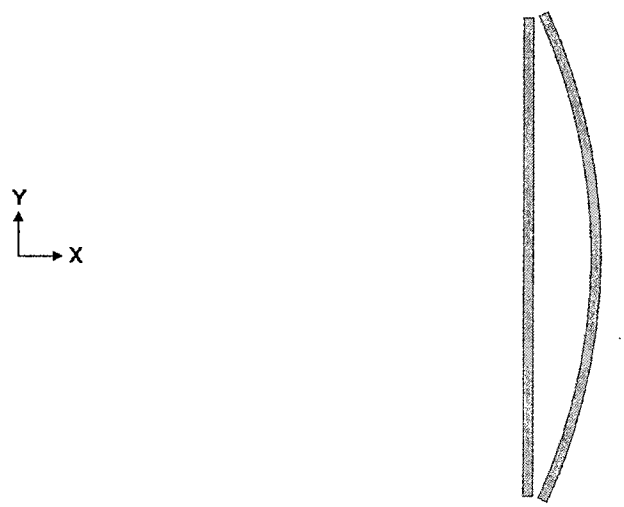
w = 7.5 - 1.69 = 5.81 in--- Door rail top section width

where,

w_{rc} = 1.69 in ---------- width of rail cutout

w_r = 7.5 in ---------- width of rail

An ANSYS model of the weld area is generated to accurately calculate the cross sectional properties of the weld. The weld area used for the ANSYS model extends to a distance 4.0 inches of the intersection point, defined as the intersection of the inner surface of the rail (at the top) and the outer surface of the cask. This is a conservative approach since the weld will extend further than this. The weld area is also shown below:



The cross sectional properties of the weld areas are:

$A = 54.84\ in^2$ ---------- Weld area

$I_c = 232.85\ in^4$ ---------- Moment of inertia about y axis from the centroid

$x_c = 40.48$ in ---------- Location of the centroid

$C_i = x_c - (D/2 - w) = 2.29$ in ---------- Distance from centroid to surface of rail weld

Using these properties the inner weld section modulus and moment due to the vertical load at the inner surface of the rail are:

$Z_c = I_c / C_i = 101.68\ in^2$ ---------- Inner weld section modulus

The vertical load, P, exerts tensile load on both the inner weld and the outer weld. The moment, M, exerts tensile load on the inner weld and compressive load on the outer fiber of the outer weld. Therefore, the inner weld stress is bounding since the exerted stresses are both tensile and additive.

σ_m = P / A = 71.5 / 54.84 = 1.30 ksi ---------- Weld membrane stress

σ_b = M / Z_c = 284.6 / 101.68 = 2.79 ksi --------- Weld bending stress

σ_{mb} = $\sigma_P + \sigma_M$ = 4.1 ksi ---------- Weld membrane plus bending stress

The factor of safety (FS) for the inner weld, based on the material yield strength, is as follows.

$$FS = \frac{S_y}{\sigma_{mb}} = \frac{25.0\,\text{ksi}}{4.1\,\text{ksi}} = 6.1 > 6$$

where:

S_y = 25.0 ksi ---------- Yield strength for SA182 F304, at 200°F

The factor of safety (FS) for the inner weld, based on the material ultimate strength, is as follows.

$$FS = \frac{S_u}{\sigma_{mb}} = \frac{66.3\,\text{ksi}}{4.1\,\text{ksi}} = 16.2 > 10$$

where:

S_u = 66.3 ksi ---------- Ultimate strength for SA182 F304, at 200°F

Trunnion Bearing Stress Evaluation

During a vertical lifting load case, the transfer cask is being lifted by the trunnions.

The load on each trunnion is 125.4 kips (228 × 1.1/2). The minimum trunnion bearing engagement depth is 7.5-inches, but only 50% of this is used in the evaluation. The diameter of the trunnion is 9 inches. The bearing stress on the trunnion (σ_b) is as follows.

$$\sigma_{brg} = \frac{W_{VL}}{A_{brg}} = \frac{125.4}{33.75} = 3.72\ \text{ksi}$$

The factor of safety (FS) is as follows.

$$FS = \frac{S_y}{\sigma} = \frac{25.0}{3.72} = 6.7$$

where:

S_y = 25.0 ksi ---------- Yield strength, SA182 F304, at 200°F

Inadvertent Lift of Transfer Cask by TSC

The inadvertent lift of the transfer cask by the TSC is considered an off-normal event. The stresses associated with this condition are required to satisfy allowable stress limits for ASME Boiler and Pressure Vessel Code, Service Level C condition. In the event the transfer cask is lifted by the TSC during handling operations instead of by the transfer cask trunnions, the weight of the transfer cask is supported by a retaining ring or retaining blocks mounted to the top of the MTC2 transfer cask top ring. Evaluation of the retaining ring and retaining block configurations is provided in the following sections.

Inadvertent Lift – Retaining Ring

For the evaluation of the retaining ring configuration, the temperature of the cask at the top is conservatively assumed to be 200°F. The retaining ring is mounted to the transfer cask top ring using a minimum of sixteen 1"- 8 UNC bolts spaced 22.5° apart. In this case, the retaining ring and mounting bolts must have sufficient strength to support the weight of the transfer cask. A bounding weight of the empty transfer cask of 108,500 lb is considered in the evaluation. A conservative load of 119,350 lb (108,500 × 1.1 dynamic load factor) is used in the finite element analysis. Additionally, the retaining ring evaluation considers a bounding maximum bolt preload of 80 ft-lb.

A summary of the stress intensities for the retaining ring is shown in Table 3.4.3-5. The maximum primary membrane stress intensity, P_m, and the maximum primary membrane plus bending stress intensity, $P_m + P_b$, are compared with the allowable stress criteria. The allowable membrane stress for the retaining ring is

$$S_{allow} = 1.5S_m = 1.5(20) = 30 \text{ ksi}$$

and the allowable membrane plus bending stress for the retaining ring is

$$S_{allow} = 1.5(1.5)S_m = 2.25(20) = 45 \text{ ksi}$$

where:

S_y = 20.0 ksi ----------design stress intensity for SA182 F304, at 200°F

For the retaining ring, the maximum stress intensity occurs at the inner radius of the bolt hole, as shown as the critical section location in Figure 3.4.3-2. The maximum retaining ring membrane stress is 9.4 ksi and membrane plus bending stress is 37.2 ksi, which give factors of safety of 3.19 and 1.21, respectively.

Bearing Stress

The single bolt tensile load, F, is 14,400 pounds. The resulting retaining ring bearing stress is

$$S = \frac{F}{A} = \frac{14{,}400}{0.8146} = 17.7\,\text{ksi}$$

where:

A = 0.8146---------- conservative bolt head bearing area

The factor of safety (FS) for the bearing stress of the retaining ring is

$$FS = \frac{S_y}{17.7} = \frac{25}{17.7} = 1.41$$

where:

S_y = 25 ksi ---------- yield strength of SA240 Type 304, at 200°F

Bolt Tensile Stress

The tensile area of the bolt is given as

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.7854\left(1 - \frac{0.9743}{8}\right)^2 = 0.6057\,\text{in}^2$$

where:

D = 1 in ---------- Nominal bolt diameter
n = 8 ---------- Threads per inch

The tensile stress is as follows:

$$\sigma = \frac{F}{A_t} = \frac{14{,}400}{0.6057} = 23.8\,\text{ksi}$$

where:

F = 14,400 lbs---------- single bolt tensile load

The safety factor for bolt failure in tension is:

$$FS = \frac{1.25S_u/3.33}{\sigma} = \frac{1.25(71.0)/3.33}{23.8} = 1.12$$

where:

S_u = 71.0 ksi ---------- ultimate strength of SA193 Grade B8, at 200°F

Bolt Thread Shear Stress

The SA193 Grade B8 bolts have lower strength than the top-forging ring. Therefore, the shear stress in the threads of the bolts is evaluated.

The shear area for the external threads for the 1" – 8 UNC bolts, A_s, is calculated as:

$$A_s = 3.1416 n L_e K_n max\left[\frac{1}{2n} + 0.57735\left(E_s min - K_n max\right)\right] = 2.4844 \text{ in}^2$$

where:

n	=	8	Threads per inch
$E_s min$	=	0.91 in	Minimum pitch diameter of bolt threads
$K_n max$	=	0.89 in	Maximum minor diameter of lid threads
L_e	=	1.5 in	Minimum thread engagement

The shear stress (τ_s) in the bolt threads is:

$$\tau_s = \frac{F}{A_s} = \frac{14{,}400 \text{ lb}}{2.4844 \text{in}^2} = 5{,}796 \text{ psi}$$

where:

F = 14,400 lbs ---------- single bolt tensile load

The shear allowable is:

$$\tau_{allowable} = \frac{1.25 \times 0.62 S_u}{5} = \frac{1.25 \times 0.62(71.0)}{5} = 11.01 \text{ ksi}$$

where:

S_u = 71.0 ksi ---------- ultimate strength for SA193 Grade B8, at 200°F

The factor of safety is:

$$FS = \frac{\tau_{allowable}}{\tau_s} = \frac{11.01}{5.80} = 1.90$$

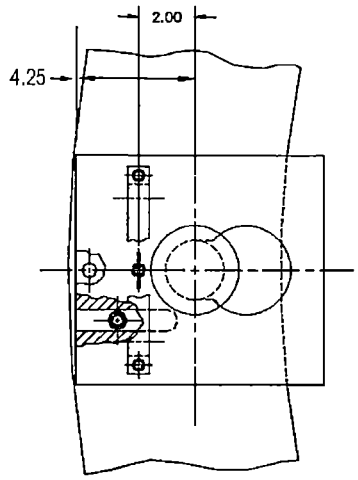
Therefore, the threads in the bolts will not fail in shear.

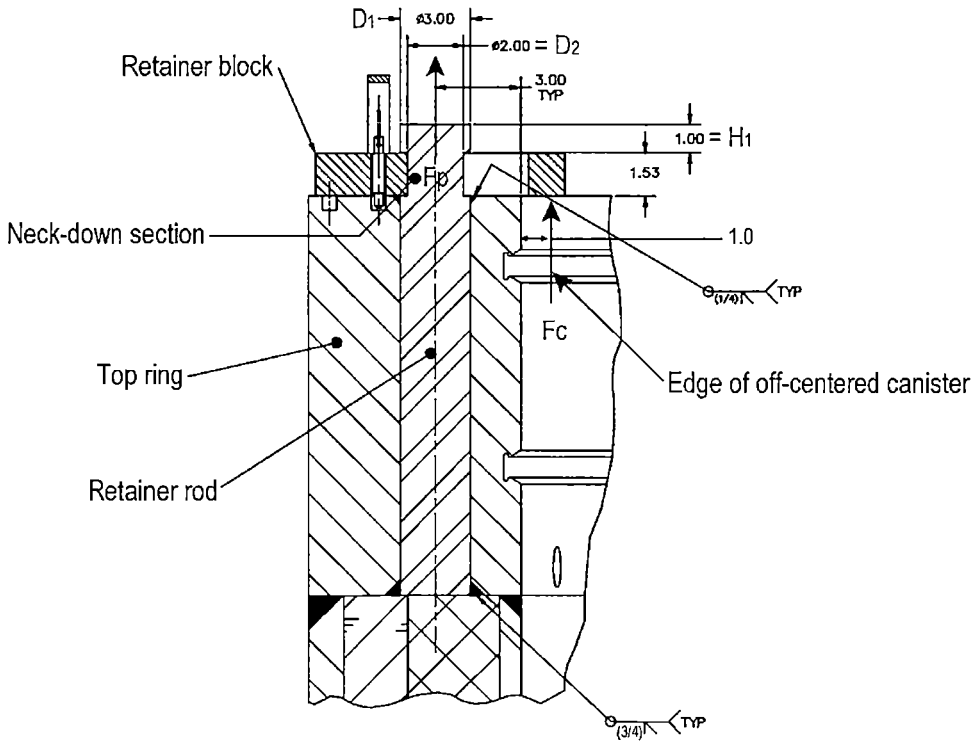
Inadvertent Lift – Retaining Blocks

The retaining blocks must have sufficient strength to support the weight of the transfer cask under an inadvertent lift condition. The three retaining blocks on the top-forging ring are spaced 120° apart. For the evaluation of the retaining block configuration the temperature of the cask at the top is assumed to be 300°F.

Retainer Rod Evaluation

During an inadvertent lift of the transfer cask, the retainer rod is subjected to a tensile load, F_P, due to the prying action of the retaining block. The top view and the side view of the retaining block are shown in the following sketches.





A conservative weight of 110,000 lb is used for this evaluation. This weight bounds the maximum weight of the transfer cask. The dynamic load factor, DLF, is 1.1. The maximum uplifting force applied by the TSC to the retainer block, F_c, is 110 kip (1.1)/3 = 40.3 kip. When the TSC is off-center, the maximum distance between the TSC outer edge and the inner edge of the transfer cask is one inch. The prying force applied to the retainer rod (Fp) is as follows.

$$Fp = \frac{40.3 \times (1+3+4.26)}{4.26} = 78.1 \text{ kip}$$

Effective Stress Areas of Retainer Rod

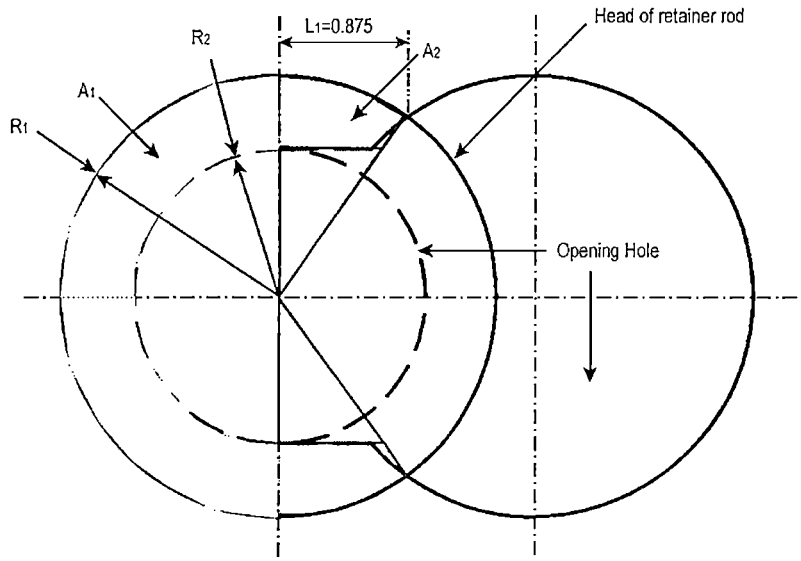
Referring to the previous sketch, the cross-sectional areas for the retainer rod evaluation are as follows.

$A_t = \frac{\pi}{4} D_2^2 = 3.976 \text{ inch}^2$ ---------- Tensile area (neck down area)

$A_{ws} = \pi D_1 H_w = 8.247 \text{ inch}^2$ ---------- Weld shear area

$A_{sh} = \pi D_2 H_1 = 7.069 \text{ inch}^2$ ---------- Head shear area (through head thickness)

The bearing area in the retainer rod just above the neck-down area is the hatched area as shown in the following sketch.



The total bearing area (A_{brg}) is as follows.

$$A_{brg} = 2(A_1 + A_2) = 2(1.411 + 0.437) = 3.696 \text{ inch}^2$$

Retainer Rod Load Capacity:

The load capabilities of the retainer rod are calculated in the following.

$F_{tensile}$ = $(A_t)(S_M)$= (3.976)(30.0) = 119.28 kip -------- Load capability at D2
F_{ws} = $(A_{ws})(S_S)$ = (8.247)(18.0) = 148.4 kip -------- Shear capability of weld
F_{brg} = $(A_{brg})(S_{brg})$ = (3.696)(22.4) = 82.79 kip -------- Bearing capability of rod head
F_{sh} = $(A_{sh})(S_S)$ = (7.069)(18.0) = 127.24 kip -------- Shear capability under rod head

where:

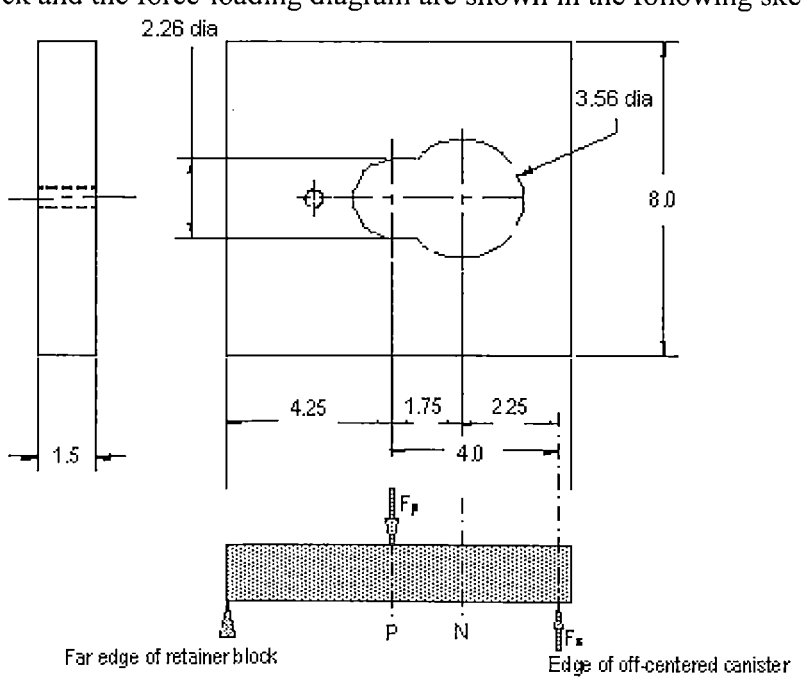
S_M = 1.5 S_m = 1.5(20.0) = 30.0 ksi
S_S = 0.9 S_m = 0.9 (20.0) = 18.0 ksi
S_{brg} = S_y = 22.4 ksi
S_y = 22.4 ksi ---------- Yield strength, A276 Type 304 stainless steel at 300°F
S_m = 20.0 ksi ---------- Design stress intensity, A276 Type 304 stainless steel at 300°F

The minimum factor of safety (FS) is as follows.

$$FS = \frac{F_{brg}}{F_p} = \frac{82.79}{78.1} = 1.06$$

Retainer Block Evaluation

The retainer block and the force-loading diagram are shown in the following sketch.



Point P is where the headed retainer rod is loaded under prying force F_p. The maximum bending stress (σ_b) in the retainer block is as follows.

$$\sigma_b = \frac{Mc}{I} = 74.9 \text{ ksi}$$

where:

$$M = F_c(4) = 161.2 \text{ kip-inch}$$
$$F_c = 40.3 \text{ kip}$$
$$I = \frac{bh^3}{12} = 1.614 \text{ inch}^4$$
$$C = 0.75 \text{ inch}$$

The factor of safety (FS) is as follows.

$$FS = \frac{2.25S_m}{\sigma_b} = 1.35$$

where:

S_m = 45.0 ksi ---------- Design Stress Intensity, A564 Type 630 (17-4PH) at 300°F

Figure 3.4.3-2 Retaining Ring Section Cut

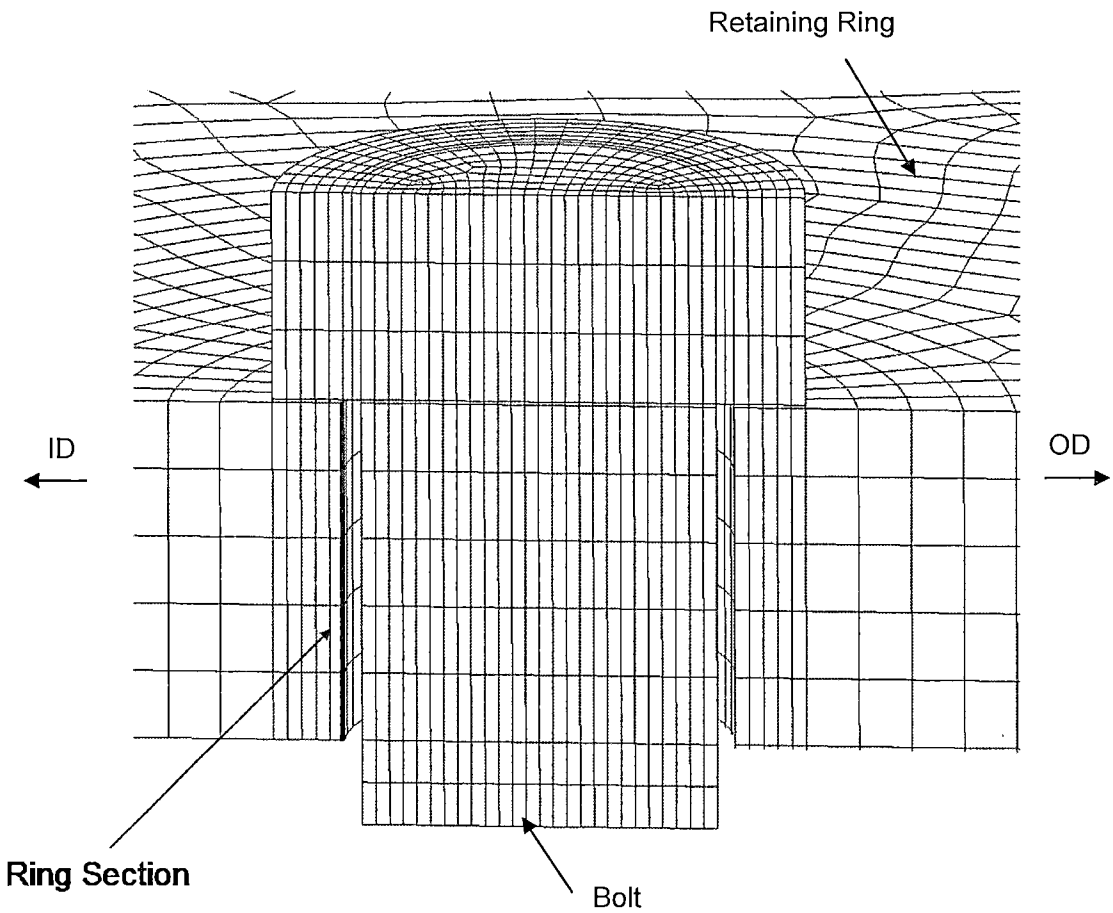


Table 3.4.3-3 Stress Intensity for MTC2 Trunnions and Top Ring

Location [a]	Position [a]	P_m [b] ksi	P_b [b] ksi	$P_m + P_b$ [b] ksi	Material	S_{yield} Ksi	$S_{ultimate}$ ksi	FS_{yield}	$FS_{ultimate}$
Trunnion-L1	x =43.9 inch	0.03	3.58	3.62	SA182	25.0	66.3	6.9	Large
Trunnion-L2	x = 45 inch	0.0007	1.95	1.95	F304	25.0	66.3	Large	Large
TopRing-A1	θ = 0°, z > 0	1.19	2.95	4.14	SA182	25.0	66.3	6.04	Large
TopRing-A2	θ = 0°, z < 0	0.06	2.67	2.74	F304	25.0	66.3	9.1	Large
TopRing-A10	θ = 10°	0.07	1.24	1.30	or	25.0	66.3	Large	Large
TopRing-A45	θ = 45°	0.13	0.61	0.74	SA336	25.0	66.3	Large	Large
TopRing-A90	θ = 90°	0.11	0.63	0.74	F304	25.0	66.3	Large	Large

Table 3.4.3-4 Stress Intensity for MTC2 Shells and Bottom Ring

Location [c]	Position[c]	$P_m + P_b$ [d] ksi	Material	S_{yield} ksi	$S_{ultimate}$ ksi	FS_{yield}	$FS_{ultimate}$
Inner Shell	θ = 0°, z=-5.625 inch	1.37	SA240 304	25.0	71.0	Large	Large
Outer Shell	θ = 8.3°, z=-5.625 inch	3.27		25.0	71.0	7.6	Large
Bottom Ring	θ = 90°, z=-165.125	0.34	SA182 F304 or SA336 F304	25.0	66.3	Large	Large

[a] The locations and positions are defined in Figure 3.4.3-1.
[b] P_m = primary membrane stress intensity; P_b = primary bending stress intensity; $P_m + P_b$ = primary membrane + bending stress intensity.
[c] The locations and positions correspond to the axis detailed in Section 3.10.5.2.
[d] $P_m + P_b$ = primary membrane + bending stress intensity.

Table 3.4.3-5 Stress Intensity for Transfer Cask Retaining Ring

Stress	Stress Intensity ksi	Material	Allowable Stress ksi	Factor of Safety
P_m	9.4	SA182 F304	30	3.19
P_m+P_b	37.2		45	1.21

3.4.3.4 Damaged Fuel Can Lift

The MAGNASTOR Damaged Fuel Can (DFC), shown in License Drawings 71160-601 and 71160-602, is provided to accommodate damaged fuel, including damaged WE15×15, WE17×17 and B&W15×15 fuel assemblies. The primary function of the DFC is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the TSC cavity.

The DFC may also contain the WE15×15, WE17×17 and B&W15×15 fuel assemblies in an undamaged condition, or damaged fuel, such as undamaged or damaged fuel rods, or fuel debris. Four DFCs may be loaded into the outer corners of the MAGNASTOR 37-assembly PWR, DF Basket Assembly.

The DFC is fabricated from SA-240, Type 304 stainless steel and has an 8.7-inch square inside dimension. The DFC may be provided in two lengths: an overall length of 166.9 inches with a nominal cavity length of 164.0 inches (WE15×15 or WE17×17 fuel assemblies only), or an overall length of 171.8 inches with a nominal cavity length of 169.0 inches (primarily B&W15×15 fuel assemblies, but WE15×15 or WE17×17 fuel assemblies may be accommodated with a DFC spacer to limit axial movement). The side plates that form the upper end of the DFC are 0.15-inch thick and the tube body walls are 0.048-inch thick (18-gage sheet). The DFC lid plate and bottom thicknesses total 11/16 (0.688) inch and the lid overall height is 2.32 inches. The DFC bottom plate thickness is 5/8 (0.625) inch. The DFC lid and bottom include screened drain holes.

In the normal condition of storage, the DFC is in a vertical orientation. The weight of the contents in the can is transferred directly through the bottom plate of the can to the TSC bottom plate, and the DFC is subjected to its self-weight only. For the lift of the DFC, the evaluation considers the weight of the DFC itself and its contents.

The MAGNASTOR DFC is evaluated for dead weight and handling loads for normal conditions of storage. Classical hand calculations are used to evaluate the stresses in the DFC. The DFC lifting components are designed with a safety factor of 3.0 on material yield strength at a temperature of 300°F.

3.4.3.4.1 Dead Weight and Handling Loading Evaluation

The weight of the MAGNASTOR DFC is conservatively assumed to be 150 pounds. The maximum compressive stress acting in the tube of the DFC is due to its own weight in addition to that of the top assembly. A 10% dynamic load factor is applied to the DFC weight for an applied load of 165 pounds to account for loads due to handling. The yield strength (S_y) for

SA-240, Type 304 stainless steel is 22,400 psi at 300°F. Based on the minimum cross-sectional area of the DFC, 1.68 in^2, the factor of safety at 300°F is:

FS = 22,400/(165/1.68)
FS = Large

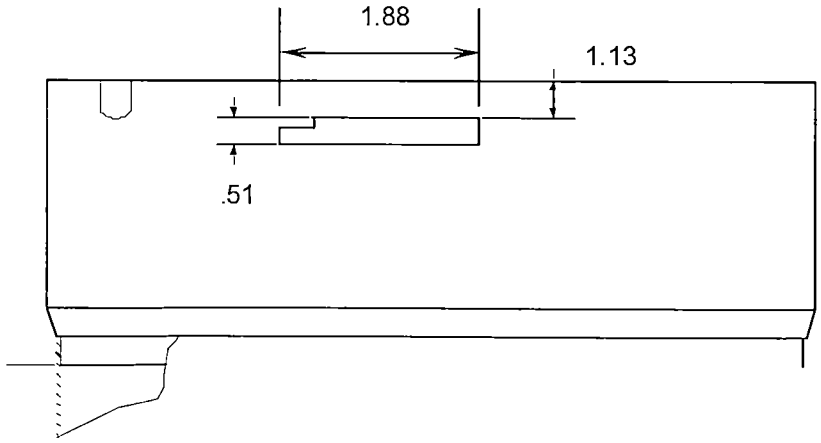
3.4.3.4.2 Lifting Evaluation

Based on the loaded weight of the DFC, the lift evaluation does not require the use of the design criteria of ANSI N14.6 or NUREG-0612. However, for purposes of conservatism and good engineering practice, a factor of safety of 3.0 on material yield strength is used for the stress evaluations for the lift condition. Since a combined stress state results from the loading and the calculated stresses are compared to material yield strength, the Von Mises stress is computed.

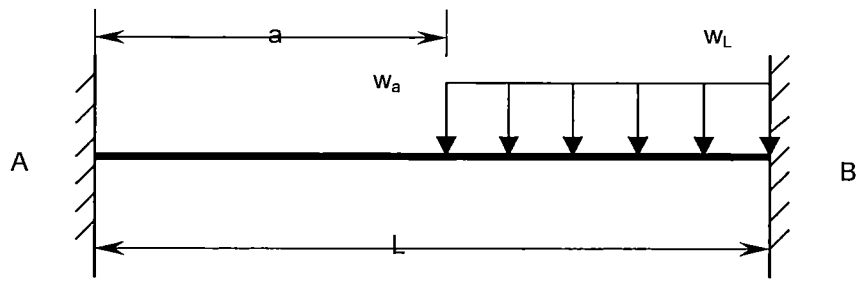
Side Plates

The side plates will be subjected to bending, shear and bearing stresses because of interaction with the lifting tool during handling operations. The lifting tool engages the 1.88-inches × 0.38-inch lifting slots with lugs that are 1 inch wide and lock into the ends of the four lifting slots.

For this evaluation, the handling load is conservatively assumed to be 2,100 lbs (actual fuel assembly weight is less than 1,600 lbs), plus the MAGNASTOR DFC weight (150 lbs), amplified by a dynamic load factor of 10 percent.



The stress in the side plate above the slot is determined by analyzing the section above the slot as a 0.15-inch thick × 1.88-inches long × 1.13-inches deep beam that is fixed at both ends. The lifting tool lug is 1-inch wide and engages the last 1 inch of the slot. The following figure represents the configuration to be evaluated:



where:

$a = 0.88$ inch

$L = 1.88$ inches

$$w_a = w_L = \frac{P}{4b_t}(1.1) = 620 \text{ lbs/inch}$$

$P = 2{,}250$ lbs ---------- Bounding weight of the loaded DFC

$b_t = 1$ inch ---------- Lifting tool lug width

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

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

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

$$= \frac{620}{2(1.88)^3}(1.88-0.88)^3(1.88+0.88) = 128.8 \text{ lbs}$$

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

$$M_A = \frac{-w_a}{12L^2}(L-a)^3(L+3a)$$

$$= \frac{-620}{12(1.88)^2}(1.88-0.88)^3(1.88+3(0.88)) = -66.1 \text{ lbs}\cdot\text{inch}$$

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

$$R_B = w_a(L-a) - R_A = 620(1.88-0.88) - 128.8 = 491.2 \text{ lbs}$$

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

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

$$= 128.8(1.88) + (-66.1) - \frac{620}{2}(1.88-0.88)^2 = -134 \text{ lbs} \cdot \text{inch}$$

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

$$\sigma_b = \frac{Mc}{I} = \frac{134(0.565)}{0.0180} = 4{,}206 \text{psi}$$

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

$$\tau = \frac{R_B}{A} = \frac{491.2}{1.13(0.15)} = 2{,}898 \text{ psi}$$

The Von Mises stress (σ_{max}) is:

$$\sigma_{max} = \sqrt{\sigma_b^2 + 3\tau^2} = \sqrt{4{,}206^2 + 3(2{,}898)^2} = 6{,}549 \text{ psi}$$

The yield strength (S_y) for SA-240, Type 304 stainless steel is 22,400 psi at 300°F. The factor of safety is calculated as:

FS = 22,400/6,549 = 3.4 >3

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

Tensile Stress

The tube body will be subjected to tensile loads during lifting operations. The load (P) includes the DFC contents (2,100 lbs design weight), the tube body weight, and the bottom assembly weight. Conservatively using 150 lbs for the tube body and bottom assembly weight, a total load of 2,250 lbs, with a 10% dynamic load factor, is used for the analysis.

The tensile stress (σ_t) is then:

$$\sigma_t = \frac{1.1P}{A} = \frac{1.1(2{,}250)}{1.680} = 1{,}473 \text{ psi}$$

where:

A = 1.680 inch^2---------- Tube cross-section area

The factor of safety (FS) based on the yield strength at 300°F (22,400 psi) is:

$$FS = \frac{22{,}400 \text{ psi}}{1{,}473} = 15.2 > 3$$

Weld Evaluation

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

The weld stress (σ_w) is:

$$\sigma_w = \frac{1.1(P)}{A} = \frac{1.1(2{,}250)}{1.680} = 1{,}473 \text{ psi}$$

where:

P = 2,250 lbs ---------- Bounding weight of the loaded DFC
A = 1.680 inch^2 ---------- Tube cross-section area

The factor of safety (FS) is:

$$FS = \frac{n \cdot S_y}{\sigma_w} = \frac{0.5(22{,}400 \text{ psi})}{1{,}473 \text{ psi}} = 7.6 > 3$$

Bottom Plate

The bottom plate is analyzed as an 8.80-in square plate, 0.625-in thick, simply supported at the edges. The distributed handling load (q) is the weight of the DFC contents (2,100 lbs design weight) plus the weight of the bottom plate (15 lbs) times a dynamic load factor of 1.1.

Using Roark's "Formulas for Stress and Strain," [13] Table 26, Case 1a for a uniformly loaded rectangular plate, simply supported at the edges, the maximum stress (S_{max}) is found by the relation:

$$S_{max} = (\beta q b^2)/t^2 = (0.2874)(30)(8.80)^2/(0.625)^2 = 1{,}710 \text{ psi}$$

where:

$q = ((2{,}100+15) \times 1.1)/(8.80)^2 = 30$ lb/in.^{2}
$\beta = 0.2874$

a = b = 8.80 inches ---------- Plate length and width

t = 0.625 inch ---------- Plate thickness

Because of the safety factor, $FS = S_y/S_{max} = 17{,}600/1{,}710 = 10.3 > 3$ at a temperature of 700°F, the design conditions that lifting stresses have a load factor of 3 on the basis of yield strength is satisfied.

Conclusion

The MAGNASTOR DFC is structurally adequate for lifting conditions.

3.5 Normal Operating Conditions

This section presents the analyses of the major structural components of MAGNASTOR for normal conditions of storage. The TSC, fuel baskets, and concrete cask are evaluated using finite element models and classical hand calculations.

3.5.1 TSC Evaluation for Normal Operating Conditions

For normal conditions of storage, the TSC is evaluated using ASME Code, Section III, Subsection NB 'Service Level A' allowable stresses. Bounding analyses are performed for two groups of TSC configurations: (1) TSC1 and TSC2 with a single-piece closure lid assembly, and (2) TSC3 and TSC4 with a composite closure lid assembly. For detailed analysis results for normal conditions, see Table 3.10.3-1 through Table 3.10.3-6 for the TSC1/TSC2 configuration and Table 3.10.3-18 through Table 3.10.3-23 for the TSC3/TSC4 configuration.

3.5.1.1 TSC Thermal Stress Analysis

The thermal stresses in the TSC during normal conditions of storage are evaluated using the finite element models described in Section 3.10.3. The thermal gradient applied to the TSC models bounds all conditions of storage; therefore, the results presented are conservative. The resulting maximum (secondary) thermal stresses in the TSC are shown in Table 3.5.1-1. The locations of the stress sections are shown in Figure 3.10.3-2 in Section 3.10.3.

3.5.1.2 TSC Dead Load

The TSC is analyzed for a dead load using the finite element models described in Section 3.10.3. The normal handling plus normal pressure conditions presented in Section 3.5.1.5 bound the resulting maximum TSC dead load stresses; therefore, results for the dead load analysis are not presented separately.

3.5.1.3 TSC Maximum Internal Pressure

The TSC is analyzed for a maximum internal pressure load using the finite element models described in Section 3.10.3. A maximum internal pressure of 110 psig is applied as a surface load to the elements along the internal surfaces of the TSC shell, bottom plate, and closure lid. This pressure bounds the maximum calculated pressure for PWR and BWR fuel under normal conditions.

The resulting maximum internal pressure load stresses for the TSC are summarized in Table 3.5.1-2 and Table 3.5.1-3 for primary membrane and primary membrane plus primary bending stress categories, respectively. The locations for the stress sections are shown in Figure 3.10.3-2 in Section 3.10.3.

The maximum tensile stress in the shield plate attachment bolts of the TSC3 configuration due to the normal pressure load is 24.18 ksi. The shield plate attachment bolt stresses due to the normal internal pressure load are evaluated in combination with other loads as discussed in Section 3.5.1.5.

The maximum stress in the TSC port cover is due to bending at its center from the internal pressure and inertial loading. Bending stress (σ) is calculated using the formulas from Reference 13 as follows.

$$\sigma = 6\frac{M_r}{t^2} = 8.03 \text{ ksi}$$

where:

$$M_r = \frac{qa^2(3+\nu)}{16}$$

$q = q_i + q_p$

$q_i = t \times \rho \times g$

q_p = 110 psi ---------- Normal condition pressure
d = 5.75 in---------- Maximum port cover diameter
a = d/2 ---------- Port cover radius
ν = 0.31 ---------- Poisson's ratio
t = 3/8 in ---------- Minimum port cover thickness
ρ = 0.291 lb/in^3 ---------- Density, SA-240 Type 304
g = 1.1g ---------- Normal condition handling acceleration

Conservatively using the temperature of 650°F for the material allowable, the factor of safety is:

$$FS = \frac{S_{allow}}{\sigma} = \frac{1.5\ S_m}{\sigma} = 3.03$$

where:

S_m = 16.2 ksi ---------- design stress intensity, SA-240 Type 304 at 650°F

The shear stress in the port cover weld is:

$$\tau_w = \frac{qA_p}{A_w} = 1.28 \text{ ksi}$$

where:

$A_p = d_p^2\pi/4$ ---------- Area of port

A_w = $d_p \pi t_w$ ---------- Weld area
d_p = 5.83 in ---------- Maximum lid port counterbore diameter
t_w = 1/8 in ---------- Port cover weld thickness
q = 110 psi ---------- Normal condition pressure and inertial loading

Conservatively using the temperature of 650°F, the factor of safety is:

$$FS = \frac{S_{allow}}{\tau_w} = \frac{0.6\ S_m}{\tau_w} = 7.6$$

where:

S_m = 16.2 ksi ---------- design stress intensity, SA-240 Type 304 at 650°F

3.5.1.4 TSC Handling Loads

The TSC is analyzed for handling loads using the finite element models described in Section 3.10.3. Normal handling is simulated by constraining the model at nodes on the closure lid simulating three lift points. A 1.1g acceleration load, which corresponds to the dead weight with a 10% dynamic load factor, is applied to the model in the axial direction. Pressure is applied to the TSC bottom plate to simulate the weight of the basket and fuel with an acceleration of 1.1g.

The resulting maximum stresses in the TSC due to handling loads are bounded by the maximum stresses for the normal handling loads plus normal pressure condition presented in Section 3.5.1.5; therefore, the stress results for the handling condition are not presented separately.

The stresses in the TSC lift lugs or restraining blocks resulting from normal handling loads are evaluated using classical methods. The TSC lift lugs (PWR configurations) and restraining blocks (BWR configurations), which are welded to the inner surface of the TSC shell, are designed to support the combined weight of the TSC lid and supplemental support equipment prior to placement of the closure welds. The total weight imposed on the lift lugs, W, conservatively considers the combined weight of the TSC closure lid assembly (10,500 pounds) and supplemental support equipment (10,000 pounds). A 10% load factor is also applied to ensure all normal operating loads are bounded. Evaluation of the PWR lift lugs is presented as it provides a bounding analysis enveloping the BWR restraining block configuration. The stresses evaluated are bearing stress on the top end of the lift lugs and shear stress through the lift lug attachment welds.

The bearing stress on the top end of the lift lugs is calculated as follows.

$$\sigma_{bearing} = \frac{W}{4A} = \frac{22{,}550\ \text{lb}}{4(0.928\ \text{in}^2)} = 6{,}075\ \text{psi}$$

where:

$W = (10{,}500 \text{ lb} + 10{,}000 \text{ lb}) \times 1.1 = 22{,}550 \text{ lb}$

$A = 0.928 \text{ inch}^2$ ---------- Bearing area of each lifting lug

The allowable bearing stress is equal to the yield strength of Type 304 stainless steel at a temperature of 125°F, or 27,885 psi. Therefore, the factor of safety (FS) is as follows.

$$FS = \frac{1.0\ S_y}{\sigma_{bearing}} = \frac{27{,}885 \text{ psi}}{6{,}075 \text{ psi}} = 4.59$$

The attachment weld for the lift lugs is an all-around 3/8-inch effective throat groove weld. The shear stress in the lift lug attachment weld (τ_w) is calculated as follows.

$$\tau_w = \frac{W}{4A_{eff}} = \frac{22{,}550 \text{ lb}}{4(5.34 \text{ in}^2)} = 1{,}056 \text{ psi}$$

where:

$A_{eff} = L_{eff} \times t_{eff} = 5.34 \text{ inch}^2$ ---------- Area of lifting lug weld

$L_{eff} = 2(5.75 + 1.375) = 14.25$ inches--------- Length of lifting lug weld

$t_{eff} = 0.375$ inch ---------- Effective throat thickness of lifting lug weld

The factor of safety (FS) for the lift lug shear stress is as follows.

$$FS = \frac{S_{allow}}{\tau_w} = \frac{0.6\ S_m}{\tau_w} = \frac{0.6 \text{ x } 20{,}000 \text{ psi}}{1{,}056 \text{ psi}} = 11.4$$

where:

$S_m = 20{,}000$ psi ---------- Design stress intensity of SA-240, Type 304 stainless steel at 125°F

3.5.1.5 TSC Load Combinations

The TSC is structurally analyzed for combined thermal, dead, maximum internal pressure, and handling loads using the finite element models described in Section 3.10.3.

The resulting maximum stresses in the TSC for combined loads are summarized in Table 3.5.1-2, Table 3.5.1-3, and Table 3.5.1-4 for primary membrane, primary membrane plus primary bending, and primary plus secondary stresses, respectively. The sectional stresses are evaluated at each of the TSC section locations described in Section 3.10.3 for each angular division of the model. The locations for the stress sections are shown in Figure 3.10.3-2 and Figure 3.10.3-5 in Section 3.10.3.

As shown in Table 3.5.1-2 through Table 3.5.1-4, the TSC maintains factors of safety greater than one for the combined load conditions. The minimum factor of safety of 1.23 occurs at Section 3 for the P_m+P_b stresses.

The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for the TSC3 and TSC4 for all normal load combinations is 34.31 ksi due to normal handling plus normal pressure. The allowable bolt tensile stress for normal conditions is limited to $S_u/2$, or 47.49 ksi, for the A193 Grade B6 bolt material at an upper-bound bolt design temperature of 525°F. Therefore, the minimum factor of safety for the shield plate attachment bolt for normal storage conditions is 1.38.

3.5.1.6 TSC Fatigue Evaluation

The purpose of this section is to evaluate whether an analysis for cyclic service is required for the TSC. For the TSC, the requirements for cyclic operation are presented in ASME Code, Section III, Subsection NB, Article NB-3222.4 [6]. The criteria for determining whether cyclic loading analysis is required are comprised of six conditions, which, if met, preclude the requirement for further analysis.

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

The evaluation of these conditions is as follows.

Condition 1 — Atmospheric to Service Pressure Cycle

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

Condition 2 — Normal Service Pressure Fluctuation

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

Condition 3 — Temperature Difference — Startup and Shutdown

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

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

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

$$\Delta T = \frac{S_a}{2E\alpha} = 57°F$$

where:

for Type 304 stainless steel,

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

E = 25.1×10^6 psi ---------- Modulus of elasticity at 650 °F

α = 9.9×10^{-6} inch/inch-°F ---------- Coefficient of thermal expansion at 650°F

Because of the large thermal mass of the TSC and the concrete cask and the relatively constant heat load produced by the TSC's contents, cyclic changes in ΔT greater than 57°F will not occur.

Condition 5 — Temperature Difference — Dissimilar Materials

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

Condition 6 — Mechanical Loads

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

The criteria of ASME Code, Section III, Subsections NB, Articles NB-3222.4 and NG-3222.4 are met; therefore, fatigue analysis is not required.

Table 3.5.1-1 TSC Thermal Stress, Q

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
Thermal	A	12	-16.87	-14.95	-4.20	-0.50	-1.60	-0.10	13.05

Table 3.5.1-2 TSC Normal Conditions, P_m Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Pressure	A	3	-0.50	-6.93	3.91	0.13	0.02	0.85	11.01	N/A	N/A
Pressure + Handling	A	3	-0.58	-9.49	4.83	-0.19	-0.03	1.01	14.51	20.00	1.38

Table 3.5.1-3 TSC Normal Conditions, $P_m + P_b$ Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Pressure	A	2	2.37	-11.47	-16.71	0.00	0.00	-0.99	19.19	N/A	N/A
Pressure + Handling	A	3	-0.25	-4.94	19.45	-0.08	-0.04	1.27	24.48	30.00	1.23

Table 3.5.1-4 TSC Normal Conditions, P + Q Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Pressure + Handling + Thermal	A	12	-41.04	-37.90	-8.45	-1.25	-0.15	-1.51	33.17	60.00	1.81

[a] See Figure 3.10.3-2 for section locations.

[b] The x, y, z components of stress are to be interpreted radial, circumferential, and axial directions, respectively.

3.5.2 Fuel Basket Evaluation for Normal Operating Conditions

3.5.2.1 PWR Fuel Basket

This section evaluates the MAGNASTOR PWR fuel basket for normal operating conditions. Factors of safety for the PWR fuel basket are calculated based on the criteria for Service Level 'A' limits from ASME Code, Section III, Subsection NG [7].

Normal Handling Evaluation

The PWR fuel basket is analyzed using classical hand calculations for a 1.1g inertia loading in the basket axial direction to account for the dead load and the handling load. During normal conditions, the PWR fuel assemblies do not apply loads to the basket; they rest on the TSC bottom. Using a bounding basket weight of 22,500 lb, the maximum stress in the fuel tube is calculated. There are 21 fuel tubes in the PWR fuel basket. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube (σ_{tube}) is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{1178}{11.4} = 0.1 \text{ ksi}$$

where:

$P_{tube} = \frac{W \times a}{n} = 1{,}178$ lb ---------- Load per tube
$W = 22{,}500$ lb ---------- Bounding basket weight
$a = 1.1g$ ---------- Inertia g-load
$n = 21$ ---------- Number of fuel tubes
$A = 11.4$ inch^2 ---------- Tube cross-sectional area

The factor of safety (FS) is as follows.

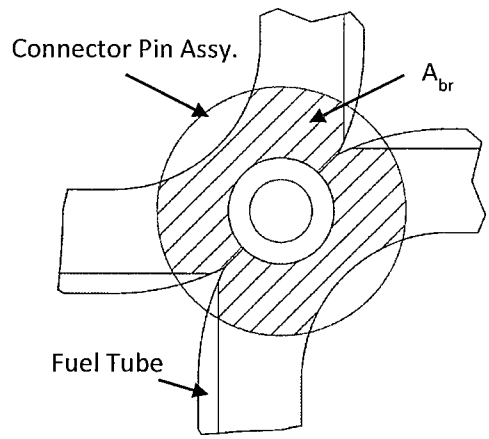
$$FS = \frac{S_m}{\sigma_{tube}} = \frac{21.4}{0.1} = \text{Large}$$

where:

$S_m = 21.4$ ksi ---------- Design stress intensity, SA-537 Class 1, at 700°F

[redacted]

[redacted]



$$\sigma_{brg} = \frac{1.1 \times P_{cpa/tube}}{A_{brg}} = 3.2 \text{ ksi}$$

where:

A_{brg}	=	0.0583 in^2	Minimum bearing area for a single tube
$P_{t/s}$	=	$P_t/4$	Load on tube from single standoff
P_t	=	675 lb	Tube weight

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{34.6}{3.2} = \text{Large}$$

where:

S_y = 34.6 ksi ---------- Yield strength, SA-537 Class 1, at 550°F

The bearing stress (σ_{brg}) in the connector pin assembly at the TSC is:

$$\sigma_{brg} = \frac{1.1 \times P_{cpa}}{A_{brg}} = 1.35 \text{ ksi}$$

where:

$$A_{brg} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.62^2 - 0.19^2\right) = 0.274 \text{ inch}^2$$

$P_{cpa} = P_t / 2$

P_t = 675 lb

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.35} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240 Type 304, at 400°F

The buckling evaluation of the fuel tube standoffs is performed for the governing condition of the 24-inch concrete cask end-drop accident, as shown in Section 3.7.2.1. The accident condition buckling is bounding due to the 60g axial inertia loading.

The weight of the side and corner weldments is carried through to the TSC bottom plate by supports at the bottom of the basket. The bounding dimensions for the supports of the weldments are 5.0 inches in length and 0.3125-inch thickness (corner weldment). The maximum weight of one weldment is 800 lb (bounding side weldment). The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding). The bearing stress (σ_{brg}) is as follows.

$$\sigma_{brg} = \frac{1.1 \times W_{sup}}{A_{sup}} = \frac{1.1 \times 1138}{1.56} = 0.8 \text{ ksi}$$

where:

W_{sup} = $800 + 2 \times (0.25 \times 675) = 1138$ lb

A_{sup} = $5.0 \times 0.3125 = 1.56$ inch^2

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.8} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240, Type 304 at 400°F

The side and corner weldments are attached to the fuel tube array with bolts. The maximum torque on the ⅝-inch bolt is 50.0 inch-lb (40 inch-lb ±10 inch-lb). The preload on the bolt (P) is as follows.

$$P = \frac{T}{0.2D} = \frac{50}{0.2 \times 0.625} = 400 \text{ lb} \qquad [12]$$

where:

T = 50 inch-lb ---------- Maximum bolt torque

D = 0.625 inch ---------- Bolt diameter

A bounding bolt load of 1,500 lb is used for the bolt evaluation. The bolt thread is a ⅝-11 UNC and the length of engagement is 0.50 inch. From Machinery's Handbook [12], the tensile stress (σ_t) in the bolt is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{1{,}500}{0.23} = 6.5 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ inch}^2$$

$$D = 0.625 \text{ inch}$$

$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{S_m}{\sigma_t} = \frac{23.3}{6.5} = 3.6$$

where:

S_m = 23.3 ksi ---------- Design stress intensity for SA 193, Gr B6 at 700°F

The shear stress (τ_{bolt}) in the bolt thread is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{1{,}500}{0.499} = 3.0 \text{ ksi}$$

where:

$$A_s = 3.1416 n L_e K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.499 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.6 S_m}{\tau_{bolt}} = \frac{0.6 \times 23.3}{3.0} = 4.66$$

where:

S_m = 23.3 ksi ---------- Design stress intensity, SA-193 Grade B6 at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{1{,}500}{0.713} = 2.1 \text{ ksi}$$

where:

$$A_n = 3.1416 n L_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.713 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{bolt}} = \frac{0.6 \times 17.3}{2.1} = 4.9$$

where:

S_m = 17.3 ksi ---------- Design stress intensity, SA-36, at 700°F

The boss is welded into the fuel tube with a 1/4-inch groove weld. The shear stress in the boss weld (τ_{weld}), is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{1{,}500}{0.98} = 1.5 \text{ ksi}$$

where:

P = 1,500 lb
A_w = $\pi D t_{weld} = \pi \times 1.25 \times 0.25 = 0.98$ inch
D = 1.25 inches ---------- Boss diameter

Using the lesser allowable, S_m, of SA-537 Class 1 or SA-36, the factor of safety (FS) is as follows.

$$FS = \frac{wf \times 0.6S_m}{\tau_{weld}} = 2.4$$

where:

wf = 0.35 ---------- Weld quality factor visual inspection (ASME Code Section III, NG, Article NG-3352)

S_m = 17.3 ksi ---------- Design stress intensity, SA-36, at 700°F

The washers under the bolts at the boss locations are subjected to shear from the bolt tensile load and the support condition at the weldment. The shear stress in the washer is:

$$\tau_{wash} = \frac{P}{A_w} = \frac{1{,}500}{1.718} = 1 \text{ ksi}$$

where:

$A_w = \pi D_s t_w = 1.718 \text{ in}^2$

D_s = 1.75 in ---------- Support diameter of washer at weldment

tw = 3/16 in ---------- Washer thickness

The factor of safety is

$$FS = \frac{0.6S_m}{\tau_{wash}} = 9.6$$

where:

S_m = 16.0 ksi ---------- Design stress intensity, SA-240 Type 304, at 700°F

The evaluation of the neutron absorber for normal handling conditions is bounded by the evaluation for the 24-inch concrete cask end-drop accident (60g) as shown in Section 3.7.2.1. Therefore, no evaluation for normal handling is presented in this section.

Thermal Stress Evaluation

The thermal stresses for the PWR fuel basket are calculated using a three-dimensional quarter-symmetry ANSYS finite element model (Section 3.10.1.4.2). The model represents the top or bottom 47 inches of the basket and calculates the stresses in the basket based upon bounding thermal gradients in basket axial and radial directions. The thermal stresses are combined with the maximum stresses for the normal handling condition. Factors of safety are calculated based on Service Level 'A' limits from ASME Code, Section III, Subsection NG [7]. The maximum handling stress in the basket is 0.1 ksi. The following presents the combined normal handling plus thermal stress (P+Q) for the PWR basket.

Component	S_{therm}, ksi	S_{total}, ksi	S_{allow}, ksi	FS
Fuel Tube	48.1	48.2	62.7	1.30
Support Weldments	17.4	17.5	62.7	3.58

The total stress is the sum of the component thermal stress and the normal handling stress. The allowable stress is $3S_m$ ($3 \times 20.9 = 62.7$ ksi for SA537 Class 1 at 755°F). Note that 755°F is conservatively used to envelope all normal, off-normal and transfer conditions.

The axial average temperature at the center of the basket is 550°F. The axial average temperature at the outer radius of the basket is 450°F. The relative thermal expansion of the basket in the axial direction between the center and outer edge of the basket is as follows.

$$\Delta x = \Delta x_{inner} - \Delta x_{outer} = 0.62 - 0.48 = 0.14 \text{ inch}$$

where:

$$\Delta x_{inner} = \Delta T \times L \times \alpha_1 = (550-70)(173.5)(7.45\times10^{-6}) = 0.62 \text{ inch}$$

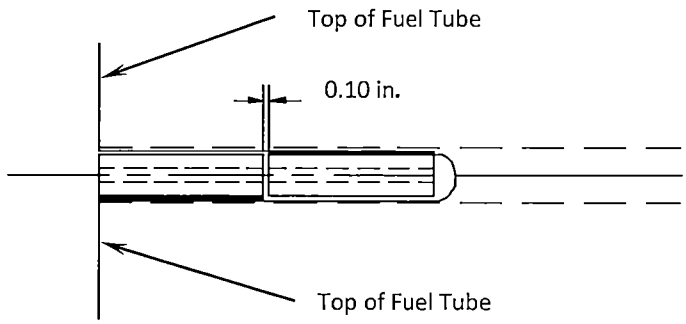
$$\Delta x_{outer} = \Delta T \times L \times \alpha_2 = (450-70)(173.5)(7.20\times10^{-6}) = 0.48 \text{ inch}$$

L = 173.5 inches ---------- Fuel tube length

α_1 = 7.45×10-6 inch/inch/°F---------- Coefficient of thermal expansion, SA537 CL1, at 550°F

α_2 = 7.20×10^{-6} inch/inch/°F---------- Coefficient of thermal expansion, SA537 CL1, at 450°F

Connector pins at the top and bottom of the basket are used to maintain the geometry of the fuel tube array during manufacturing. A pin is inserted into the connector pin to maintain geometry between adjacent fuel tubes. Adjacent fuel tube connector pins have a 0.10-inch gap between the connector pins; see the following sketch. There are a minimum of two connector pins in the radial direction of the PWR basket. Therefore, the relative thermal expansion between the adjacent tubes is approximately 0.07 inch (0.14/2), which is less than the pin gap of 0.10 inch. No axial thermal stresses are produced by the axial expansion of the basket.



The maximum shear load calculated by ANSYS in the basket attachment bosses is 3.5 kip due to the radial thermal expansion of the basket. The shear stress in the boss (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A} = \frac{3.5}{0.92} = 3.8 \text{ ksi}$$

where:

$$A = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = 0.92 \text{ inch}^2$$

D_o = 1.25 inches
D_i = 0.63 inch

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{boss}} = \frac{0.6 \times 17.3}{3.8} = 2.7$$

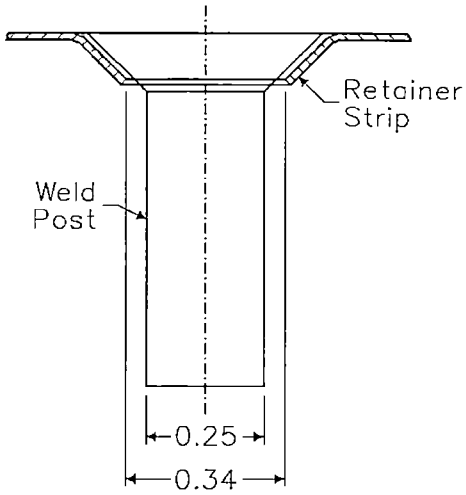
where:

S_m = 17.3 ksi ---------- Design stress intensity, SA-36, at 700°F

Based on the analysis results from the thermal stress model, the thermal expansion of the basket does not result in additional tensile load in the attachment bolts. Therefore, no additional bolt analysis for thermal loads is required.

Neutron Absorber Retainer Thermal Stress Evaluation

The attachment of the retainer strip and neutron absorber to the fuel tube using weld posts allows each component to move independently during thermal growth. In the case of the stainless steel retainer strip, the expansion of the neutron shield material, which is composed primarily of aluminum, and the carbon steel fuel tube tends to tighten the joint created by the weld post. Thermal stresses may develop between the weld posts because the carbon steel fuel tube expands at a different rate than the retainer strip.



The equation used to calculate the difference in expansion between carbon and stainless steel, Δ, is as follows.

$$\Delta = (\alpha_{ss} \times \Delta T \times L) - (\alpha_{cs} \times \Delta T \times L) \qquad (1)$$

The standard formula to calculate the deflection of a beam or plate is as follows.

$$\Delta = \frac{PL}{AE} = \frac{\sigma L}{E} \qquad (2)$$

Substituting equation (1) into equation (2) and solving the retainer strip thermal stress, σ, is as follows.

$$\sigma = \frac{E\Delta}{L} = E(\alpha_{ss} - \alpha_{cs})(\Delta T) = 38.4 \text{ ksi} \qquad (3)$$

where:

α_{ss} = 10.0×10^{-6} inch/inch/°F ---------- Coefficient of thermal expansion, SA-240 Type 304, at 755°F

α_{cs} = 7.7×10^{-6} inch/inch/°F---------- Coefficient of thermal expansion, SA-537 Class 1, at 755°F

ΔT = 755°F -70°F = 630°F ---------- Difference between maximum PWR temperature and ambient conditions

T_{max} = 755°F---------- Bounding basket temperature

E = 24.4×10^{6} psi ---------- Modulus of elasticity, SA-240 Type 304, at 755°F

The factor of safety (FS) is as follows.

$$FS = \frac{3S_m}{\sigma} = \frac{46.5}{38.4} = 1.21$$

where:

S_m = 15.5 psi ---------- Design stress intensity,SA-240 Type 304, at 755°F

3.5.2.2 PWR Fuel Basket with Damaged Fuel Cans

This section evaluates the MAGNASTOR PWR fuel basket with square pins and the damaged fuel can configuration (DF Basket Assembly) for normal operating conditions.

Normal Handling Evaluation

The PWR DF basket is analyzed using classical hand calculations for a 1.1g inertia loading in the basket axial direction. During normal conditions, the PWR fuel assemblies do not apply loads to the basket; they rest on the TSC bottom plate. Using a bounding basket weight of 25,000 lb, the maximum stress in the fuel tube is calculated. Conservatively assuming the entire basket weight is carried through the 17 fuel tubes of the DF basket, the stress in the tube (σ_{tube}) is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{1618}{11.4} = 0.1 \text{ ksi}$$

where:

$P_{tube} = \frac{W \times a}{n} = 1{,}618$ lb ---------- Load per tube

W = 25,000 lb ---------- Bounding basket weight

a = 1.1g ---------- Inertia g-load

n = 17---------- Number of fuel tubes

A = 11.4 inch^2 ---------- Tube cross-sectional area

The factor of safety (FS) is as follows.

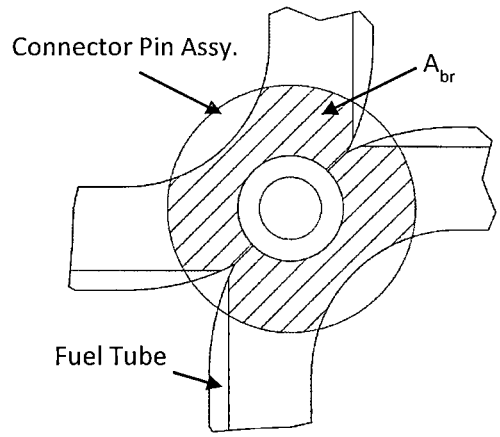
$$FS = \frac{S_m}{\sigma_{tube}} = \frac{21.4}{0.1} = \text{Large}$$

where:

S_m = 21.4 ksi Design stress intensity, SA-537 Class 1, at 700°F

[redacted]

[redacted]



$$\sigma_{brg} = \frac{1.1 \times P_{cpa/tube}}{A_{brg}} = 3.2 \text{ ksi}$$

where:

A_{brg} = 0.0583 in^2 ---------- Minimum bearing area for a single tube

$P_{t/s}$ = $P_t/4$ ---------- Load on tube from single standoff

P_t = 675 lb ---------- Tube weight

The factor of safety (FS) for bearing is as follows:

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{34.6}{3.2} = \text{Large}$$

where:

S_y = 34.6 ksi ---------- Yield strength, SA-537 Class 1, at 550°F

The bearing stress (σ_{brg}) in the standoff at the TSC bottom plate is:

$$\sigma_{brg} = \frac{1.1 \times P_{cpa}}{A_{brg}} = 1.35 \text{ ksi}$$

where:

$$A_{brg} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.62^2 - 0.19^2\right) = 0.274 \text{ inch}^2$$

P_{cpa} = $P_t/2$

P_t = 675 lb

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.35} = \text{Large}$$

where:

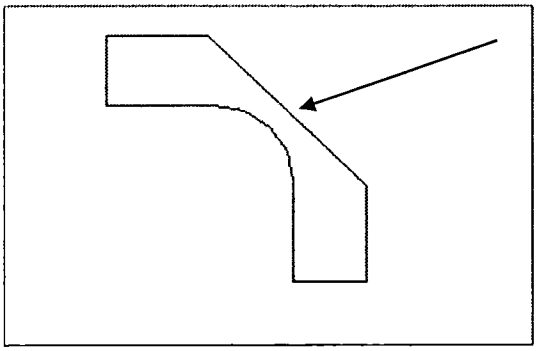
S_y = 20.7 ksi ---------- Yield strength, SA-240 Type 304, at 400°F

[redacted]

The weight of the side and corner weldments is carried to the TSC bottom plate by supports at the bottom of the basket. The corner weldment is the bounding condition with a weight of 2,450

lb and three contact points with the bottom plate. The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding).

Three contact points are comprised of two square areas of 1×0.94 inches and a bearing area at the corner of the damaged fuel cell. The bearing area at the corner has the shape shown below due to the 45° chamfer at the corner of the corner weldment.



The shape of this edge of the bearing area is due to the 45° chamfer

The area corresponding to the bearing area at the bottom of the corner weldment is 2.21 in^2 inches. The total bearing area A_{sup} is of 2×1×0.94 + 2.18 or 4.06 in^2 inches

The bearing stress (σ_{brg}) is:

$$\sigma_{brg} = \frac{1.1 \times W_{sup}}{A_{sup}} = \frac{1.1 \times 2{,}788}{4.06} = 0.8 \text{ ksi}$$

where:

W_{sup} = 2,450 lb

W_{sup} = 2,788 lb = $W_{cor} + 2\left(\frac{P_t}{4}\right)$ ----- Weight supported by the corner weldment

W_{cor} = 2,450 lb ---------- Weight of corner weldment

P_t = 675 lb ---------- Bounding weight of fuel tube assembly

A_{sup} = 4.06 in^2 ---------- Bearing area for DF corner weldment

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.8} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240, Type 304, 400°F

The side and corner weldments are attached to the fuel tube array with bolts. The bolt evaluation presented in Section 3.5.2.1 bounds the evaluation for the PWR DF basket configuration. The thermal stress evaluation of the PWR DF basket is performed using the finite element models presented in Section 3.10.1.6, and the results are bounded by those presented in Section 3.5.2.1

for the standard PWR basket configuration. The thermal stress evaluation of the neutron absorber is bounded by the evaluation presented in Section 3.5.2.1. The evaluation of the neutron absorber for normal handling conditions is bounded by the evaluation for the 24-in concrete cask end-drop accident (60g) as shown in Section 3.7.2.1.1.

3.5.2.3 BWR Fuel Basket

This section evaluates the MAGNASTOR BWR basket for normal operating conditions. Factors of safety for the BWR basket are calculated based on the criteria for Service Level 'A' limits from ASME Code, Section III, Subsection NG [7].

Normal Handling Evaluation

The BWR basket is analyzed using classical hand calculations for a 1.1g inertia loading in the basket axial direction to account for the dead load and the handling load. During normal conditions, the BWR fuel assemblies do not apply loads to the basket; they rest on the TSC bottom. Standoffs at the ends of the fuel tubes, side weldments and corner weldments provide support of the basket in the axial direction. [redacted] Using a bounding weight of 22,000 lb, the maximum stress in the fuel tube extension is calculated. There are 45 fuel tubes in the BWR basket. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube (σ_{tube}) is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{538}{1.5} = 0.4 \text{ ksi}$$

where:

$P_{tube} = \frac{W \times a}{n} = 538$ lb ---------- Load per tube
$W = 22{,}000$ lb ---------- Bounding basket weight
$a = 1.1g$ ---------- Inertia g-load
$n = 45$ ---------- Number of fuel tubes
$A = 1.5$ inch^2 ---------- Fuel tube extension cross-sectional area

The factor of safety (FS) is as follows.

$$FS = \frac{S_m}{\sigma_{tube}} = \frac{21.13}{0.4} = \text{Large}$$

where:

$S_m = 21.13$ ksi ---------- Design stress intensity, SA-537 Class 1, at 725°F

Using the conservative load in the fuel tube above (P_{tube}), the bearing stress (σ_{brg}) between the fuel tube extension and the TSC bottom plate is as follows. The bearing area (A_{brg}) is identical to the cross-sectional area of the fuel tube extension.

$$\sigma_{brg} = \frac{P_{tube}}{A_{brg}} = \frac{538}{1.5} = 0.4 \text{ ksi}$$

where:

A_{brg} = 1.5 in^2

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.4} = \text{Large}$$

where:

S_y = 20.7 ksi ..... Yield Strength, SA-240, Type 304, 400°F

Note: The limiting material property (TSC bottom plate) is used.

The weight of the side and corner weldments is transferred to the canister bottom plate by standoffs at the bottom of the weldments. The loading conditions of the corner weldment standoffs bound those of the side weldment. The dimensions for the corner support weldment are 8.0-inch length and 0.375-inch thickness. The bounding weight of the corner weldment is 1,200 pounds. Conservatively, the corner weldment is assumed to support one-quarter the weight of four fuel tubes (400 lb per tube, bounding).

The bearing stress is as follows.

$$\sigma_{brg} = \frac{W_{sup}}{A_{sup}} = \frac{1760}{3.0} = 0.6 \text{ ksi}$$

where:

$W_{sup} = 1.1 \times (1{,}200 + 4 \times (0.25 \times 400)) = 1760$ lb

$A_{sup} = 8.0 \times 0.375 = 3.0$ in^2

The factor of safety (FS) for bearing is

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.6} = \text{large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240 Type 304, at 400°F

The buckling evaluation of the fuel tube corner extension is performed for the governing condition of the 24-inch concrete cask end-drop accident, as prescribed in Section 3.7.2.2. The accident event buckling evaluation is bounding due to the 60g axial inertia loading.

The side and corner weldments are attached to the fuel tube array with bolts. The maximum torque on the ⅝-inch bolt is 50 inch-lb (40 ±10 inch-lb). The preload on the bolt (P) is as follows.

$$P = \frac{T}{0.2D} = \frac{50}{0.2 \times 0.625} = 400 \text{ lb} \qquad [12]$$

where:

T = 50 inch-lb ---------- Maximum bolt torque
D = 0.625 inch ---------- Bolt diameter

The bolt thread is a ⅝-11 UNC and the minimum length of engagement is 0.47 inch. A bolt load of 1,800 lb is conservatively used for the evaluation. From Machinery's Handbook [12], the tensile strength (σ_t) in the bolt is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{1{,}800}{0.23} = 7.8 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ inch}^2$$

D = 0.625 inch
n = 11

The factor of safety (FS) is as follows.

$$FS = \frac{S_m}{\sigma_t} = \frac{23.3}{7.8} = 3.0$$

where:

S_m = 23.3 ksi ---------- Design stress intensity for SA-193, Gr B6, at 700°F

The shear stress in the bolt thread (τ_{bolt}) is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{1{,}800}{0.469} = 3.84 \text{ ksi}$$

where:

$$A_s = 3.1416 n L_e K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.469 \text{ inch}^2$$

$n = 11$

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{bolt}} = \frac{0.6 \times 23.3}{3.83} = 3.65$$

where:

S_m = 23.3 ksi ---------- Design stress intensity, SA-193 Grade B6, at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{1{,}800}{0.67} = 2.7 \text{ ksi}$$

where:

$$A_n = 3.1416nL_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.67 \text{ inch}^2$$

L_e = 0.47 inch
$E_{n\,max}$ = 0.5732
$D_{s\,min}$ = 0.6113
$n = 11$

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{bolt}} = \frac{0.6 \times 18.1}{2.7} = 4.02$$

where:

S_m = 18.1 ksi ---------- Design stress intensity, SA-516, Type B, Grade 70, at 700°F

The boss is welded into the fuel tube with a 3/16-inch groove weld. The shear stress in the boss weld (τ_{weld}) is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{1{,}800}{0.59} = 3.05 \text{ ksi}$$

where:

P = 1000 lb
$A_w = \pi D t_{weld} = \pi \times 1.00 \times 0.1875 = 0.59$ inch
D = 1.00 inch ---------- Smallest boss diameter

Using the lesser allowable, S_m, of SA-537 Class 1 or SA-695 Type B, Gr 40, the factor of safety (FS) is as follows.

$$FS = \frac{0.35 \times 0.6S_m}{\tau_{weld}} = 1.25$$

where:

S_m = 18.1 ksi ---------- Design stress intensity, SA-516 Type B Grade 70, at 700°F

The washers under the bolts are subjected to shear from the bolt tensile load and the support condition at the weldment. The washer is evaluated using the maximum bolt load (1,800 lb). The maximum washer shear stress, using an area defined by the bolt head perimeter and the washer thickness, is

$$\tau_{wash} = \frac{P}{A_w} = \frac{1{,}800}{0.617} = 2.92 \text{ ksi}$$

where:

A_w = 0.617 in^2 ---------- Shear area of washer

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{wash}} = \frac{0.6 \times 16.0}{2.92} = 3.29$$

where:

S_m = 16.0 ksi ---------- Design stress intensity, SA-240 Type 304, at 700°F

The evaluation of the neutron absorber for normal handling conditions is bounded by the evaluation for the 24-inch concrete cask end-drop accident (60g) as shown in Section 3.7.2.2. Therefore, no evaluation for normal handling is presented in this section.

Thermal Stress Evaluation

The thermal stresses for the BWR fuel basket are calculated using a three-dimensional periodic half-symmetry ANSYS finite element model (Section 3.10.2.2). The model calculates the stresses in the basket based upon an applied temperature distribution. The thermal stresses are combined with the normal handling conditions stresses by hand. Factors of safety are calculated based on Service Level 'A' limits from ASME Code, Section III, Subsection NG [7]. The maximum handling stress in the basket is 0.4 ksi. The following presents the combined normal handling plus thermal stress (P+Q) for the BWR fuel basket.

Component	S_{therm}, ksi	S_{total}, ksi	S_{allow}, ksi	FS
Fuel Tube	3.49	3.89	63.39	Large
Side Weldments	0.83	1.23	63.39	Large
Corner Weldments	1.02	1.42	63.39	Large

The total stress is the sum of the component thermal stress and the normal condition stress. The allowable stress is $3S_m$ ($3 \times 21.13 = 63.39$ ksi for SA-537 Class 1 steel at 725°F). Note that 725°F is conservatively used to bound all normal, off-normal and transfer conditions.

The average temperature at the center of the basket is 520°F. The average temperature at the outer radius of the basket is 440°F. The relative thermal expansion of the basket in the axial direction between the center and outer edge of the basket is as follows.

$$\Delta x = \Delta x_{inner} - \Delta x_{outer} = 0.53 - 0.44 = 0.11 \text{ inch}$$

where:

$$\Delta x_{inner} = \Delta T \times L \times \alpha_1 = (520-70)(166.5)(7.33\times10^{-6}) = 0.55 \text{ inch}$$

$$\Delta x_{outer} = \Delta T \times L \times \alpha_2 = (440-70)(166.5)(7.18\times10^{-6}) = 0.44 \text{ inch}$$

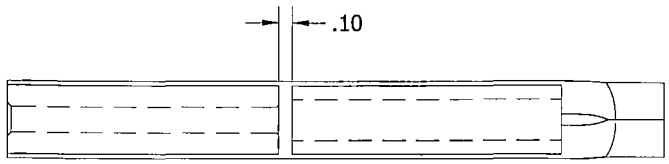
L = 166.5 inch ---------- Fuel tube length

α_1 = 7.33×10^{-6} inch/inch/°F ---------- Coefficient of thermal expansion, SA537 CL1, at 520°F

α_2 = 7.18×10^{-6} inch/inch/°F ---------- Coefficient of thermal expansion, SA537 CL1, at 440°F

Adjacent fuel tube connector pins have a 0.10-inch gap between the connector pins at the top or bottom of the basket (see the following sketch). There are a minimum of three sets of connector pins in the radial direction of the basket. Therefore, the relative thermal expansion between the adjacent tubes is approximately 0.04 inch (0.11/3), which is less than the pin gap of 0.10 inch.

Since the relative thermal expansion of the basket between the center and outer edge of the basket is less than the pin gap, no axial thermal stresses are produced by the axial expansion of the basket.



The maximum shear load calculated by ANSYS in the basket attachment bosses is 40 lbs due to the radial thermal expansion of the basket. The shear stress in the boss (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A} = \frac{40}{0.47} = 0.085 \text{ ksi}$$

where:

$$A = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = 0.47 \text{ inch}^2$$

D_o = 1.00 inch
D_i = 0.63 inch

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_m}{\tau_{boss}} = \frac{0.6 \times 18.1}{0.085} = \text{Large}$$

where:

S_m = 18.1 ksi ---------- Design stress intensity, SA-516, Grade 70, at 700°F

The thermal expansion of the basket does not add significant additional tensile loads to the bolts; therefore, no additional bolt analysis for thermal loads is required.

Neutron Absorber Retainer Thermal Stress Evaluation

The stainless steel retainer strips are fastened to the carbon steel fuel tube using fixed weld posts spaced along the length of the tube. Because of the dissimilar material properties, differential thermal expansion of the components results in thermal stresses in some of the components. Since the stress due to differential thermal expansion is not a function of length, the evaluation

provided in Section 3.5.2.1 for retainer for the PWR is applicable to that for the BWR. No further analysis is required.

3.5.3 Concrete Cask Evaluations for Normal Operating Conditions

The structural evaluation of the concrete cask for normal conditions considers the combination of thermal stresses, dead and live loads, and wind loads (see Chapter 2 for load combinations). The analysis results are presented in Section 3.5.3.3. The conservative stress due to wind loads is obtained from Section 3.7.3.2.

3.5.3.1 Concrete Cask Thermal Stresses

Using the finite element models presented in Section 3.10.4, structural evaluations of the concrete cask are performed for normal conditions thermal loads, both with and without the optional inner rebar cage. The analysis conservatively considered a bounding temperature profile corresponding to the off-normal thermal event (106°F ambient).

The following summarizes the bounding thermal stresses in the concrete cask for normal conditions.

Component	Stress (ksi)
Circumferential Rebar	20.2
Vertical Rebar	20.5
Concrete, Compression	1.63
Concrete, Tension	0.129

3.5.3.2 Dead and Live Loads

Dead Loads

The concrete cask dead load consists primarily of the weight of the concrete. Assuming all dead loads are reacted by the lower concrete surface only, stress levels can be determined. Under these conditions, the only stress component is the vertical axial compression stress. The maximum stress (σ_{cask}) at the base of the concrete cask in the concrete is as follows.

$$\sigma_{cask} = \frac{W_{cask}}{A} = \frac{231{,}000}{8{,}785} = 26 \text{ psi}$$

where:

W_{cask} = 231,000 lb ---------- Bounding weight for empty concrete cask
D_o = 136.0 inch

D_i = 85.5 inch
A = $\pi (D_o^2 - D_i^2) / 4 = 8{,}785$ inch^2

The concrete bearing strength (f_b) is much larger than the applied load.

$$f_b = \phi(0.85 f_c' A) = 0.85(0.85 \times 3800 \times 8785) = 24.1 \times 10^6 \text{ lb} > 231{,}000 \text{ lb}$$

where:

f_c' = 3,800 psi---------- Compressive strength, concrete, at 300°F

Live Loads

The live load calculation considers the loaded transfer cask positioned on top of the concrete cask for transfer of the TSC for development of the peak live load bounding condition. Assuming live loads are reacted by concrete sections (no credit taken for steel liner), stress levels are conservatively determined. Under these conditions, the only stress component is the vertical axial compression stress ($\sigma_{\text{concrete cask}}$).

$$\sigma_{\text{concrete cask}} = \frac{W_{TFR}}{A} = \frac{232{,}000}{8{,}785} = 26 \text{ psi}$$

where:

W_{TFR} = 232,000 lb---------- Loaded transfer cask with transfer adapter
D_o = 136.0 inch
D_i = 85.5 inch
A = $\pi (D_o^2 - D_i^2) / 4 = 8{,}785$ inch^2

3.5.3.3 Concrete Cask Combined Stresses

The load combinations described in Chapter 2 are used to evaluate the concrete cask for normal conditions of storage (Load Conditions 1, 2, and 3). Bounding stresses for all concrete cask configurations are summarized in Table 3.5.3-1, Table 3.5.3-2, and Table 3.5.3-3 for the various loading conditions on the concrete cask.

The allowable compressive stress for concrete (S_{con}) is as follows.

$$S_{con} = \phi f_c' = 2{,}660 \text{ psi}$$

where:

ϕ = 0.7---------- Strength reduction factor [5]

$f_c' = 3{,}800$ psi ---------- Compressive strength of concrete at 300°F

The concrete ultimate strength allowable is 8% to 15% of the compressive stress [14]; therefore, the allowable ultimate strength (S_{tc}) is as follows.

$$S_{tc} = 0.08 \times S_{con} = 0.08 \times 2{,}660 = 213 \text{ psi or } 0.21. \text{ ksi}$$

The maximum concrete compressive stress is 2,160 psi (see Table 3.5.3-2); therefore, the minimum factor of safety (FS) for normal conditions is as follows.

$$FS = \frac{2{,}660}{2{,}160} = 1.23$$

From Section 3.5.3.1, the maximum concrete tensile stress due to thermal load is 0.129 ksi. Multiplying the stress by a 1.275 factor for normal conditions thermal stresses (see Chapter 2), the factor of safety (FS) for concrete ultimate strengths is as follows.

$$FS = \frac{S_{tc}}{S_t \times 1.275} = \frac{0.213}{0.129 \times 1.275} = 1.30$$

The allowable stress for rebar (S_{rebar}) is as follows.

$$S_{rebar} = \phi F_r = 54.0 \text{ ksi}$$

where:

$\phi = 0.9$ ---------- Strength reduction factor [5]

$F_r = 60.0$ ksi ---------- Yield strength, rebar

From Section 3.5.3.1, the maximum rebar stress due to thermal load is 20.5 ksi. The stresses due to other loadings are negligible for normal conditions. Compressive loads are carried by the concrete. Multiplying the stress by a 1.275 factor for normal conditions thermal stresses (see Chapter 2), the factor of safety (FS) for the rebar is as follows.

$$FS = \frac{S_{rebar}}{S_t \times 1.275} = \frac{54.0}{20.5 \times 1.275} = 2.07$$

Table 3.5.3-1 Concrete Cask Vertical Stress Summary – Outer Surface, psi

Condition	Dead	Live	Wind	Thermal	Seismic	Flood	Tornado	Total
1	-39	-45	0	0	0	0	0	-84
2	-29	-33	0	0	0	0	0	-62
3	-29	-33	-24	0	0	0	0	-86

Table 3.5.3-2 Concrete Cask Vertical Stress Summary – Inner Surface, psi

Condition	Dead	Live	Wind	Thermal	Seismic	Flood	Tornado	Total
1	-39	-45	0	0	0	0	0	-84
2	-29	-33	0	-2083	0	0	0	-2145
3	-29	-33	-15	-2083	0	0	0	-2160

Table 3.5.3-3 Concrete Cask Circumferential Stress Summary – Inner Surface, psi

Condition	Dead	Live	Wind	Thermal	Seismic	Flood	Tornado	Total
1	0	0	0	0	0	0	0	0
2	0	0	0	-2083	0	0	0	-2083
3	0	0	0	-2083	0	0	0	-2083

3.6 Off-Normal Operating Events

This section presents the analyses of the major structural components of MAGNASTOR for off-normal events of storage. MAGNASTOR is evaluated using finite element models and classical hand calculations for the fuel baskets and TSC. Off-normal environmental events are defined as -40°F with no solar load, 106°F with solar load, and half-blockage of the concrete cask air inlets. Bounding analyses are performed for two groups of TSC configurations: (1) TSC1 and TSC2 with a single-piece closure lid assembly, and (2) TSC3 and TSC4 with a composite closure lid assembly. For detailed analysis results for off-normal conditions, see Table 3.10.3-7 through Table 3.10.3-11 for the TSC1/TSC2 configuration and Table 3.10.3-24 through Table 3.10.3-28 for the TSC3/TSC4 configuration.

3.6.1 TSC Evaluations for Off-Normal Operating Events

3.6.1.1 Thermal Stresses for Off-Normal Events

The thermal stresses of the TSC are calculated using the ANSYS finite element models described in Section 3.10.3. As discussed in Section 3.5.1.1, the temperature gradient applied to the TSC bounds the temperature gradient for all conditions of storage. Therefore, the maximum thermal stresses for the off-normal severe ambient temperature event are bounded by those presented in Table 3.5.1-1.

3.6.1.2 Off-Normal TSC Load Analyses

Based on the load combinations specified in Table 2.3-2, the following two off-normal load events are evaluated.

- Off-normal internal pressure + normal handling + thermal (ASME Code, Level B)
- Normal internal pressure + off-normal handling (ASME Code, Level C)

Detailed off-normal condition stress analyses results for the TSC1/TSC2 and TSC3/TSC4 configurations are presented in Sections 3.10.3.1 and 3.10.3.2, respectively.

Off-Normal Internal Pressure with Normal Handling

The TSC is analyzed for off-normal pressurization and normal handling loads using the finite element models described in Section 3.10.3. A 1.1g acceleration load is applied to the loaded TSC in the axial direction to simulate normal handling. To represent the off-normal pressure, an internal pressure of 130 psig is applied to all internal surfaces of the TSC shell, bottom plate and closure lid. This pressure bounds the maximum calculated pressure for PWR and BWR fuel under normal conditions. A bounding temperature profile is considered for the thermal stress calculation, as discussed in Section 3.10.3.

The resulting maximum stresses in the TSC for Service Level 'B' off-normal loads are summarized in Table 3.6.1-1 for primary membrane, Table 3.6.1-2 for primary membrane plus primary bending, and Table 3.6.1-3 for primary plus secondary stress categories. The minimum factor of safety of 1.18 ($P_m + P_b$) occurs at Section 3. The locations for the stress sections are shown in Section 3.10.3.

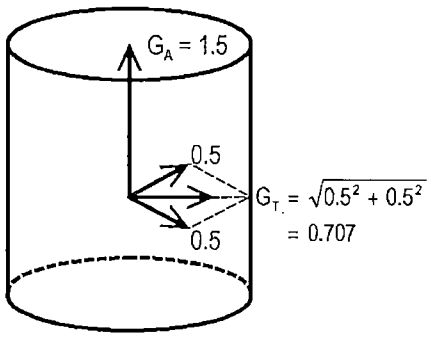
The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for the TSC3 and TSC4 for normal handling plus off-normal internal pressure is 38.37 ksi. The allowable bolt tensile stress for 'Service Level B' off-normal conditions is limited to $1.15 \times S_u/2$, or 54.61 ksi, for the A193 Grade B6 bolt material at an upper-bound bolt design temperature of 525°F. Therefore, the minimum factor of safety for the shield plate attachment bolt for off-normal internal pressure plus normal handling is 1.42.

Off-Normal Handling with Normal Internal Pressure

An evaluation is performed for the off-normal handling loads on the TSC during the installation of the TSC in the concrete cask, removal of the TSC from the concrete cask, and removal from the transfer cask. The TSC is handled vertically in both the concrete and transfer casks.

The TSC is analyzed for handling loads using the finite element models described in Section 3.10.3. The off-normal TSC handling loads are defined as 0.5g applied in all directions (i.e., in the global x, y, and z directions) in addition to a 1g lifting load applied in the finite element model. The resulting off-normal handling accelerations are 0.707g in the lateral direction and 1.5g (0.5g + 1.0g) in the vertical direction. To represent the normal pressure, an internal pressure of 110 psig is applied to all internal surfaces of the TSC shell, bottom plate and closure lid.

Off-Normal Handling



The resulting maximum stresses in the TSC for Service Level 'C' off-normal loads are summarized in Table 3.6.1-1 for primary membrane, Table 3.6.1-2 for primary membrane plus primary bending, and Table 3.6.1-3 for primary plus secondary stress categories. The minimum factor of safety of 1.27 ($P_m + P_b$) occurs at Section 3. The locations for the stress sections are shown in Section 3.10.3.

The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for the TSC3 and TSC4 for off-normal handling plus normal internal pressure is 38.21 ksi. The allowable bolt tensile stress for 'Service Level C' off-normal conditions is limited to 1.25 × $S_u/2$, or 59.36 ksi, for the A193 Grade B6 bolt material at an upper-bound bolt design temperature of 525°F. Therefore, the minimum factor of safety for the shield plate attachment bolt for off-normal handling plus normal internal pressure is 1.55.

The maximum stress in the TSC port cover is due to bending at its center from the internal pressure and inertial loading. Bending stress (σ) is calculated using the formulas from Reference 13 as follows.

$$\sigma = 6\frac{M_r}{t^2} = 9.5 \text{ ksi}$$

where:

$$M_r = \frac{qa^2(3+\nu)}{16}$$

$q = q_i + q_p$

$q_i = t \times \rho \times g$

q_p = 130 psi ---------- Off-Normal condition pressure
d = 5.75 in ---------- Maximum port cover diameter
a = d/2 ---------- Port cover radius
ν = 0.31 ---------- Poisson's ratio
t = 3/8 in ---------- Minimum thickness of the port cover
ρ= 0.291 lb/in^3 ---------- Density, SA-240 Type 304
g = 1.5g ---------- Off-Normal condition handling acceleration

Conservatively using the temperature of 650°F for the material allowable, the factor of safety is:

$$FS = \frac{S_{allow}}{\sigma} = \frac{1.65\ S_m}{\sigma} = 2.81$$

where:

S_m = 16.2 ksi ---------- design stress intensity, SA-240 Type 304 at 650°F

The shear stress in the port cover weld is:

$$\tau_w = \frac{qA_p}{A_w} = 1.52 \text{ ksi}$$

where:

$A_p = d_p^2\pi/4$ ---------- Area of port
$A_w = d_p \pi t_w$ ---------- Weld area
d_p = 5.83 in ---------- Maximum lid port counterbore diameter
t_w = 1/8 in ---------- Port cover weld thickness

q = 130 psi ---------- Off-Normal condition pressure and inertial loading

Conservatively using the temperature of 650°F, the factor of safety is:

$$FS = \frac{S_{allow}}{\tau_w} = \frac{0.6\ S_m(1.1)}{\tau_w} = 7.03$$

where:

S_m = 16.2 ksi ---------- design stress intensity, SA-240 Type 304 at 650°F

Table 3.6.1-1 TSC Off-Normal Events, P_m Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Off-Normal Pressure + Normal Handling	B	3	-0.67	-10.75	5.54	-0.21	-0.03	1.16	16.51	22.00	1.33
Normal Pressure + Off-Normal Handling	C	3	-0.62	-10.75	5.15	-0.25	-0.02	1.07	16.10	24.50	1.52

Table 3.6.1-2 TSC Off-Normal Events, $P_m + P_b$ Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Off-Normal Pressure + Handling	B	3	-0.28	-5.53	22.31	0.00	0.00	1.47	27.94	33.00	1.18
Normal Pressure + Off-Normal Handling	C	3	-0.23	-6.17	21.24	-0.14	0.05	1.35	27.49	34.80	1.27

Table 3.6.1-3 TSC Off-Normal Events, P + Q Stresses

Load Case	Service Level	Section[a]	Component Stresses (ksi)[b]						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Off-Normal Pressure + Normal Handling + Thermal	B	12	-44.54	-41.22	-9.07	-1.36	0.06	-1.71	36.12	60.00	1.66

[a] See Figure 3.10.3-2 for section cut locations.
[b] The x, y, z components of stress are to be interpreted radial, circumferential and axial directions, respectively.

3.6.2 Fuel Basket Evaluation for Off-Normal Operating Events

3.6.2.1 PWR Fuel Basket

This section evaluates the MAGNASTOR PWR basket for off-normal events using both classical hand calculations and finite element analysis methods. Factors of safety for the PWR basket are calculated based on the criteria for Service Level 'C' limits from ASME Code, Section III, Subsection NG [7].

The inertia loading for off-normal handling events is a 1.5g vertical acceleration and a 0.707g (0.5g in each transverse direction) transverse acceleration. The basket stresses due to the transverse loading are calculated using the three-dimensional periodic finite element models described in Section 3.10.1. Both half-symmetry models for the 0° and 45° basket orientations are used. Using a bounding weight of 22,500 pounds for the PWR basket, the maximum stress in the fuel tube in the axial direction is calculated. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube due to the axial acceleration is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{1607}{11.4} = 0.14 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{22500 \times 1.5}{21} = 1{,}607 \text{ lb}$$

W = 22,500 lb ---------- Bounding basket weight
n = 21 ---------- Number of fuel tubes
a = 1.5g ---------- Inertia g-load
A = 11.4 inch^2 ---------- Tube cross-sectional area

The maximum primary membrane and primary membrane plus bending due to transverse loading (S_{tran}) from the finite element analysis results are shown in the following table. See Figure 3.10.1-11 through Figure 3.10.1-16 for locations of critical sections where the stresses are reported. The combined maximum stress intensity (S_{tot}) is conservatively obtained by adding the maximum stresses due to axial load (σ_{tube}) to the maximum stresses due to transverse load (S_{tran}). The combined stresses and factors of safety are presented in the following table. The allowable stresses for the off-normal events (Level C) are $1.5S_m$ for membrane stresses and $2.25S_m$ for membrane plus bending stresses. A bounding temperature of 755°F is conservatively used.

Component	S_{tran}, ksi	S_{tot}, ksi	S_{allow}, ksi	FS
Fuel Tube, P_m	2.4	2.5	31.4	Large
Fuel Tube, $P_m + P_b$	17.5	17.6	47.0	2.66
Support Weldments, P_m	2.5	2.6	31.4	Large
Support Weldments, $P_m + P_b$	9.6	9.7	47.0	4.85

Axial support of the fuel tubes is provided by fuel tube standoffs at the top and bottom of the basket and the side and corner weldments. Fuel tube standoffs are formed by extensions of the fuel tube corners or use of connector pin assemblies. Referring to Figure 3.10.1-11, the interior tubes (Tube #4) are supported by four standoffs, the side fuel tubes (Tube #1) are supported by two standoffs and the side and corner weldments, and the corner fuel tubes (Tube #3) are supported by three standoffs and the corner weldment. Therefore, the standoffs support one-fourth of a fuel tube's weight. Evaluation of the connector pin assembly (CPA) standoff provides a bounding evaluation which envelops all end of tube configurations.

The bearing stress on the fuel tube (σ_{brg}) is as follows.

[redacted]

The bearing stress (σbrg) in the standoff at the TSC bottom plate is:

$$\sigma_{brg} = \frac{1.5 \times P_{cpa}}{A_{brg}} = 1.85 \text{ ksi}$$

where:

$$A_{brg} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.62^2 - 0.19^2\right) = 0.274 \text{ inch}^2$$

$$P_{cpa} = P_t / 2$$

$$Pt = 675 \text{ lb}$$

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.85} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240 Type 304, at 400°F

The weight of the side and corner weldments is carried through to the TSC bottom plate by supports at the bottom of the basket. The bounding dimensions for the supports of the weldments are 5.0 inches in length and 0.3125-inch thickness (corner weldment). The maximum weight of one weldment is 800 lb (bounding, side weldment). The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding). The bearing stress is as follows.

$$\sigma_{brg} = \frac{1.5 \times W_{sup}}{A_{sup}} = 1.1 \text{ ksi}$$

where:

$$W_{sup} = 800 + 2 \times (0.25 \times 675) = 1138 \text{ lb}$$
$$A_{sup} = 5.0 \times 0.3125 = 1.56 \text{ inch}^2$$

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.1} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240, Type 304 at 400°F

The buckling evaluation of the fuel tube standoffs is performed in Section 3.7.2.1. The accident condition buckling evaluation is bounding due to the conservative 60g axial inertia loading.

A bounding bolt load of 2,500 lb is used for the bolt evaluation for off-normal conditions of storage. The bolt thread is a ⅝-11 UNC and the length of engagement is 0.50 inch. From Machinery's Handbook [12], the tensile stress (σ_t) in the bolt is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{2,500}{0.23} = 10.9 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ inch}^2$$

$$D = 0.625 \text{ inch}$$

$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{1.5S_m}{\sigma_t} = \frac{1.5 \times 23.3}{10.9} = 3.2$$

where:

S_m = 23.3 ksi ---------- Design stress intensity for SA 193, Gr B6 at 700°F

The shear stress (τ_{bolt}) in the bolt thread is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{2{,}500}{0.499} = 5.0 \text{ ksi}$$

where:

$$A_s = 3.1416nL_e K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.499 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.9S_m}{\tau_{bolt}} = \frac{0.9 \times 23.3}{5.0} = 4.2$$

where:

S_m = 23.3 ksi ---------- Design stress intensity, SA-193 Grade B6 at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{2{,}500}{0.713} = 3.5 \text{ ksi}$$

where:

$$A_n = 3.1416nL_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.713 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.9S_m}{\tau_{bolt}} = \frac{0.9 \times 17.3}{3.5} = 4.4$$

where:

S_m = 17.3 ksi ---------- Design stress intensity, SA-36, at 700°F

The boss is welded into the fuel tube with a 1/4-inch groove weld. The shear stress in the boss weld (τ_{weld}), is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{2{,}500}{0.98} = 2.6 \text{ ksi}$$

where:

P = 2,500 lb
A_w = $\pi D t_{weld} = \pi \times 1.25 \times 0.25 = 0.98 \text{ inch}^2$
D = 1.25 inches ---------- Boss diameter

Using the lesser allowable, S_m, of SA-537 Class 1 or SA-36, the factor of safety (FS) is as follows.

$$FS = \frac{wf \times 0.9S_m}{\tau_{weld}} = 2.1$$

where:

wf = 0.35 ---------- Weld quality factor visual inspection (ASME Code Section III, NG, Article NG-3352)
S_m = 17.3 ksi ---------- Design stress intensity, SA-36, at 700°F

The washers under the bolts at the boss locations are subjected to shear from the bolt tensile load and the support condition at the weldment. The shear stress in the washer is:

$$\tau_{wash} = \frac{P}{A_w} = \frac{2{,}500}{1.718} = 1.5 \text{ ksi}$$

where:

$A_w = \pi D_s t_w = 1.718 \text{ in}^2$

D_s = 1.75 in ---------- Support diameter of washer at weldment

t_w = 3/16 in ---------- Washer thickness

The factor of safety is

$$FS = \frac{0.9S_m}{\tau_{wash}} = 9.6$$

where:

S_m = 16.0 ksi ---------- Design stress intensity, SA-240 Type 304, at 700°F

The analysis presented in Section 3.7.2.1 bounds the off-normal analysis of the neutron absorber and retainer strip; therefore, no additional analysis is required.

3.6.2.2 PWR Fuel Basket with Damaged Fuel Cans

This section evaluates the MAGNASTOR PWR basket with square pins and the damaged fuel can configuration (DF Basket Assembly) for off-normal events. The inertia loading for off-normal handling events is a 1.5g vertical acceleration and a 0.707g (0.5g in each transverse direction) transverse acceleration. The basket stresses due to the transverse loading are calculated using the three-dimensional periodic finite element models described in Section 3.10.1.5 (Figures 3.10.1-17 and 3.10.1-18 for the 0° and 45° basket orientations, respectively). Using a bounding weight of 25,000 pounds for the PWR basket with damaged fuel cans, the maximum stress in the fuel tube in the axial direction is calculated. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube due to the axial acceleration is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{2206}{11.4} = 0.2 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{25000 \times 1.5}{17} = 2{,}206 \text{ lb}$$

W = 25,000 lb ---------- Bounding basket weight

n = 17---------- Number of fuel tubes

a = 1.5g ---------- Inertia g-load

A = 11.4 inch^2 ---------- Tube cross-sectional area

The maximum stress in the support weldment (σ_{sw}) due to the axial acceleration of 1.5g is calculated to be 0.9 ksi based on a bounding weight of 2,450 pounds and support area of 4.06 in^2 for the corner weldment.

The maximum primary membrane and primary membrane plus bending stresses due to transverse loading (S_{tran}) from the finite element analysis results are shown in the following table. The combined maximum stress intensity (S_{tot}) is conservatively obtained by adding the maximum stresses due to axial load (σ_{tube} or σ_{sw}) to the maximum stresses due to transverse load (S_{tran}). The combined stresses and factors of safety are presented in the following table. The allowable stresses for the off-normal events (Level C) are $1.5S_m$ for membrane stresses and $2.25S_m$ for membrane plus bending stresses. A bounding temperature of 755°F is conservatively used.

Component	S_{tran}, ksi	S_{tot}, ksi	S_{allow}, ksi	FS
Fuel Tube, P_m	1.7	1.9	31.4	Large
Fuel Tube, $P_m + P_b$	24.3	24.5	47.0	1.92
Support Weldments, P_m	0.3	1.2	31.4	Large
Support Weldments, $P_m + P_b$	2.7	3.6	47.0	Large

Axial support of the fuel tubes is provided by fuel tube standoffs at the top and bottom of the basket and the side and corner weldments. Fuel tube standoffs are formed by extensions of the fuel tube corners or use of connector pin assemblies. Referring to Figure 3.10.1-19, the interior tubes (Tube #4) are supported by four standoffs and the side fuel tubes (Tube #1) are supported by two standoffs and the side and corner weldments. Therefore, the standoffs support one-fourth of a fuel tube's weight. Evaluation of the connector pin assembly (CPA) standoff provides a bounding evaluation which envelops all end of tube configurations. The fuel tube bearing stress (σ_{brg}) is:

$$\sigma_{brg} = \frac{1.5 \times P_{t/s}}{A_{brg}} = 4.34 \text{ ksi}$$

where:

A_{brg} = 0.0583 in^2 ---------- Minimum bearing area for a single tube
$P_{t/s}$ = $P_t/4$ ---------- Load on tube from single standoff
P_t = 675 lb ---------- Tube weight

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{34.6}{4.34} = 8.0$$

where:

S_y=34.6 ksi---------- Yield strength, SA-537 Class 1, at 550°F

The bearing stress (σ_{brg}) in the standoff at the TSC bottom plate is:

$$\sigma_{brg} = \frac{1.5 \times P_{cpa}}{A_{brg}} = 1.85 \text{ ksi}$$

where:

$$A_{brg} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.62^2 - 0.19^2\right) = 0.274 \text{ inch}^2$$

$$P_{cpa} = P_t / 2$$

$$P_t = 675 \text{ lb}$$

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.85} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240 Type 304, at 400°F

The weight of the side and corner weldments is carried to the TSC bottom plate by supports at the bottom of the basket. The corner weldment is the bounding condition with a weight of 2,450 lb and three contact points with the bottom plate. The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding). The bearing stress (σ_{brg}) is:

$$\sigma_{brg} = \frac{1.5 \times W_{sup}}{A_{sup}} = \frac{1.5 \times 2{,}788}{4.06} = 1.03 \text{ ksi}$$

where:

W_{sup} = 2,788 lb = $W_{cor} + 2\left(\frac{P_t}{4}\right)$ ----- Weight supported by the corner weldment

W_{cor} = 2,450 lb ---------- Weight of corner weldment

P_t = 675 lb ---------- Bounding weight of fuel tube assembly

A_{sup} = 4.06 in^2 ---------- Bearing area for DF corner weldment

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{1.03} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield strength, SA-240, Type 304, at 400°F

The buckling evaluation of the basket standoffs is performed in Section 3.7.2.1. The accident condition buckling evaluation is bounding due to the conservative 60g axial inertia loading.

The maximum tensile load in the attachment bolts and the maximum shear load on the fuel tube boss for the off-normal condition is bounded by the evaluation for normal conditions presented in Section 3.5.2.1.

The evaluation of the neutron absorber and retainer strip for the off-normal condition is bounded by the analysis presented in Section 3.7.2.1.

3.6.2.3 BWR Fuel Basket

The analysis of the BWR basket for off-normal events uses both classical hand calculations and finite element analysis methods. The ANSYS finite element model and boundary conditions are presented in Section 3.10.2 for the 0° and 45° basket orientations. Factors of safety for the BWR basket are calculated based on the criteria for Service Level 'C' limits from ASME Code, Section III, Subsection NG [7]. The inertia loading for off-normal events is a 1.5g vertical acceleration and a 0.707g (0.5g in each transverse direction) transverse acceleration.

For off-normal events of storage, a 1.5g acceleration (a) is applied to the basket in the axial direction. Using a bounding weight of 22,000 lb for the BWR basket, the maximum stress in the fuel tube in the axial direction is calculated. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube due to the axial acceleration is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{733}{1.5} = 0.49 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{22{,}000 \times 1.5}{45} = 733 \text{ lb}$$

W = 22,000 lb ---------- Bounding basket weight
N = 45---------- Number of fuel tubes
a = 1.5g ---------- Inertia g-load
A = 1.5 inch^2 ---------- Tube extension cross-sectional area

The maximum primary membrane and primary membrane plus bending stresses due to transverse loading (S_{tran}) from the finite element analysis results are as follows. See Figure 3.10.2-13 through Figure 3.10.2-20 for locations of critical sections where stresses are reported. The combined maximum stress intensity (S_{tot}) is conservatively obtained by adding the maximum stresses due to axial load (σ_{tube}) to the maximum stresses due to transverse load (S_{tran}). The combined stresses and factors of safety are presented in the following table. The allowable stresses for the off-normal events (Level C) are $1.5S_m$ for membrane stresses and $2.25S_m$ for membrane plus bending stresses.

Component	S_{tran}, ksi	S_{tot}, ksi	S_{allow}, ksi	FS
Fuel Tube, P_m	7.05	7.54	31.4 (1)	4.16
Fuel Tube, $P_m + P_b$	14.75	15.24	47.0 (1)	3.08
Corner Weldment, P_m	1.8	2.29	32.1 (2)	Large
Corner Weldment, $P_m + P_b$	9.83	10.32	48.2 (2)	4.67
Side Support Weldment, P_m	1.7	2.19	32.1 (2)	Large
Side Support Weldment, $P_m + P_b$	4.96	5.45	48.2 (2)	8.84

The weight of the basket is assumed to be completely supported by 45 fuel tube extensions, and no support is assumed from the side and corner weldments. The bearing stress on the fuel tube is

$$\sigma_{brg} = \frac{P_{tube}}{A_{brg}} = \frac{0.733}{1.5} = 0.49 \text{ ksi}$$

where:

A = 1.5 inch^2 ---------- Fuel tube extension cross-sectional area

The factor of safety for bearing is

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.49} = \text{Large}$$

where:

S_y = 20.7 ksi ..... Yield Strength, SA-240, Type 304, 400°F

Note: The limiting material property (TSC bottom plate) is used.

The weight of the side and corner weldments is transferred to the TSC bottom plate by standoffs at the bottom of the basket. The loading conditions of the corner weldment standoffs bound those of the side weldment. The dimensions for the corner support weldment are 8.0 inches in length and 0.375-inch thickness. The bounding weight of the corner weldment is 1,200 pounds.

Conservatively, the corner weldment is assumed to support one-quarter the weight of four fuel tubes (400 lb per tube, bounding). The bearing stress is as follows.

$$\sigma_{brg} = \frac{W_{sup}}{A_{sup}} = 0.8 \text{ ksi}$$

where:

$$W_{sup} = 1.5 \times (1{,}200 + 4 \times (0.25 \times 400)) = 2{,}400 \text{ lb}$$
$$A_{sup} = 8.0 \times 0.375 = 3.0 \text{ inch}^2$$

The factor of safety (FS) for bearing is as follows.

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{20.7}{0.8} = \text{Large}$$

where:

S_y = 20.7 ksi ---------- Yield Strength, SA-240, Type 304, 400°F

The maximum bolt load due to off-normal load is 1,365 pounds for the 0° basket and 1,388 lb for the 35° basket. A bolt load of 1,800 lb is used for the evaluation, which bounds the combined maximum bolt load and bolt preload (400 lb). From Machinery's Handbook [12], the tensile strength (σ_t) in the bolt is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{1{,}800}{0.23} = 7.83 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ inch}^2$$
$$D = 0.625 \text{ inch}$$
$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{1.5S_m}{\sigma_t} = \frac{1.5 \times 23.3}{7.83} = 4.46$$

where:

S_m = 23.3 ksi ---------- Design stress intensity for SA-193, Gr B6, at 700°F

The shear stress in the bolt thread (τ_{bolt}) is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{1{,}800}{0.469} = 3.84 \text{ ksi}$$

where:

$$A_s = 3.1416 n L_e K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.469 \text{ inch}^2$$

L_e = 0.47
K_{nmax} = 0.546
E_{smin} = 0.5589
n = 11

The factor of safety (FS) is as follows.

$$FS = \frac{0.9S_y}{\tau_{bolt}} = \frac{0.9 \times 23.3}{3.84} = 5.46$$

where:

S_m = 23.3 ksi ---------- Design stress intensity, SA-193 Grade B6, at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{1{,}800}{0.67} = 2.7 \text{ ksi}$$

where:

$$A_n = 3.1416 n L_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.67 \text{ inch}^2$$

L_e = 0.47 inch
$E_{n\,max}$ = 0.5732
$D_{s\,min}$ = 0.6113
n = 11

The factor of safety (FS) is as follows.

$$FS = \frac{0.9S_m}{\tau_{bolt}} = \frac{0.9 \times 18.1}{2.7} = 6.03$$

where:

S_m=18.1 ksi---------- Design Stress Intensity, SA-516, Grade 70, 700°F

The boss is welded into the fuel tube with a 3/16-inch groove weld. The shear stress in the boss weld (τ_{weld}) is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{1{,}800}{0.59} = 3.05 \text{ ksi}$$

where:

P = 1,800 lb

$A_w = \pi D t_{weld} = \pi \times 1.00 \times 0.1875 = 0.59$ inch

D = 1.00 inch ---------- Smallest boss diameter

The factor of safety (FS) is as follows.

$$FS = \frac{0.35 \times 0.9 S_m}{\tau_{weld}} = 1.87$$

where:

S_m = 18.1 ksi ---------- Design Stress Intensity, SA-516, Grade 70, at 700°F

The washers under the bolts are subjected to shear due to the tensile load of the bolts. The washer is evaluated using the maximum bolt load (1,800 lb). The maximum washer shear stress, using an area defined by the perimeter of the bolt head and washer thickness, is

$$\tau_{wash} = \frac{P}{A_w} = \frac{1{,}800}{0.617} = 2.92 \text{ ksi}$$

where:

A_w = 0.617 in^2---------- Shear area of washer

The factor of safety (FS) is as follows.

$$FS = \frac{0.9 S_m}{\tau_{wash}} = \frac{0.9 \times 16.0}{2.92} = 4.93$$

where:

S_m = 16.0 ksi ---------- Design stress intensity, SA-240 Type 304, at 700°F

The buckling evaluation of the fuel tube corner extension is performed in Section 3.7.2.2. The accident condition buckling evaluation is bounding due to the 60g axial inertia loading.

The maximum shear load on a boss for the off-normal condition is 151 pounds. The shear stress in the boss is as follows.

$$\tau_{boss} = \frac{P}{A} = \frac{151}{0.47} = 0.32 \text{ ksi}$$

where:

$$A = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(1.00^2 - 0.63^2\right) = 0.47 \text{ in}^2$$

D_o = 1.00 in

D_i = 0.63 in

The factor of safety is

$$FS = \frac{0.9S_m}{\tau_{boss}} = \frac{0.9 \times 18.1}{0.32} = \text{Large}$$

where:

S_m = 18.1 ksi ----------Design stress intensity, SA-516, Grade 70, at 700°F

The analysis presented in Section 3.7.2.2 bounds the off-normal analysis of the neutron absorber and retainer strip; therefore, no additional analysis is required.

3.6.3 Concrete Cask Evaluation for Off-Normal Operating Events

Section 3.5.3.1 presents the thermal stress evaluation for normal conditions for the concrete cask. The analysis used the 106°F ambient condition thermal gradient, which is the off-normal event; therefore, the analysis is conservative. The analysis bounds both the normal and off-normal events; therefore, no thermal stress evaluation is presented in this section. All analyses of the concrete cask are bounded by the analyses presented in the normal and accident sections.

3.7 Storage Accident Events

This section presents the analyses of the structural components of MAGNASTOR for storage accident events. MAGNASTOR is evaluated using finite element models and classical hand calculations for the TSC, fuel baskets, and concrete cask.

3.7.1 TSC Evaluations for Storage Accident Conditions

The TSC is analyzed for an accident pressurization of 250 psig, a 24-inch end drop of the concrete cask, and the hypothetical concrete cask tip-over accident. Bounding analyses are performed for two groups of TSC configurations: (1) TSC1 and TSC2 with a single-piece closure lid assembly, and (2) TSC3 and TSC4 with a composite closure lid assembly. For detailed analyses results for accident conditions, see Table 3.10.3-12 through Table 3.10.3-17 for the TSC1/TSC2 configuration and Table 3.10.3-29 through Table 3.10.3-34 for the TSC3/TSC4 configuration.

3.7.1.1 Accident Pressurization

Accident pressurization is a hypothetical event that assumes the failure of all of the fuel rods contained within the TSC. No postulated storage condition is expected to lead to the rupture of all fuel rods. The TSC is analyzed for accident pressurization and dead weight loads using the finite element models and conditions described in Section 3.10.3. Dead weight is simulated by applying a 1.0g acceleration load in the axial direction in conjunction with pressure being applied to the TSC bottom plate to simulate the weight of the basket and fuel. To represent the accident pressure, an internal pressure of 250 psig is applied to all inner surfaces of the TSC shell, bottom plate and closure lid. This pressure bounds the maximum calculated pressure for PWR and BWR fuel under normal conditions. The canister bottom plate, which is resting on the pedestal plate, is conservatively subjected to the 250 psig pressure and the dead weight of the fuel and basket.

The resulting TSC stresses for the accident pressurization condition are summarized in Table 3.7.1-1 and Table 3.7.1-2 for primary membrane and primary membrane plus primary bending stress categories, respectively. The minimum factor of safety of 1.59 occurs at Section 3 for the P_m+P_b stresses. The locations for the stress sections are shown in Section 3.10.3.

The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for TSC3 and TSC4 for accident internal pressure is 52.69 ksi. The allowable bolt tensile stress for 'Service Level D' off-normal conditions is limited to the lesser of $0.7 \times S_u$ and S_y, or

66.48 ksi, for the A193 Grade B6 bolt material at an upper-bound bolt design temperature of 525°F. Therefore, the minimum factor of safety for the shield plate attachment bolt for accident internal pressure loading is 1.26.

Results of analysis of this event demonstrate that the TSC is not significantly affected by the increase in internal pressure that results from the hypothetical rupture of all PWR or BWR fuel rods in the TSC.

The maximum stress in the TSC port cover is due to bending at its center from the internal pressure and inertial loading. Bending stress (σ) is calculated using the formulas from Reference 13 as follows.

$$\sigma = 6\frac{M_r}{t^2} = = 18.7 \text{ ksi}$$

where:

$$M_r = \frac{qa^2(3+\nu)}{16}$$

$q = q_i + q_p$

$q_i = t \times \rho \times g$

$q_p = 250$ psi ---------- Accident condition pressure
$d = 5.75$ in---------- Maximum port cover diameter
$a = d/2$ ---------- Port cover radius
$\nu = 0.31$ ---------- Poisson's ratio
$t = 3/8$ in ---------- Minimum port cover thickness
$\rho = 0.291$ lb/in^3 ---------- Density, SA-240 Type 304
$g = 60g$ ---------- 24-inch drop acceleration

Conservatively using the temperature of 650°F for the material allowable, the factor of safety is:

$$FS = \frac{S_{allow}}{\sigma} = \frac{3.6 S_m}{\sigma} = 3.12$$

where:

S_m = 16.2 ksi---------- design stress intensity, SA-240 Type 304 at 650°F

The shear stress in the port cover weld is:

$$\tau_w = \frac{qA_p}{A_w} = 3.0 \text{ ksi}$$

where:

$A_p = d_p^2\pi/4$ ---------- Area of port
$A_w = d_p \pi t_w$ ---------- Weld area
d_p = 5.83 in ---------- Maximum lid port counterbore diameter

t_w = 1/8 in ---------- Port cover weld thickness
q = 257 psi ---------- Accident condition pressure and inertial loading

Conservatively using the temperature of 650°F, the factor of safety is:

$$FS = \frac{S_{allow}}{\tau_w} = \frac{0.42\ S_u}{\tau_w} = 8.88$$

where:

S_u = 63.4 ksi----------design stress intensity, SA-240 Type 304 at 650°F

3.7.1.2 Concrete Cask 24-inch End-Drop

This section addresses the TSC stresses and potential TSC shell buckling associated with the postulated 24-inch end-drop accident of the concrete cask. The evaluation of the TSC during the end impact is performed using an inertial load of 60g. This inertial load conservatively bounds the maximum calculated acceleration including dynamic load factor (DLF).

3.7.1.2.1 TSC End Impact Stress Evaluation

The TSC is analyzed for the concrete cask 24-inch drop accident condition using the finite element models described in Section 3.10.3. The 24-inch drop is simulated by applying a 60g acceleration load in the axial direction, with pressure applied to the TSC bottom plate to simulate the inertial load of the basket and fuel. To represent the normal pressure, an internal pressure of 110 psig is applied to all inner surfaces of the TSC shell, bottom plate and closure lid. The canister bottom plate, which is resting on the pedestal plate, is conservatively subjected to the pressure due to the 60g inertia of the basket and fuel, as well as the 110 psig internal pressure.

The resulting maximum stresses in the TSC for the 24-inch drop accident events are summarized in Table 3.7.1-1 and Table 3.7.1-2 for primary membrane, and primary membrane plus primary bending stress categories, respectively. The minimum factor of safety of 3.71 occurs at section 4 (lower TSC shell) for the P_m stresses. The locations for the stress sections are shown in Section 3.10.3.

The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for TSC3 and TSC4 for the 24-inch drop plus normal internal pressure is 58.08 ksi. The allowable bolt tensile stress for accident conditions is limited to the lesser of 0.7 × S_u or S_y, or 66.48 ksi, based on the yield strength and ultimate tensile strength of the A193 Grade B6 bolt material at a bounding design temperature of 525°F. Thus, the minimum factor of safety for the shield plate attachment bolt for the 24-inch drop plus normal pressure is 1.14.

3.7.1.2.2 TSC Buckling Evaluation

During the 24-inch bottom-end drop of the concrete cask, the 60g inertial load conservatively applied to the closure lid assembly generates longitudinal compressive stresses in the TSC shell. The critical buckling stress (S_{CR}) in the TSC shell based on the TSC geometry and material properties is as follows.

$$S_{CR} = E\frac{0.605 - 10^{-7} m^2}{m(1 + 0.004\phi)} = 34.5 \text{ ksi} \qquad [15]$$

where:

$E = 25.8 \times 10^3$ ksi ---------- Modulus of elasticity of SA-240, Type 304, at 500°F

$\phi = \frac{E}{S_y} = 1{,}330$ ---------- Inverse strain parameter

$S_y = 19.4$ ksi ---------- Yield strength of SA-240, Type 304, at 500°F

$m = \frac{r_m}{t} = 71.5$ ---------- Mean radius to thickness ratio

$r_m = 35.75$ inch ---------- Mean radius TSC shell

$t = 0.5$ inch ---------- Thickness of TSC shell

The results from the 24-inch end-drop analysis are screened for the maximum longitudinal compressive stress. The maximum longitudinal compressive stress, S_z, of 9.3 ksi occurs at the intersection of the TSC shell and bottom plate (see Section 3.10.3). The factor of safety (FS) is as follows.

$$FS = \frac{S_{CR}}{S_z} = \frac{34.5 \text{ ksi}}{9.3 \text{ ksi}} = 3.7$$

Therefore, buckling of the TSC does not occur.

3.7.1.3 Concrete Cask Tip-Over

The TSC is analyzed for the concrete cask tip-over using the finite element models described in Section 3.10.3. A tapered inertial load (40g at top of TSC closure lid and 1g at the base of the concrete cask) is considered as a side impact load on the TSC. The 40g inertial load is conservatively used in the evaluation to bound the calculated maximum g-load for the TSC during the concrete cask tip-over event including the dynamic load factor (Section 3.7.3.7).

The resulting maximum stresses in the TSC for tip-over conditions are summarized in Table 3.7.1-1 and Table 3.7.1-2 for primary membrane and primary membrane plus primary bending

stress categories, respectively. The minimum factor of safety is 1.20 at Section 11 for the P_m stresses and 1.08 at Section 5 for the P_m+P_b stresses. The factor of safety, P_m+P_b, for the structural lid closure weld, Section 11, is 1.39. The locations for the stress sections are shown in Section 3.10.3. Note that the maximum stresses occur at the section cut at the 0-degree location.

The maximum tensile stress in the shield plate attachment bolts of the closure lid assembly for TSC3 and TSC4 for the concrete cask tip-over plus normal internal pressure is 29.21 ksi. The allowable bolt tensile stress for accident conditions is limited to the lesser of $0.7 \times S_u$ or S_y, or 66.48 ksi, based on the yield strength and ultimate tensile strength of the A193 Grade B6 bolt material at a bounding design temperature of 525°F. Thus, the minimum factor of safety for the shield plate attachment bolt for the concrete cask tip-over plus normal pressure is 2.28.

3.7.1.4 Flood

This evaluation considers design basis flood conditions of a 50-foot depth of water having a velocity of 15 feet per second. The hydrostatic pressure (P_h) exerted on the TSC during a 50-foot flood event is as follows.

$$P_h = \rho \times h = \left(62.4\,\frac{\text{lb}}{\text{ft}^3}\right)\left(\frac{1\,\text{ft}^3}{1728\,\text{in}^2}\right)\times(50\,\text{ft})\left(\frac{12\,\text{in}}{1\,\text{ft}}\right) = 22\ \text{psi}$$

where:

ρ = 62.4 lb/ft^3 ---------- Density of water
h = 50 ft ---------- Immersion depth

During normal conditions, the TSC is evaluated for an internal pressure of 110 psig. Because the pressure differential is reduced during flood conditions (110 – 22 = 88 psig), stresses in the TSC shell are reduced. Therefore, the hydrostatic pressure exerted by the 50-foot depth of water actually reduces the stress in the TSC. MAGNASTOR is, therefore, not adversely affected by the design basis flood.

3.7.1.5 Tornado and Tornado-Driven Missiles

The postulated tornado wind loading and tornado missile impacts are not capable of overturning the concrete cask, or penetrating the boundary established by the concrete cask. Consequently, there is no effect on the TSC. Stresses resulting from the decreased external pressure due to a tornado are bounded by the stresses due to the accident internal pressure condition evaluated in Section 3.7.1.1.

Table 3.7.1-1 TSC Accident Events, P_m Stresses

Load Case	Service Level	Section[b]	Component Stresses[a] (ksi)						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Accident Pressure	D	3	-1.13	-15.79	8.74	0.29	0.06	1.93	24.90	47.15	1.89
Normal Pressure + 24-inch Drop	D	4	-0.03	7.81	-4.26	0.00	0.00	0.00	12.07	44.80	3.71
Normal Pressure + Tip-Over	D	11	-23.89	-17.09	-19.05	10.77	-1.77	-8.92	29.05	34.72	1.20

Table 3.7.1-2 TSC Accident Events, $P_m + P_b$ Stresses

Load Case	Service Level	Section[b]	Component Stresses[a] (ksi)						S_{int}	S_{allow}	FS
			S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
Accident Pressure	D	3	-0.46	-7.35	35.72	0.09	0.07	2.43	43.24	68.60	1.59
Normal Pressure + 24-inch Drop	D	12	17.98	18.23	1.64	0.67	0.76	-0.94	17.24	68.60	3.98
Normal Pressure + Tip-Over	D	5	0.68	59.72	41.78	0.02	0.81	0.28	59.06	63.75	1.08

[a] The x, y, z components of stress are to be interpreted radial, circumferential and axial directions, respectively.

[b] See Figure 3.10.3-2 for section cut locations.

3.7.2 Fuel Baskets Evaluation for Storage Accident Events

3.7.2.1 PWR Basket

3.7.2.1.1 24-inch Concrete Cask End Drop

For the 24-inch drop accident condition, an inertia loading of greater than or equal to 50g, in the basket axial direction, is conservatively applied. The basket is evaluated using classical hand calculations. Using a bounding weight of 22,500 lb for the PWR basket, the maximum stress in the fuel tube is calculated. Factors of safety for the PWR basket are calculated based on the criteria for Service Level 'D' limits from ASME Code, Section III, Subsection NG [7] and Appendix F [8]. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{64286}{11.4} = 5.6 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{22{,}500 \times 60}{21} = 64{,}286 \text{ lb}$$

W = 22,500 lb ---------- Bounding basket weight
n = 21 ---------- Number of fuel tubes
A = 11.4 inch^2 ---------- Tube cross-sectional area

The factor of safety (FS) is as follows.

$$FS = \frac{0.7 \times S_u}{\sigma_{tube}} = \frac{0.7 \times 68.4}{5.6} = 8.6$$

where:

S_u = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, at 700°F

[redacted]

The membrane stress (σ_m) in the standoffs is

$$\sigma_m = \frac{a \times P_{so}}{A_m} = 40.9 \text{ ksi}$$

where:

$A_m = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.75^2 - 0.19^2\right) = 0.413 \text{ in}^2$

$P_{so} = P_t/2$ ---------- Load per connector pin assembly standoff

P_t = 675 lb ---------- Fuel tube assembly weight

a = 50g ---------- Accident condition acceleration

The factor of safety (FS) for membrane stress is

$$FS = \frac{0.7S_u}{\sigma_m} = \frac{0.7(68.4)}{40.9} = 1.17$$

where:

S_y = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, 550°F

The bounding shear stress (τ) in the fuel tube at the interface of the CPA is:

$$\tau = \frac{50 \times P_{s/t}}{A_s} = 21.3 \text{ ksi}$$

where:

A_s = t x l ---------- Tube corner shear area

t = 0.60 inch ---------- Tube shoulder length

l = 0.66 = 2 x l_s ---------- Total shoulder attachment length

l_s = 0.33 inch ---------- Tube thickness at edge of pin slot

$P_{s/t} = P_t/4$ ---------- CPA-to-fuel tube load

P_t = 675 lb ---------- Bounding weight of fuel tube assembly

The factor of safety (FS) for shear is:

$$FS = \frac{0.42S_u}{\tau} = \frac{0.42 \times 68.4}{21.3} = 1.35$$

where:

S_u= 68.4 ksi ---------- Ultimate strength, SA537 Class 1, 550°F

The weight of the side and corner weldments is carried through to the TSC base plate by supports at the bottom of the weldments. The bounding dimensions for the supports of the weldments are 5.0 inches in length and 0.3125-inch thickness (corner weldment). The maximum weight of one weldment is 800 lb (bounding, side weldment). The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding). The membrane stress (σ_m) is as follows.

$$\sigma_m = \frac{60 \times W_{sup}}{A_{sup}} = \frac{60 \times 1{,}138}{1.56} = 43.8 \text{ ksi}$$

where:

$W_{sup} = 800 + 2 \times (0.25 \times 675) = 1138$ lb

$A_{sup} = 5.0 \times 0.3125 = 1.56 \text{ inch}^2$

The factor of safety (FS) is as follows.

$$FS = \frac{0.7S_u}{\sigma_m} = \frac{0.7 \times 68.4}{43.8} = 1.09$$

where:

S_u = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, at 700°F

[redacted]

$$P_{so} = \frac{W \times 60}{n} = \frac{22500 \times 60}{32} = 42.2 \text{ kips}$$

where:

W = 22,500 lb ---------- Bounding basket weight
n = 32 ---------- Number of connector pin assemblies

Using the Euler buckling theory, the critical buckling load (P_{cr}) is as follows.

$$P_{cr} = \frac{\pi^2 EI}{(K\,L)^2} = \frac{\pi^2 \times (27.3 \times 10^6) \times 0.015}{(2 \times 3.0)^2} = 112.3 \text{ kip} \quad [9]$$

where:

D = 0.75 inch ---------- Standoff diameter
L = 3.0 inch ---------- Standoff length
$I = \frac{\pi r^4}{4} = 0.015 \text{ inch}^4$
K = 2.0 ---------- Buckling constant, clamped-free
E = 27.3×10^6 psi ---------- SA-537, Class 1, at 500°F

The factor of safety (FS) for buckling of the basket standoff is as follows.

$$FS = \frac{P_{cr}}{P_{cpa}} = \frac{112.3 \text{ kip}}{42.2 \text{ kip}} = 2.66$$

PWR Neutron Absorber Evaluation

During the end impact condition, the PWR neutron absorber and the weld post are subject to shearing force in the longitudinal direction of the neutron absorber. The neutron absorber is considered to be supported by two weld posts located at the bottom end of the neutron absorber.

The evaluation is conservatively performed for an acceleration of 60g at a bounding temperature of 350°F. The inertia load applied to the neutron absorber (F_{na}) at each weld post during the end impact is as follows.

$$Fna = L \times W \times t \times \rho \times a / 2 = 525 \text{ lb}$$

where:

ρ = 0.1 lb/in^3 ---------- Bounding density of the neutron absorber
a = 60g ---------- End drop acceleration
t = 0.125 in ---------- Thickness of neutron absorber
L = 173 in ---------- Length of neutron absorber
W = 8.1 in ---------- Width of neutron absorber

The shearing capacity of the neutron absorber is as follows.

$$F_{shear_na} = A_s \times \Phi_a = 0.44 \times 2260 = 994 \text{ lb}$$

where:

A_s = $L_{NA} \times 1.414 \times 2 \times t = 0.44$ in^2 ---------- Shear area at both sides of each weld-post (at the 45° shear planes)
L_{NA} = 1.25 in ---------- Min. edge distance of the neutron absorber
Φ_a = 0.42 S_u = 2.26 ksi ---------- Allowable shear stress
S_u = 5.38 ksi ---------- Tensile strength of neutron absorber at 350°F

The factor of safety (FS) is as follows.

$$FS = F_{shear_na} / F_{na} = 994 / 525 = 1.89$$

The strength of the weld posts is significantly higher than that of the neutron absorber. Therefore, no evaluation is required for the weld posts for the concrete cask 24-inch end-drop condition.

3.7.2.1.2 PWR Basket with Damaged Fuel Cans – 24-inch End Drop

For the 24-inch drop accident condition, an inertia loading of greater than or equal to 50g, in the basket axial direction, is conservatively applied. Using a bounding weight of 25,000 lb for the PWR basket, the maximum stress in the fuel tube is calculated conservatively assuming the entire basket weight is carried through the fuel tubes. The stress in the tube is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = \frac{88235}{11.4} = 7.7 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{25{,}000 \times 60}{17} = 88{,}235 \text{ lb}$$

W = 22,500 lb ---------- Bounding basket weight
n = 17---------- Number of fuel tubes
A = 11.4 inch^2 ---------- Tube cross-sectional area

The factor of safety (FS) is as follows.

$$FS = \frac{0.7 \times S_u}{\sigma_{tube}} = \frac{0.7 \times 68.4}{7.7} = 6.2$$

where:

S_u = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, at 700°F

[redacted]

$$\sigma_m = \frac{a \times P_{so}}{A_m} = 40.9 \text{ ksi}$$

where:

$$A_m = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = \frac{\pi}{4}\left(0.75^2 - 0.19^2\right) = 0.413 \text{ in}^2$$

P_{so} = $P_t/2$ ---------- Load per connector pin assembly standoff
P_t = 675 lb ---------- Fuel tube assembly weight
a = 50g ---------- Accident condition acceleration

The factor of safety (FS) for membrane stress is:

$$FS = \frac{0.7S_u}{\sigma_m} = \frac{0.7(68.4)}{40.9} = 1.17$$

where:

S_u = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, 550°F

The bounding shear stress (τ) in the fuel tube at the interface of the CPA is:

$$\tau = \frac{50 \times P_{s/t}}{A_s} = 21.3 \text{ ksi}$$

where:

A_s = t x l ---------- Tube corner shear area
t = 0.60 inch ---------- Tube shoulder length
l = 0.66 = 2 x l_s ---------- Total shoulder attachment length
l_s = 0.33 inch ---------- Tube thickness at edge of pin slot
$P_{s/t}$ = $P_t/4$ ---------- CPA-to-fuel tube load
P_t = 675 lb ---------- Bounding weight of fuel tube assembly

The factor of safety (FS) for shear is:

$$FS = \frac{0.42S_u}{\tau} = \frac{0.42 \times 68.4}{21.3} = 1.35$$

where:

S_u= 68.4 ksi ---------- Ultimate strength, SA537 Class 1, 550°F

The weight of the side and corner weldments is carried to the TSC bottom plate by supports at the bottom of the basket. The corner weldment is the bounding condition with a weight of 2,450 lb and three contact points with the bottom plate. The weldment supports one-quarter of the weight of two fuel tubes (675 lb per tube, bounding). The membrane stress (σ_m) is as follows.

$$\sigma_m = \frac{50 \times W_{sup}}{A_{sup}} = \frac{50 \times 2{,}788}{4.06} = 34.3 \text{ ksi}$$

where:

W_{sup} = 2,788 lb = $W_{cor} + 2\left(\frac{P_t}{4}\right)$ ----- Weight supported by the corner weldment
W_{cor} = 2,450 lb ---------- Weight of corner weldment
P_t = 675 lb ---------- Bounding weight of fuel tube assembly
A_{sup} = 4.06 in^2 ---------- Bearing area for DF corner weldment

The factor of safety (FS) is as follows.

$$FS = \frac{0.7S_s}{\sigma_m} = \frac{0.7 \times 68.4}{34.3} = 1.40$$

where:

S_u = 68.4 ksi ---------- Ultimate strength, SA-537 Class 1, at 700°F

[redacted]

an end drop accident provides a bounding evaluation which envelopes all end of tube configurations. The load in one standoff (P_{so}) is:

$$P_{cpa} = \frac{W \times 60}{n} = \frac{25000 \times 60}{32} = 46.9 \text{ kips}$$

where:

W = 25,000 lb ---------- Bounding basket weight
n = 32 ---------- Number of connector pin assemblies

Using the Euler buckling theory, the critical buckling load (P_{cr}) is as follows.

$$P_{cr} = \frac{\pi^2 EI}{(K\,L)^2} = \frac{\pi^2 \times (27.3 \times 10^6) \times 0.015}{(2 \times 3.0)^2} = 112.3 \text{ kip} \quad [9]$$

where:

D = 0.75 inch ---------- Pin diameter
L = 3.0 inch ---------- Pin length
$I = \frac{\pi r^4}{4} = 0.015 \text{ inch}^4$
K = 2.0 ---------- Buckling constant, clamped-free
E = 27.3×10^6 psi ---------- SA-537, Class 1, at 500°F

[redacted]

$$FS = \frac{P_{cr}}{P_{cpa}} = \frac{112.3 \text{ kip}}{46.9 \text{ kip}} = 2.39$$

In the analysis presented in Section 3.7.2.1.1, the shear force on the neutron absorber for the end impact is shown to be proportional to its weight and will vary linearly with the change in thickness and width. For the accident condition at 60g, the shear force on the PWR damaged fuel can neutron absorber with a thickness of 0.145 inch and a width of 8.9 inches is:

$$F_{na} = 525 \times \frac{0.145}{0.125} \times \frac{8.9}{8.1} = 669 \text{ lb}$$

where 525 lb is the shear force for a neutron absorber thickness of 0.125 inch and width of 8.1 inches (see Section 3.7.2.1.1).

The factor of safety is:

$$FS = F_{shear,\,na} / F_{na} = 994 / 669 = 1.48$$

where 994 lb is the shearing capacity of the neutron absorber for accident conditions.

The strength of the weld posts is significantly higher than that of the neutron absorber for both the normal and accident conditions and no evaluation is required.

3.7.2.1.3 Concrete Cask Tip-Over

The analysis results for the PWR basket subjected to a hypothetical concrete cask tip-over accident are presented in this section. Factors of safety for the PWR basket are calculated based on the criteria for Service Level 'D' limits from ASME Code, Section III, Subsection NG [7] and Appendix F [8].

PWR Neutron Absorber and Retainer

The PWR neutron absorber and retainer are conservatively evaluated for a 60g side-impact load and for the concrete cask tip-over event. The retainer strip consists of 304 stainless steel and is restrained by an array of posts welded to the inside surface of the fuel tube. Two rows of posts are separated four inches apart and a spacing of ten inches exists between the posts along the axial direction of the fuel tube.

The pitches of the slotted holes in the neutron absorber are the same as the holes in the retainer strip through which the weld posts are connected to the fuel tube. The slotted holes are used to prevent interference during differential thermal expansion between the neutron absorber and the fuel tube. The head of the weld posts supporting the retainer strip are engaged in the recessed conical pockets of the retainer.

As shown in Figure 3.7.2-3, a quarter-symmetry finite element model is generated to represent one-half of the ten-inch periodic section for the PWR design. The model is comprised of the retainer strip with the conical slot, the neutron absorber, and the weld post. Inelastic properties are employed for the stainless steel retainer strip and the neutron absorber at 700°F to adequately represent the stiffness at the maximum temperature condition. Note that the peak fuel tube temperature is less than 720°F and occurs in a localized region. The difference in material properties between 700°F and 720°F is not significant and has no effect on the conclusion of the analysis, which uses a very conservative acceleration time history for the impact loading. The model for the neutron absorber plate is comprised of three layers of materials. The two outer layers employ the inelastic properties of aluminum 1100 series cladding at 700°F. The center layer represents the neutron absorber material, which is assigned a yield strength of 10 psi and an elastic modulus of elasticity of 1,000 psi. The low yield strength for the core material allows the neutron absorber core to provide only a minimal contribution of stiffness to the neutron absorber plate. The weld post was modeled as being rigid to maximize deformation of the conical-shaped section of the retainer by the weld post. Symmetry conditions were imposed along the planes of symmetry, which are present on all four sides of the model. The parts are modeled independently and the automatic contact surface option in LS-DYNA was used between the parts to transfer load between the neutron absorber, the retainer and the weld post. The evaluation of the side impact was performed using LS-DYNA and the impact was simulated by imposing the

acceleration time history whose maximum acceleration was 60g. This conservatively envelops the maximum tip-over acceleration of 35g.

Since the function of the retainer is to maintain the neutron absorber in its position, the criteria for the retainer is to limit the motion of the neutron absorber during and after the impact. This is confirmed by considering the permanent strain and the permanent displacement of the retainer. The strain of 2.1%, which is minimal, is local to the conical-shaped hole. Since inelastic strains are not recovered, this indicates that maximum inelastic strain during the impact is also limited to 2.1 percent. Such a minimal strain level indicates that the conical pocket retains its configuration for the weld post to restrain the retainer. The final maximum displacement of the retainer strip at the axial midpoint between the weld posts is computed to be 0.05 inch, which is consistent with the minimal plastic strain in the retainer. This also confirms that the retainer remains engaged with the weld post during and after the impact.

The maximum stress intensity in the stainless steel retainer strip is determined to be 33.8 ksi, which is also local to conical-shaped hole at the weld post. The allowable stress for accident condition is $0.9S_u$ per ASME Section III Appendix F. The ultimate strength (S_u) of Type 304 stainless steel at 720°F is 63.1 ksi.

The factor of safety (FS) is as follows.

$$FS = \frac{0.9 \times 63.1}{35.8} = 1.68$$

The peak force on the weld post determined from the analysis is 47 pounds. The shear area governs the capacity of the melt. The depth of the melt (h) is 0.13 inch. The diameter of the weld post (D) is 0.25 inch. The governing stress is the shear stress in the base material. The allowable shear stress for the accident condition is $0.42S_u$. The ultimate strength (S_u) of the base material (SA240, Type 304) at 720°F is 63,100 psi. The melt capacity, F_{cap}, is calculated as shown in the following.

$$\begin{aligned} F_{cap} &= 0.42 \times n \times S_u \times h \times BD \\ &= 0.42 \times 0.3 \times 63{,}100 \times 0.13 \times (3.1416 \times 0.25) \\ &= 812 \text{ lb} \end{aligned}$$

where:

n = 0.3 ---------- The design factor per ASME Code, Section III, Subsection NG, Table NG-3352-1 for the intermittent plug melt employing a surface visual examination method per NG-5260.

The factor of safety (FS) is as follows.

$$FS = \frac{812}{47} = \text{Large}$$

PWR Basket for Concrete Cask Tip-over

The evaluation for the tip-over accident for the PWR basket uses the three-dimensional periodic plastic finite element models described in Section 3.10.1.5. The models correspond to 0° and 45° basket orientations, respectively.

Fuel Tube Evaluation

The PWR fuel tubes are evaluated for the bounding basket orientations of 0° and 45°. The maximum membrane and membrane plus bending nodal stress intensities for the fuel tubes are reported in Table 3.7.2-1 and 3.7.2-2. A bounding temperature of 750°F is conservatively used for determining allowable values. The ANSYS plastic finite element model follows the material stress-strain curve and allows for nonlinear behavior above the yield strength point. The stress allowables for plastic analysis are based on ASME Code, Section III, Appendix F. The allowable primary membrane stress is $0.7S_u$. The allowable primary membrane plus bending stress intensity is $0.9S_u$. The minimum factors of safety for the fuel tubes are 1.14 for primary membrane stresses (45° basket orientation) and 1.34 for membrane plus bending stress (45° basket orientation).

The fuel tubes are constructed by welding two tube halves together using a full-penetration weld for the length of the fuel tube. A surface MT weld examination per ASME Code, Section III, Subsection NG, Article NG-5233 is used, which has a 0.65 weld quality factor (wf). From the plastic analysis of the PWR basket, the maximum membrane and membrane plus bending stress intensities at the tube welds are 8.9 ksi (0° basket orientation) and 22.1 ksi (0° basket orientation), respectively.

The factors of safety (FS) for the weld are:

Membrane:

$$FS = \frac{0.7S_u \times wf}{\sigma} = 3.42$$

Membrane plus bending:

$$FS = \frac{0.9S_u \times wf}{\sigma} = 1.77$$

where:

S_u=66.9 ksi---------- Ultimate strength, SA-537 Class 1, at 750°F.

The bearing stress (σ_{brg}) on the pin is evaluated using the bounding load of 18,000 pounds. The bearing area is determined based on the width and length of contact between the pin and fuel tube slot.

$$\sigma_{brg} = \frac{P}{LS} = 39.6 \text{ ksi}$$

where:

P=18.0 kip ---------- Maximum load on pin

L=1.625 inch---------- Length of pin

S=0.28 in---------- Width of pin and slot contact

Per ASME Appendix F-1336, the allowable bearing stress is $2.1S_u$; therefore, the factor of safety is:

$$FS = \frac{2.1S_u}{\sigma_{brg}} = 3.04$$

where:

S_u=57.3 ksi---------- Ultimate strength, A36, at 750°F

Corner Support Weldment Evaluation

The corner support weldment is comprised of two major components: the corner mounting plates and the support bars, which are located on five-inch centers.

The analysis results for the corner weldment plates are presented in Table 3.7.2-3 and Table 3.7.2-4 and for the support bars in Table 3.7.2-5 and Table 3.7.2-6. The minimum factor of safety for the corner weldment mounting plates is 1.65. The minimum factor of safety for the support bars is 1.99. The allowable values are determined at a temperature of 700°F.

The support bar is a continuous bar that is bent at the ridge gusset. The support bars are welded to the corner mounting plate with a minimum 5/16-inch groove weld on the sides of the bars using the visual inspection criteria per ASME Code, Section III, Subsection NG, Article NG-

5260. A weld quality factor of 0.35 is applied based on visual inspection of the weld per ASME Code, Section III, Subsection NG, Article NG-3352.

The welded joint between the support bar and corner mounting plate is capable of carrying bending, axial and shear loads. The maximum weld loads occur in the 0° basket orientation. The critical location is the support bar/mounting plate weld at the lower end of the basket. The bending moment (M), axial load (P) and shear load (V) are 4,952 in-lb, 2,426 lb, and 2,421 lb, respectively. The weld stress intensity (σ_{weld}) is as follows.

$$\sigma_{weld} = \sqrt{\left(\frac{M}{S_w} + \frac{P}{A_w}\right)^2 + 4\left(\frac{V}{A_w}\right)^2} = 21.3 \text{ ksi}$$

where:

$S_w = 0.875 \times 0.3125 \times 1.21 = 0.331 \text{ in}^3$

$A_w = 0.875 \times 0.3125 \times 2 = 0.547 \text{ in}^2$

The factor of safety (FS) for the weld is as follows.

$$FS = \frac{0.35(S_u)}{\sigma_{weld}} = 1.12$$

where:

S_u=68.4 ksi---------- Ultimate strength, SA-537 Class 1, at 700°F

The corner weldment ridge gusset is welded to the corner support weldment with two 1/8-inch groove welds on each side of the gusset. The gussets exert compressive loads on the support weldment; however, only shear and bending loads are transferred through the welds. The welds have a visual inspection criterion per ASME III-NG-5260. Visual inspection of the weld has a weld quality factor of 0.35, per ASME III-NG-3352. The stress intensity in the weld is as follows.

$$\sigma_{weld} = \sqrt{\left(\frac{M}{S_w}\right)^2 + 4\left(\frac{V}{A_w}\right)^2} = 10.0 \text{ ksi}$$

where:

M=5.0 in-kips ---------- Bounding bending moment

V=1.0 kips---------- Bounding shear load

$A_w = 2 \times (L_w \times t_w) = 2.0 \text{ in}^2$

$S_w = L_w \times t_g \times t_w = 0.50 \text{ in}^3$

$L_w = 10.0 - 2.0 = 8.0$ in ---------- Length of weld

$t_w = 0.125$ in ---------- Weld size

$t_g = 0.50$ in ---------- Gusset thickness

The factor of safety (FS) in the weld is as follows.

$$FS = \frac{0.35 \times S_u}{\sigma_{weld}} = 2.37$$

where:

$S_u = 68.4$ ksi ---------- Ultimate strength, SA-537 Class 1, at 700°F

Side Support Weldment Evaluation

The analysis results for the side support weldment are presented in Table 3.7.2-7 and Table 3.7.2-8. The minimum factors of safety for membrane and membrane plus bending are 5.57 (0° basket orientation) and 2.05 (0° basket orientation), respectively. The allowable values are determined at a temperature of 700°F.

Side and Corner Weldment/Fuel Tube Attachment Evaluation

The corner and side support weldments are the primary structure that maintains the geometry of the fuel tube array during a hypothetical tip-over accident. The support weldments are bolted to the fuel tubes at 20 circumferential locations. The boss and bolt connection is designed so that the bolts are only loaded in tension, including preload. Otherwise, the support weldments apply a bearing load on the fuel tube array. The maximum calculated bolt load from the finite element results is 2,773 lb (45° basket orientation). Therefore, combined with the bolt preload, 400 lb, the maximum bolt load is 3,173 pounds. A bounding load of 5,000 lb is conservatively used for evaluation

The tensile stress in the bolt is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{5.0}{0.23} = 21.7 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ in}^2$$

$$D = 0.625 \text{ inch}$$

$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{S_y}{\sigma_t} = \frac{70.0}{21.7} = 3.23$$

where:

S_y=70.0 ksi---------- Yield strength for SA 193, Gr B6 at 700°F

The shear stress (τ_{bolt}) in the bolt thread is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{5.0}{0.499} = 10.0 \text{ ksi}$$

where:

$$A_s = 3.1416 n L_e K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.499 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.42 S_u}{\tau_{bolt}} = \frac{0.42 \times 90.6}{10.0} = 3.81$$

where:

S_u=90.6 ksi---------- Ultimate strength, SA-193 Grade B6 at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{5.0}{0.713} = 7.0 \text{ ksi}$$

where:

$$A_n = 3.1416 n L_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.713 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.42S_u}{\tau_{boss}} = \frac{0.42 \times 62.0}{7.0} = 3.72$$

where:

S_u=62.0 ksi---------- Ultimate strength, SA-36, at 700°F

The boss is welded into the fuel tube with a 1/4-inch groove weld. The weld uses the visual inspection criteria per ASME Code, Section III, Subsection NG, Article NG-5260 and a quality faction of 0.35. The shear stress in the boss weld, using the lesser of SA-537 Class 1 and SA-36 S_m allowable, is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{5.0}{0.98} = 5.1 \text{ ksi}$$

where:

$P = 5{,}000$ lb

$A_w = \pi D t_{weld} = \pi \times 1.25 \times 0.25 = 0.98$ inch

$D = 1.25$ inch

The factor of safety (FS) is as follows.

$$FS = \frac{0.35 \times 0.42S_u}{\tau_{weld}} = \frac{0.35 \times 0.42 \times 62.0}{5.1} = 1.79$$

where:

S_u=62.0 ksi---------- Ultimate strength, SA-36, at 700°F

The washers under the bolts at the boss locations are subjected to shear from the bolt tensile load and the support condition at the weldment. The bounding bolt tensile force is 5.0 kips and the shear stress is as follows.

$$\tau_{wash} = \frac{P}{A_w} = \frac{5.0}{1.718} = 2.91 \text{ ksi}$$

where:

$A_w = \pi D_s t_w = 1.718 \text{ in}^2$

D_s= 1.75 in ---------- Support diameter of washer at weldment

t_w= 0.3125 in ---------- Washer thickness

The factor of safety is as follows.

$$FS = \frac{0.42S_u}{\tau_{wash}} = 9.12$$

where:

S_u=63.2 ksi---------- Ultimate strength, SA-240, Type 304, 700°F

The bosses transfer shear loads between the support weldments and fuel tube array. The maximum shear load, Ps, on a boss is 195 lb (45° basket orientation). Using a bounding load of 1,000 lb, the shear stress in the boss is as follows.

$$\tau_{boss} = \frac{P_s}{A_b} = \frac{1.0}{0.92} = 1.1 \text{ ksi}$$

where:

$$A_b = \frac{\pi\left(D_o^2 - D_i^2\right)}{4} = 0.92 \text{ in}$$

D_o= 1.25 in ---------- Boss outer diameter

D_i= 0.63 in ---------- Boss inner diameter

The factor of safety is as follows.

$$FS = \frac{0.42S_u}{\tau_{boss}} = \text{Large}$$

where:

S_u=62.0 ksi---------- Ultimate strength, SA-36, at 700°F

Basket Buckling Evaluation

For the hypothetical concrete cask tip-over accident, a buckling evaluation of a side wall of the fuel tube is performed per NUREG/CR-6322 [9]. Using the plastic model, the governing buckling load of a fuel tube occurs in the 0° basket orientation, Tube 12 in Figure 3.10.1-11. The maximum compression force and bending moment are extracted from the analysis results at the bottom of the tube sidewall. These loads for Tube 12 are 25.6 kip compression and 5.16 inch-kip bending. The factor of safety is calculated based on the interaction Equations 31 and 32

in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members subjected to stresses beyond the yield limit of the material. Methodology and equations for the buckling evaluation are summarized as follows.

Symbols and Units:

P = Applied axial compressive loads, kips

M = Applied bending moment, kips-inch

P_a = Allowable axial compressive load, kips

P_{cr} = Critical axial compression load, kips

P_e = Euler buckling loads, kips

P_y = Average yield load, equal to profile area times specified yield strength, kips

C_c = Column slenderness ratio separating elastic and inelastic buckling

C_m = Coefficient applied to bending term in interaction equation

M_m = Critical moment that can be resisted in the absence of axial load, kip-inch

M_p = Plastic moment, kip-inch.

F_a = Axial compressive stress permitted in the absence of bending moment, ksi

F_e = Euler stress for a prismatic member divided by factor of safety, ksi

K = Ratio of effective column length to actual unsupported length

l = Unsupported length of member, inch

r = Radius of gyration, inch

S_y = Yield strength, ksi

A = Cross sectional area of member, inch^2

Z_x = Plastic section modulus, inch

λ = Allowable reduction factor, dimensionless.

From NUREG/CR-6322, the following interaction equations (Eqn. 31 and 32) are used for the evaluation of accident events.

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

$$\frac{P}{P_y} + \frac{M}{1.18 M_p} \leq 1.0$$

where:

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

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

and

$$\lambda = \frac{1}{\pi}\left(\frac{Kl}{r}\right)\sqrt{\frac{S_y}{E}}$$

$$F_e = \frac{\pi^2 E}{1.30\left(\frac{kl}{r}\right)^2}$$

$$P_e = 1.92 \times A \times F_e$$

$$P_y = S_y \times A$$

$$C_m = 0.85 \text{ for members with joint translation (sideways)}$$

$$M_p = S_y \times Z_x$$

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

From NUREG/CR-6322, the factors of safety are calculated using the following equations.

$$P_1 = \frac{P}{P_{cr}}$$

$$M_1 = \frac{C_m M}{\left(1-\frac{P}{P_e}\right)M_m}$$

$$P_2 = \frac{P}{P_y}$$

$$M_2 = \frac{M}{1.18}M_p$$

$$FS_1 = \frac{1}{P_1+M_1}$$

$$FS_2 = \frac{1}{P_2+M_2}$$

For the PWR basket fuel tube the following parameters are used in the buckling evaluation.

t = 0.31 in ---------- Tube thickness

b = 10.00 in ---------- Model length

l = 8.20 in ---------- Sidewall length

K = 0.80 ---------- Effective length factor

E = 27.3×10^6 psi ---------- Modulus of elasticity, SA-537 Class 1, at 700°F

S_y = 35.4 ksi ---------- Yield strength, SA-537 Class 1, at 700°F

For P = 25.6 kip and M = 5.16 inch-kip (Tube 12, 0° basket orientation):

$$P_1 = \frac{P}{P_{cr}} = 0.24$$

$$M_1 = \frac{C_m M}{\left(1 - \frac{P}{P_e}\right) M_m} = 0.63$$

$$P_2 = \frac{P}{P_y} = 0.23$$

$$M_2 = \frac{M}{1.18 M_p} = 0.51$$

The factors of safety are listed as follows.

$$FS_1 = \frac{1}{P_1 + M_1} = \frac{1}{0.24 + 0.63} = 1.14$$

$$FS_2 = \frac{1}{P_2 + M_2} = \frac{1}{0.23 + 0.51} = 1.36$$

Basket Displacement

The nominal geometry of the PWR basket defines the fuel tube openings as 8.86 in × 8.86 in for the manufactured fuel tubes and 8.76 in × 8.76 in for the fuel slots developed by four adjacent tubes. The maximum width of a PWR fuel assembly is 8.54 inches. Based on the quasistatic analysis results using the three-dimensional periodic plastic models for the cask tip-over accident, the minimum clearance between the fuel assembly and the fuel tube is 0.24 inch for the manufactured tubes and 0.11 inch for the developed tubes during the 35-g side impact loading.

As presented in Section 3.10.7, a three-dimensional half-symmetry model for a PWR fuel tube is constructed using the LS-DYNA program to calculate the maximum displacement of a fuel tube as a function of time due to the side impact load for cask tip-over accident. The LS-DYNA analysis considers a displacement loading based on a bounding maximum diagonal displacement of the fuel tubes during the impact (see Figure 3.7.2-1) obtained from the finite element analysis

results using the three-dimensional periodic plastic model. The permanent displacement in the tube diagonal direction, after the impact, is calculated to be 0.008 inch, which is less than the fabrication tolerance of the fuel tubes and, therefore, not significant.

3.7.2.1.4 PWR Basket with Damaged Fuel Cans – Concrete Cask Tip-over

The evaluation for the tip-over accident for the PWR DF basket uses the three-dimensional periodic plastic finite element models described in Section 3.10.1.5. The models are shown in Figures 3.10.1-17 and 3.10.1-18, which correspond to 0° and 45° basket orientations, respectively.

Fuel Tube Evaluation

The PWR fuel tubes are evaluated for the bounding basket orientations of 0° and 45°. The maximum membrane and membrane plus bending stress intensities for the fuel tubes are reported in Table 3.7.2-9 and Table 3.7.2-10. A bounding temperature of 750°F is conservatively used for determining allowable values. The minimum factors of safety for the fuel tubes are 1.14 for the primary membrane stress (45° basket orientation) and 1.39 for membrane plus bending stress (45° basket orientation).

The fuel tubes are constructed by welding two tube halves together using a full-penetration weld for the length of the fuel tube. An external surface MT weld examination per ASME Code, Section III, Subsection NG, Article NG-5233 is used, which has a 0.65 weld quality factor (wf). From the plastic analysis of the PWR basket, the maximum membrane and membrane plus bending stress intensities at the tube welds are 9.3 ksi (45° basket orientation) and 25.6 ksi (45° basket orientation), respectively.

The factors of safety (FS) for the weld are:

Membrane:

$$FS = \frac{0.7S_u \times wf}{\sigma} = 3.27$$

Membrane plus bending:

$$FS = \frac{0.9S_u \times wf}{\sigma} = 1.53$$

where:

S_u=66.9 ksi---------- Ultimate strength, SA-537 Class 1, at 750°F.

The bearing stress (σ_{brg}) on the pin is evaluated using the bounding load of 20,000 pounds. The bearing area is determined based on the width and length of contact between the pin and fuel tube slot.

$$\sigma_{brg} = \frac{P}{LS} = 44.0 \text{ ksi}$$

where:

P=20.0 kip ---------- Maximum load on pin in model

L=1.625 inch---------- Length of pin in model

S=0.28 in---------- Width of pin and slot contact

The factor of safety is:

$$FS = \frac{2.1S_u}{\sigma_{brg}} = 2.73$$

where:

S_u=57.3 ksi---------- Ultimate strength, A36, at 750°F

Corner Support Weldment Evaluation

The corner support weldment is comprised of two major components: formed plates and ridge gussets.

The calculated maximum stress intensities for the weldment plates are presented in Table 3.7.2-11 and Table 3.7.2-12 and for the gussets in Table 3.7.2-13 and Table 3.7.2-14. The minimum factor of safety for the corner weldment plates is 1.74. The minimum factor of safety for the ridge gussets is 2.30. The allowable values are determined at a temperature of 700°F. All weld sections of the fabricated tube are full penetration. A surface MT weld examination per ASME Code, Section III, Subsection NG, Article NG-5233 is used, which has a 0.65 weld quality factor (wf). The minimum factor of safety is 1.15 for the governing weld location (Section 14 of Figure 3.10.1-21).

The ridge gussets are welded to the corner weldment plates with a full-penetration weld. A surface MT weld examination per ASME Code, Section III, Subsection NG, Article NG-5233 is used, which has a 0.65 weld quality factor (wf). The welded joint between the support bar and corner weldment plate is capable of carrying bending, axial and shear loads. The maximum weld loads occur in the 45° basket orientation. The bending moment (M), axial load (P) and shear load (V) are 3,171 in-lb, 5,646 lb, and 4,144 lb, respectively. The weld stress intensity (σ_{weld}) is as follows.

$$\sigma_{weld} = \sqrt{\left(\frac{M}{S_w} + \frac{P}{A_w}\right)^2 + 4\left(\frac{V}{A_w}\right)^2} = 21.4 \text{ ksi}$$

where:

$S_w = 2.00 \times 0.75^2/6 = 0.1875 \text{ inch}^3$

$A_w = 0.75 \times 2.00 = 1.50 \text{ inch}^2$

The factor of safety (FS) for the weld is as follows.

$$FS = \frac{0.65(S_u)}{\sigma_{weld}} = 2.08$$

where:

S_u=68.4 ksi---------- Ultimate strength, SA-537 Class 1, at 700°F

Side Support Weldment Evaluation

The analysis results for the side support weldment are presented in Table 3.7.2-15 and Table 3.7.2-16. The minimum factors of safety for membrane and membrane plus bending stress intensities are 6.56 (0° basket orientation) and 2.13 (0° basket orientation), respectively. The allowable values are determined at a temperature of 700°F.

Side and Corner Weldment/Fuel Tube Attachment Evaluation

The evaluation of the bolt and boss connections between the support weldments and the fuel tubes for the PWR damaged fuel can configuration is bounded by the evaluation for the PWR basket with square pins in Section 3.7.2.1.3.

Basket Buckling Evaluation

For the hypothetical concrete cask tip-over accident, a buckling evaluation of a side wall of the fuel tube is performed per NUREG/CR-6322 [9]. Using the plastic model, the governing buckling load of a fuel tube occurs in the 0° basket orientation, Tube 12 in Figure 3.10.1-19. The maximum compression force and bending moment are extracted from the analysis results at the bottom of the tube sidewall. These loads for Tube 12 are 28.8 kip compression and 4.81 inch-kip bending. Using the interaction Equations 31 and 32 in NUREG/CR-6322, the factors of safety are calculated to be 1.33 and 1.56, respectively.

Basket Displacement

The nominal geometry of the PWR basket defines the fuel tube openings as 8.86 in × 8.86 in for the manufactured fuel tubes and 8.76 in × 8.76 in for the fuel slots developed by four adjacent

tubes. The maximum width of a PWR fuel assembly is 8.54 inches. Based on the quasistatic analysis results using the three-dimensional periodic plastic models for the cask tip-over accident, the minimum clearance between the fuel assembly and the fuel tube is 0.24 inch for the manufactured tubes and 0.10 inch for the developed tubes during the 35g side impact loading. The minimum clearance between the damaged fuel can tube and the damaged fuel assembly is bounded by these values.

PWR Neutron Absorber and Retainer

The PWR damaged fuel can neutron absorber and retainer are evaluated for a 60g side-impact load and for the concrete cask tip-over event using LS-DYNA. This conservatively envelops the maximum tip-over acceleration of 35g. The analysis follows that presented in Section 3.7.2.1.3, except that the model shown in Figure 3.7.2-3 is modified to reflect a few changes in the geometry, i.e., the different width of the damaged fuel can neutron absorber and the increased thickness of the retainer. Also, the thickness of the absorber in the analysis has been conservatively increased from the nominal value of 0.125 inch to the maximum fabricated thickness of 0.145 inch. All other analysis details are otherwise identical.

The corresponding maximum stress intensity (twice maximum shear) is 34.0 ksi. The allowable stress intensity for accident condition is $0.9S_u$. Using the maximum shear stress, which is a more conservative approach than using the section average stress, the factor of safety for the retainer strip is:

$$FS = 0.9S_u / 34.0 = 0.9 \times 63.2 / 34.0 = 1.67$$

where:

S_u=63.2 ksi---------- Ultimate strength of Type 304 stainless steel at 700°F

The maximum strain is 2.2%, which is minimal, and indicates that the conical pocket retains its configuration for the weld post to restrain the retainer. The final maximum displacement of the retainer strip at the axial midpoint between the weld posts is computed to be 0.05 inch, and confirms that the retainer remains engaged with the weld post during and after the impact.

The peak force on the weld post determined from the analysis is 57 pounds. From Section 3.7.2.1.3, the weld capacity, F_{cap}, is 812 pounds. The factor of safety (FS) is as follows.

$$FS = \frac{812}{57} = \text{Large}$$

3.7.2.2 BWR Fuel Basket

3.7.2.2.1 24-inch Concrete Cask End-Drop

For the 24-inch concrete cask drop, a 60g acceleration (a) is conservatively applied to the BWR basket in the axial direction. The basket is evaluated using classical hand calculations. Factors of safety for the BWR basket are calculated based on the criteria for Service Level 'D' limits from ASME Code, Section III Subsection NG [7] and Appendix F [8]. Using a bounding weight of 22,000 pounds for the BWR basket, the maximum primary membrane stress in the fuel tube extensions is calculated. Conservatively assuming the entire basket weight is carried through the fuel tubes, the stress in the tube is as follows.

$$\sigma_{tube} = \frac{P_{tube}}{A} = 19.6 \text{ ksi}$$

where:

$$P_{tube} = \frac{W \times a}{n} = \frac{22{,}000 \times 60}{45} = 29{,}333 \text{ lb}$$

W = 22,000 lb ---------- Bounding basket weight

n = 45---------- Number of fuel tubes

A = 1.5 in^2 ---------- Tube extension cross-sectional area

The factor of safety (FS) is as follows.

$$FS = \frac{0.7 \times S_u}{\sigma_{tube}} = \frac{0.7 \times 67.65}{19.6} = 2.42$$

where:

S_u = 67.65 ksi---------- Ultimate strength, SA-537 Class 1, at 725°F

The weight of the side and corner weldments is transferred to the canister bottom plate by standoffs at the bottom of the weldments. The loading conditions of the corner weldment standoffs bound those of the side weldment. The dimensions for the corner support weldment are 8.0 inches in length and 0.375-inch thickness. The bounding weight of the corner weldment is 1,200 pounds. Conservatively, the corner weldment is assumed to support one-quarter of the weight of four fuel tubes (400 lb per tube, bounding). The membrane stress (σ_m) is as follows.

$$\sigma_m = \frac{W_{sup}}{A_{sup}} = \frac{90{,}000}{3.0} = 32.0 \text{ ksi}$$

where:

$$W_{sup} = 60 \times (1{,}200 + 4 \times (0.25 \times 400)) = 96{,}000 \text{ lb}$$
$$A_{sup} = 8.0 \times 0.375 = 3.0 \text{ inch}^2$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.7S_u}{\sigma_m} = \frac{0.7 \times 67.65}{32.0} = 1.48$$

where:

S_u = 67.65 ksi---------- Ultimate strength, SA-537 Class 1, at 725°F

The forty-five fuel tube extensions support the BWR basket during a 60g bottom end drop accident. The bounding temperature at the bottom of the basket is 500°F. The extensions are subjected to compressive loads; therefore, a buckling evaluation of the extensions is presented below. The load on one fuel tube extension (P_{tube}) is as follows.

$$P_{tube} = \frac{W \times 60}{n} = \frac{22000 \times 60}{45} = 29.3 \text{ kip}$$

where:

W = 22,000 lb ---------- Bounding basket weight

n = 45---------- Number of fuel tubes

Using the Euler buckling theory, the critical buckling load (P_{cr})

$$P_{cr} = \frac{\pi^2 EI}{(K\,L)^2} = \frac{\pi^2 \times 27.3e3 \times 0.585}{(2 \times 3.0)^2} = 4{,}378 \text{ kip} \qquad [9]$$

where:

L = 3.0 in

I = 0.585 in^4

K = 2.0 ---------- Buckling constant, clamped-free

E = 27.3 × 10^6 psi---------- Modulus of elasticity of SA-537, Class 1, 500°F

The factor of safety (FS) for buckling of the hinge pins is as follows.

$$FS = \frac{P_{cr}}{P_{pin}} = \frac{4{,}378}{29.3} = \text{Large}$$

BWR Neutron Absorber Evaluation

During the end impact condition, the BWR neutron absorber and the weld post are subject to shearing force in the longitudinal direction of the neutron absorber. The neutron absorber is considered to be supported by two weld posts located at the bottom end of the neutron absorber.

The evaluation is conservatively performed for an acceleration of 60g at a bounding temperature of 350°F. The inertia load applied to the neutron absorber (F_{na}) at each weld post during the end impact is as follows.

$$F_{na} = L \times W \times t \times \rho \times a / 2 = 272 \text{ lb}$$

where:

ρ = 0.1 lb/in^3 ---------- Bounding density of the neutron absorber

a = 60g ---------- End drop acceleration

t = 0.1 in ---------- Thickness of neutron absorber

L = 165 in ---------- Length of neutron absorber

W = 5.5 in ---------- Width of neutron absorber

The shearing capacity of the neutron absorber is as follows.

$$F_{shear_na} = A_s \times \Phi_a = 0.15 \times 2260 = 339 \text{ lb}$$

where:

A_s = $L_{NA} \times 1.414 \times 2 \times t = 0.15$ in^2 - Shear area at both sides of each weld-post (at the 45° shear planes)

L_{NA} = 0.53 in ---------- Min. edge distance of the neutron absorber

Φ_a = 0.42 S_u = 2.26 ksi ---------- Allowable shear stress

S_u = 5.38 ksi ---------- Tensile strength of neutron absorber at 350°F

The factor of safety (FS) is as follows.

$$FS = F_{shear_na} / F_{na} = 339 / 272 = 1.25$$

The strength of the weld posts is significantly higher than that of the neutron absorber. Therefore, no evaluation is required for the weld posts for the concrete cask 24-inch end-drop evaluation.

3.7.2.2.2 Concrete Cask Tip-over

The analysis results for the BWR basket subjected to a hypothetical concrete cask tip-over accident are presented in this section. Each basket component is evaluated in the following sections. Factors of safety for the BWR basket are calculated based on the criteria for Service Level 'D' limits from ASME Code, Section III, Subsection NG [7] and Appendix F [8].

BWR Fuel Tube Evaluation

The BWR basket fuel tubes are analyzed for a tip-over accident using the three-dimensional periodic plastic finite element models described in Section 3.10.2. The fuel tube is conservatively evaluated for a 35g side impact load. Stresses are calculated for the fuel tubes for 0° and 45° basket orientations (see Figure 3.10.2-13 and Figure 3.10.2-15 for tube IDs). The stresses in each fuel tube are post processed at the 16 locations shown in Figure 3.10.2-14 and Figure 3.10.2-16. At these locations both the section elastic stress intensity and maximum nodal plastic stress intensity at the section are calculated. If the plastic nodal stress at a section cut is less than the tube yield stress used in the analysis (35.4 ksi for SA-537 Class 1 at 500° F), the section elastic stress intensity is the reported stress result. If the plastic stress is above the yield stress, the plastic nodal stress intensity is reported. Table 3.7.2-9 summarizes the highest stress results for the fuel tubes for the 0° and 45° basket orientations. The minimum factors of safety for the fuel tubes are 1.07 (45° basket orientation) for membrane stresses and 1.21 (0° basket orientation) for primary membrane plus bending stresses. The critical stress locations occur in the fuel tube corners.

The fuel tubes are constructed by welding two tube halves together using a full penetration weld the length of the fuel tube at the center of opposing flats. A surface PT or MT weld examination per ASME III-NG-5233 is used, which has a 0.65 weld quality factor (wf). The weld location and orientation are not specified on the assembly drawings; therefore, the maximum weld stress intensity is checked at each side of a tube (section cuts #2, #6, #10, #14) in Figure 3.10.2-13 and Figure 3.10.2-14.

Based on the plastic analysis results of the BWR basket, the maximum membrane and membrane plus bending stress intensities at the tube weld is 13.4 ksi (Tube 24, 45° basket) and 30.0 ksi (Tube 25, 0° basket), respectively. The factors of safety for the weld are as follows.

Membrane:

$$FS = \frac{0.7S_u \times wf}{\sigma} = \frac{0.7 \times 67.65 \times 0.65}{13.4} = 2.30$$

Membrane plus bending:

$$FS = \frac{0.9S_u \times wf}{\sigma} = \frac{0.9 \times 67.65 \times 0.65}{30.0} = 1.32$$

where:

S_u = 67.65 ksi---------- Ultimate strength, SA-537 Class 1, at 725°F

The pins provide a load path for loads transferred between adjacent tubes. The bearing stresses at the pins are calculated by extracting the total compression force at each tube and pin interface

from the analysis results. The maximum bearing force is 10,274 lb (0° basket orientation). The maximum bearing stress at the pin is as follows.

$$\sigma_{brg} = \frac{F_{brg}}{A_{brgs}} = 60.4 \text{ ksi}$$

where:

F_{brg}=10,274 lb ---------- Maximum bearing force at pin

L_b=1.00 in ---------- Length of pin/tube contact

w_f=0.17 in ---------- Minimum width of pin/tube contact

$A_{brg} = L_b w_f = 0.17 \text{ in}^2$

Per ASME Appendix F-1336, the allowable bearing stress is $2.1S_u$. The factor of safety using the lesser of the basket and pin material allowables is

$$FS = \frac{2.1S_u}{\sigma_{brg}} = \frac{2.1 \times 67.65}{60.4} = 2.35$$

where:

S_u = ---------- 67.65 ksiUltimate strength, SA-537 Class 1, at 725°F

BWR Neutron Absorber and Retainer

The BWR neutron absorber and retainer are conservatively evaluated for a 60g side-impact load and for the concrete cask tip-over event. The retainer strip assembly consists of 304 stainless steel and is restrained by an array of posts welded to the inside surface of the fuel tube. Two rows of post are separated 3.6 inches apart, and a spacing of 12 inches exists between the posts along the axial direction of the fuel tube.

The neutron absorber is supported by the retainer strip at the inside surface of the fuel tube. The pitches of the slotted holes in the neutron absorber are the same as the holes in the retainer strip through which the weld posts are connected to the fuel tube. The slotted holes are used to prevent interference during differential thermal expansion between the neutron absorber and the fuel tube. The head of the weld posts supporting the retainer strip are engaged in the recessed conical pockets of the retainer.

The finite element model for the BWR neutron absorber and retainer is similar to the model shown in Figure 3.7.2-3, with the exception of the spacing of the posts in the lateral direction and the axial direction. This resulted in minimal change to the finite element mesh used for the PWR model. Boundary conditions applied in the PWR model shown in Figure 3.7.2-3 were also

applied to the BWR model. LS-DYNA was used to determine the dynamic response to a 60g loading, which was also used for the PWR design.

The results of the transient evaluations show that the maximum strain in the retainer for the BWR fuel is 2.5%, which is minimal, and is local to the conical-shaped hole. Since inelastic strains are not recovered, this indicates that maximum inelastic strain during the impact is also limited to 2.5 percent. Such a minimal strain level indicates that the conical pocket retains its configuration for the weld post to restrain the retainer. The final displacement of the retainer strip at the midpoint between the weld posts is computed to be 0.07 inch, which is consistent with the minimal plastic strain in the retainer. This also confirms that the retainer remains engaged with the weld post during and after the impact.

The peak force on the weld post determined from the analysis is 50 pounds. The shear area governs the capacity of the weld. The depth of the weld (h) is 0.13 inch. The diameter of the weld post (D) is 0.25 inch. The governing stress is the shear stress in the base material. The allowable shear stress for the accident condition is $0.42S_u$. The ultimate strength (S_u) of the base material (SA240, Type 304) is 63,200 psi. The weld capacity, F_{cap}, is calculated as shown in the following.

$$F_{cap} = 0.42 \times n \times S_u \times h \times BD$$
$$= 0.42 \times 0.3 \times 63{,}200 \times 0.13 \times (3.1416 \times 0.25)$$
$$= 813 \text{ lb}$$

where:

n = 0.3 ---------- The design factor per ASME Code, Section III, Subsection NG, Table NG-3352-1 for the intermittent plug weld employing a surface visual examination method per NG-5260.

The factor of safety (FS) is as follows.

$$FS = \frac{813}{50} = 16$$

BWR Corner Support Weldment Evaluation

The BWR basket corner support weldment is analyzed for the tip-over accident using the three-dimensional periodic plastic finite element model and boundary conditions described in Section 3.10.2. The analysis results for the corner support weldment are presented in Table 3.7.2-10. The sections used for the corner support weldment are shown in Figures 3.10.2-17 and 3.10.2-18. The maximum stress is compared to the primary membrane stress allowable. The minimum

factor of safety for the corner support weldment is 1.16 for membrane stress and 1.39 for membrane plus bending stress. The allowable stresses were evaluated at 700 °F.

Each support plate is welded to the corner weldment with a 5/16-inch groove weld on each side of the plate. The welds have a visual inspection criterion per ASME III-NG-5260 and a weld quality factor of 0.35, per ASME III-NG-3352. The ridge gussets are welded to the corner plate with a 0.25" bevel weld that is continuous along the length of the basket. Inspection is MT or PT, and per ASME III-NG-5231 the weld quality factor is 0.55. At each of these weld locations in the model, the membrane force along the plate or gusset length (F_{ax}), the transverse shear force perpendicular to the plate or gusset (F_t), and the bending moment (M_z) in the weld joint are extracted from the finite element analysis results. The weld stress intensity (σ_{weld}) is then computed using the following expression.

$$\sigma_{weld} = \sqrt{(\sigma_{ax} + \sigma_m)^2 + 4\tau^2}$$

where:

$$\sigma_{ax} = \frac{F_{ax}}{A_{weld}}$$

$$\sigma_m = \frac{M_z}{S_{weld}}$$

$$\tau = \frac{F_t}{A_{weld}}$$

For the ridge gusset weld,

A_{weld} = $L \times t_w = 2.50$ in^2

S_{weld} = $(L \times t_w^2)/6 = 0.104$ in^3

L_p = 10.0 in ---------- Length of basket model

t_w = 0.25 in ---------- Weld size

For the ridge gusset weld the largest stress intensity is 23.98 ksi (45°, weld 2).

The factor of safety is

$$FS = \frac{0.55(S_u)}{\sigma_{weld}} = \frac{0.55 \times 68.4}{23.98} = 1.57$$

where:

S_u = 68.4 ksi ---------- Ultimate stress, SA-537 Class 1, at 700°F

For the side support plate weld,

$A_{weld} = 2 \times (L_p \times t_w) = 3.62 \text{ in}^2$

$S_{weld} = L_p \times W_p \times t_w = 1.35 \text{ in}^3$

L_p = 5.8 in---------- Length of support plate

W_p = 0.75 in ---------- Plate thickness

t_w = 0.3125 in ---------- Weld size

For the support plate weld, the largest stress intensity for the membrane plus bending is 11.6 ksi (0°, weld 8). The factor of safety (FS) for the weld is as follows.

$$FS = \frac{0.35(S_u)}{\sigma_{weld}} = \frac{0.35 \times 68.4}{11.6} = 2.06$$

where:

S_u = 68.4 ksi ---------- Ultimate stress, SA-537 Class 1, at 700°F

BWR Side Support Weldment Evaluation

The BWR basket side support weldment is analyzed for the tip-over accident using the three-dimensional periodic finite element model and boundary conditions described in Section 3.10.2. The analysis results for the side support weldment are presented in Table 3.7.2-11. The maximum primary membrane plus bending stress intensity is conservatively compared to the primary membrane stress allowable. The minimum factor of safety for the side support weldment is 6.27 for membrane stress and 3.04 for membrane plus bending stress.

BWR Side and Corner Weldment / Fuel Tube Attachment Evaluation

The corner and side support weldments are the primary structure that maintains the geometry of the fuel tube array during a hypothetical tip-over accident. The support weldments are bolted to the fuel tubes at 24 circumferential locations. The boss and bolt connection is designed so that the bolts are only loaded in tension, including preload. Otherwise, the support weldments apply a bearing load on the fuel tube array.

During a hypothetical concrete cask tip-over accident, the maximum tensile load on a bolt is 4,755 lb (0° basket model). The tensile load is conservatively rounded up to 5,000 lb. Combining this load with the bolt preload (400 lb), the tensile load (P) on the bolt is 5,400 pounds.

The bolt thread is a ⅝-11 UNC and the length of engagement is a minimum of 0.47 inch. The bolt material is SA-193 Grade B6 stainless steel. From Machinery's Handbook [12], the ultimate stress in the bolt (σ_t) is as follows.

$$\sigma_t = \frac{P}{A_t} = \frac{5.4}{0.23} = 23.5 \text{ ksi}$$

where:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2 = 0.23 \text{ inch}^2 \quad [12]$$

$$D = 0.625 \text{ inch}$$

$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.7S_u}{\sigma_t} = 2.70$$

where:

S_u=90.6 ksi---------- Ultimate stress, SA 193, Gr B6, at 700°F

The shear stress in the bolt thread (τ_{bolt}) is as follows.

$$\tau_{bolt} = \frac{P}{A_s} = \frac{5.4}{0.469} = 11.5 \text{ ksi}$$

where:

$$A_s = 3.1416nL_eK_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right] = 0.469 \text{ inch}^2 \; [12]$$

$$L_e = 0.47 \text{ inch}$$

$$K_{n\,max} = 0.546$$

$$E_{s\,min} = 0.5589$$

$$n = 11$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.42S_u}{\tau_{bolt}} = 3.31$$

where:

S_u = 90.6 ksi ---------- Ultimate strength for SA 193, Gr B6, at 700°F

The shear stress in the boss thread (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P}{A_n} = \frac{5.4}{0.67} = 8.1 \text{ ksi}$$

where:

$$A_n = 3.1416 n L_e D_{s\,min}\left[\frac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right] = 0.67 \text{ inch}^2 \text{ [12]}$$

L_e = 0.47 inch
$E_{n\,max}$ = 0.5732
$D_{s\,min}$ = 0.6113
n = 11

The factor of safety (FS) is as follows.

$$FS = \frac{0.6S_y}{\tau_{boss}} = 2.01$$

where:

S_y = 27.2 ksi ---------- Yield Strength, SA-516, Grade 70, at 700°F

The boss is welded into the fuel tube with a 3/16-inch groove weld. The weld uses the visual inspection criteria per ASME Code, Section III, Subsection NG, Article NG-5260 and a quality factor of 0.35. The side weldment boss weld is evaluated using 2,400 lbs which bounds the maximum load of 1,923 lbs (45°, location 9) combined with the bolt preload of 400 lbs. The corner weldment boss weld is evaluated using a bounding bolt tension (P) of 5,400 lbs.

For the side weldment, the shear stress in the boss weld (τ_{weld}) is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{2.4}{0.59} = 4.07 \text{ ksi}$$

where:

$$A_w = \pi D t_{weld} = \pi \times 1.00 \times 0.1875 = 0.59 \text{ in}^2$$

D = 1.00 inch ---------- Boss Diameter

For the corner weldment, the shear stress in the boss weld (τ_{weld}) is as follows.

$$\tau_{weld} = \frac{P}{A_w} = \frac{5.4}{0.81} = 6.67 \text{ ksi}$$

where:

$A_w = \pi D t_{weld} = \pi \times 1.38 \times 0.1875 = 0.81 \text{ in}^2$

D = 1.38 inch ---------- Boss Diameter

The minimum factor of safety (FS) for the bosses is as follows.

$$FS = \frac{0.35 \times 0.42 S_u}{\tau_{weld}} = 1.51$$

where:

S_u=68.4 ksi---------- Ultimate stress, SA-537, Class 1, at 700°F

The washers under the bolts are subjected to shear from the bolt tensile load and the support condition at the weldment. The washer is evaluated using a bounding bolt load tensile load of 5,400 lb. The maximum washer shear stress, using an area defined by the bolt head perimeter and the washer thickness, is as follows.

$$\tau_{wash} = \frac{P}{A_w} = \frac{5.4}{0.617} = 8.75 \text{ ksi}$$

where:

$A_w = 0.617 \text{ in}^2$

The factor of safety is as follows.

$$FS = \frac{0.42 S_u}{\tau_{wash}} = 3.03$$

where:

S_u=63.2 ksi---------- Ultimate strength, SA-240 Type 304, 700°F

The maximum shear load in the bosses for side support weldment attachment (P_1) is 2.8 kip (0° basket orientation). The maximum shear load in the corner support weldment (P_2) is 5.5 kip. For the side weldment boss, the shear stress in the boss (τ_{boss}) is as follows.

$$\tau_{boss} = \frac{P_1}{A} = \frac{2.8}{0.47} = 5.96 \text{ ksi}$$

where:

$$A = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = 0.47 \text{ inch}^2$$

D_o = 1.00 inch

D_i = 0.63 inch

The factor of safety (FS) is as follows.

$$FS = \frac{0.42S_u}{\tau_{boss}} = 4.93$$

where:

S_u = 70.0 ksi ---------- Ultimate strength, SA-695 Type B, Gr 40, at 700°F

For the corner weldment boss, the shear stress in the boss (τ_{boss}) is as follows

$$\tau_{boss} = \frac{P_2}{A} = \frac{5.5}{1.17} = 4.70 \text{ ksi}$$

where:

$$A = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) = 1.17 \text{ inch}^2$$

D_o = 1.375 inch

D_i = 0.63 inch

The factor of safety (FS) is as follows.

$$FS = \frac{0.42S_u}{\tau_{boss}} = 6.26$$

where:

S_u = 70.0 ksi ---------- Ultimate strength, SA-695 Type B, Gr 40, at 700°F

BWR Basket Buckling Evaluation

The buckling evaluation of the BWR basket is an evaluation of a side of the fuel tube per NUREG/CR-6322 [9]. Using the plastic finite element model, the critical buckling of a fuel tube occurs in the 0° basket orientation (Tube 25, Figure 3.10.2-13). The applied loads on a side of the fuel tube are 22.87 kip axial compression and 3.20 inch-kip bending moment.

The factor of safety is calculated based on the interaction Equations 31 and 32 in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members subjected to stresses beyond the yield limit of the material. Methodology and equations for the buckling evaluation are the same as those presented in Section 3.7.2.1.3 for the PWR basket.

For the BWR basket fuel tube, the following parameters are used in the buckling evaluation.

t = 0.25 inch ---------- Tube thickness

b = 10.00 inches ---------- Unit thickness

l = 5.34 inches ---------- Sidewall length

K = 0.80 ---------- Effective length factor

E = 25.5×10^6 psi ---------- SA-537 Class 1, at 700°F

S_y = 32.3 ksi ---------- Yield strength, SA-537 Class 1, at 700°F

For P = 22.87 kip and M = 3.20 inch-kip (Tube 25, 0° basket orientation)

$$P_1 = \frac{P}{P_{cr}} = 0.27$$

$$M_1 = \frac{C_m M}{\left(1 - \frac{P}{P_e}\right) M_m} = 0.63$$

$$P_2 = \frac{P}{P_y} = 0.28$$

$$M_2 = \frac{M}{1.18} M_p = 0.54$$

The factors of safety are as follows.

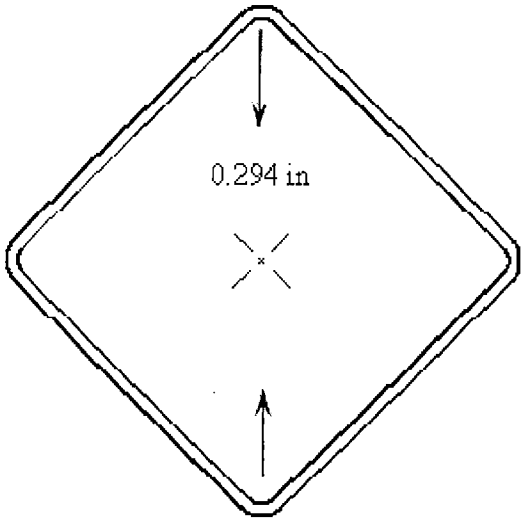
$$FS_1 = \frac{1}{P_1 + M_1} = 1.11$$

$$FS_2 = \frac{1}{P_2 + M_2} = 1.22$$

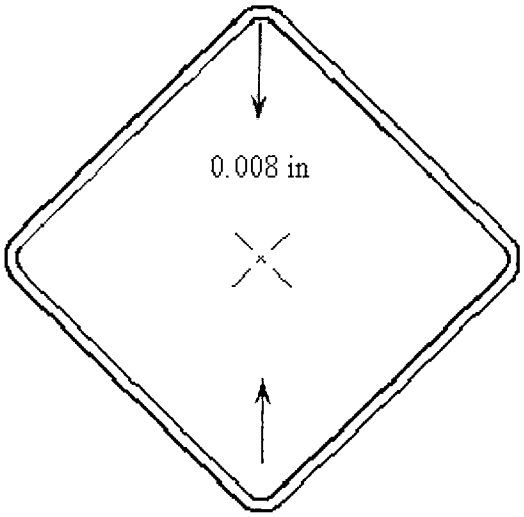
BWR Basket Displacement

The nominal dimensions of the fuel tube opening for the BWR basket is 5.86 in × 5.86 in for the manufactured fuel tubes and 5.77 in × 5.77 in for the developed fuel slot formed by four adjacent fuel tubes. The maximum width of a BWR fuel assembly is 5.52 inches. Based on the quasi-static analysis results using the three-dimensional periodic plastic models for the cask tip-over accident, the minimum clearance between the fuel assembly and the fuel tube is 0.29 inch for the manufactured tubes and 0.22 inch for the developed tubes during the 35-g side impact loading. As presented in Section 3.10.7, a three-dimensional half-symmetry model for a BWR fuel tube is constructed using the LS-DYNA program to calculate the maximum displacement of the fuel tube as function of time due to the side impact loading for the cask tip-over accident. The LS-DYNA analysis consider a displacement loading based on the maximum diagonal displacement of the fuel tubes during the impact (see Figure 3.7.2-2) from the LS-DYNA analysis presented in Section 3.10.6. The permanent displacement in the tube diagonal direction, after the impact, is calculated to be 0.004 inch, which is less than the minimum clearance between the fuel assembly and the tube.

Figure 3.7.2-1 PWR Basket Fuel Tube Displacement for Tip-Over Accident

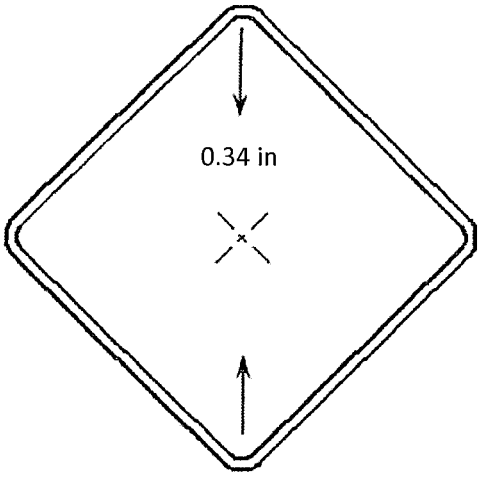


Maximum Diagonal Displacement During Impact

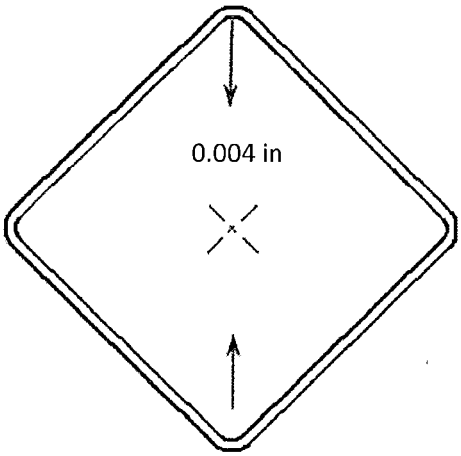


Maximum Diagonal Displacement After Impact

Figure 3.7.2-2 BWR Basket Fuel Tube Displacement for Tip-Over Accident



Maximum Diagonal Displacement During Impact



Maximum Diagonal Displacement After Impact

Figure 3.7.2-3 PWR Neutron Absorber and Retainer Finite Element Model

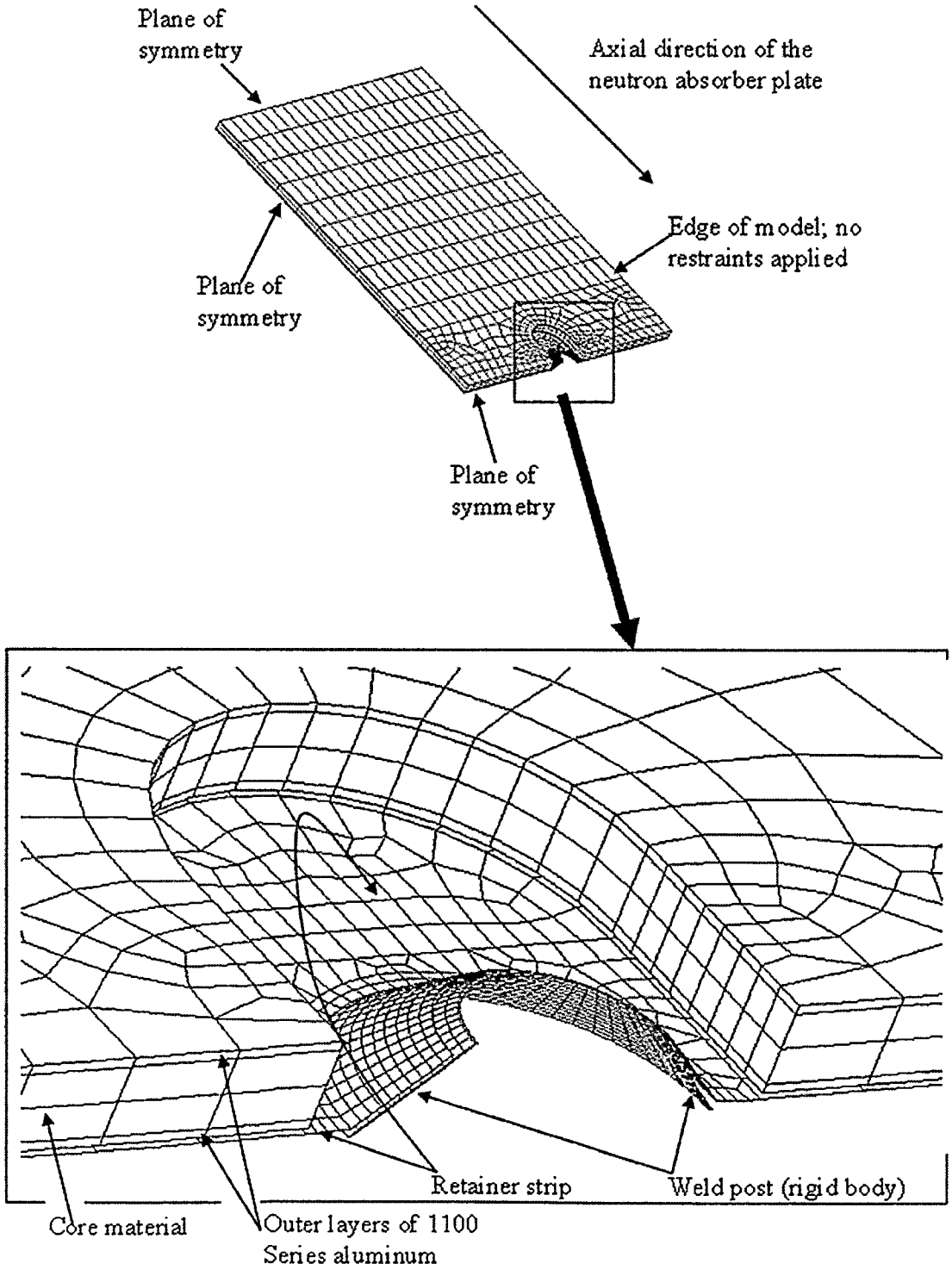


Table 3.7.2-1 PWR Fuel Tube Stress Intensity – Concrete Cask Tip-over Accident, 0° Orientation

[redacted]

Table 3.7.2-2 PWR Fuel Tube Stress Intensity – Concrete Cask Tip-over Accident, 45° Orientation

[redacted]

Table 3.7.2-3 PWR Corner Weldment Mounting Plate Stress Intensity – Concrete Cask Tip-over Accident, 0° Orientation

[redacted]

Table 3.7.2-4 PWR Corner Weldment Mounting Plate Stress Intensity – Concrete Cask Tip-over Accident, 45° Orientation

[redacted]

Table 3.7.2-5 PWR Corner Support Bar Stress Intensity – Concrete Cask Tip-over Accident, 0° Orientation

[redacted]

Table 3.7.2-6 PWR Corner Support Bar Stress Intensity – Concrete Cask Tip-over Accident, 45° Orientation

[redacted]

Table 3.7.2-7 PWR Side Weldment Stress Intensity – Concrete Cask Tip-over Accident, 0° Orientation

[redacted]

Table 3.7.2-8 PWR Side Weldment Stress Intensity – Concrete Cask Tip-over Accident, 45° Orientation

[redacted]

Table 3.7.2-9 PWR Fuel Tube Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 0° Orientation

[redacted]

Table 3.7.2-10 PWR Fuel Tube Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 45° Orientation

[redacted]

Table 3.7.2-11 PWR Corner Weldment Plate Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 0° Orientation

[redacted]

Table 3.7.2-12 PWR Corner Weldment Plate Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 45° Orientation

[redacted]

Table 3.7.2-13 PWR Corner Weldment Ridge Gussets Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 0° Orientation

[redacted]

Table 3.7.2-14 PWR Corner Weldment Ridge Gussets Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 45° Orientation

[redacted]

Table 3.7.2-15 PWR Side Weldment Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 0° Orientation

[redacted]

Table 3.7.2-16 PWR Side Weldment Stress Intensity – Concrete Cask Tip-over Accident, Basket with Damaged Fuel Cans, 45° Orientation

[redacted]

Table 3.7.2-17 BWR Fuel Tube Stress Intensity – Concrete Cask Tip-over Accident

Tube[a]	Basket (deg)	P_m (ksi)			Tube[a]	Basket (deg)	$P_m + P_b$ (ksi)		
		S	S_{allow}	FS			S	S_{allow}	FS
8	45	44.40	47.35	1.07	25	0	50.46	60.88	1.21
16	45	42.25	47.35	1.12	8	45	44.47	60.88	1.37
21	0	42.24	47.35	1.12	20	0	43.54	60.88	1.40
20	0	41.80	47.35	1.13	22	0	43.42	60.88	1.40
9	45	41.72	47.35	1.13	21	0	43.41	60.88	1.40

Table 3.7.2-18 BWR Corner Support Weldment Stress Intensity – Concrete Cask Tip-over Accident

Section[b]	Basket (deg)	Pm (ksi)			Section[b]	Basket (deg)	Pm + Pb (ksi)		
		S	Sallow	FS			S	Sallow	FS
72	0	41.27	47.88	1.16	49	45	44.20	61.56	1.39
71	0	41.27	47.88	1.16	37	0	42.02	61.56	1.47
49	45	41.14	47.88	1.16	48	0	41.96	61.56	1.47
48	0	41.12	47.88	1.16	72	0	41.63	61.56	1.48
68	0	40.97	47.88	1.17	71	0	41.60	61.56	1.48

[a] See Figure 3.1.2-13 and Figure 3.10.2-15 for tube locations for 0° and 45° basket orientations, respectively.

[b] See and Figure 3.10.2-17 and Figure 3.10.2-18 for tube locations for 0° and 45° basket orientations, respectively.

Table 3.7.2-19 BWR Side Support Weldment Stress Intensity – Concrete Cask Tip-over Accident

Section[a]	Basket (deg)	Pm (ksi)			Section[a]	Basket (deg)	Pm + Pb (ksi)		
		S	Sallow	FS			S	Sallow	FS
14	45	7.64	47.88	6.27	11	0	20.24	61.56	3.04
15	0	7.50	47.88	6.38	13	45	14.54	61.56	4.23
11	0	5.83	47.88	8.21	14	45	14.43	61.56	4.27
13	45	5.48	47.88	8.74	6	45	13.25	61.56	4.65

[a] See Figure 3.10.2-19 and Figure 3.10.2-20 for tube locations for 0°and 45° basket orientations, respectively.

3.7.3 Concrete Cask Evaluation for Storage Accident Events

A bounding structural evaluation of the concrete is performed for accident events, including the extreme temperature events (133°F ambient), tornado and tornado-driven missiles, flood, earthquake, concrete cask 24-inch drop and the tip-over accident.

3.7.3.1 Concrete Cask Thermal Stresses

Using the finite element models presented in Section 3.10.4, structural evaluations of the concrete cask are performed for accident thermal loads, both with and without the optional inner rebar cage. The analyses considered a temperature profile corresponding to the accident thermal condition (133°F ambient). The following summarizes the bounding thermal stresses in the concrete cask for accident events.

Component	Stress (ksi)
Circumferential Rebar	22.1
Vertical Rebar	22.7
Concrete, Compression	1.63
Concrete, Tension	0.138

3.7.3.2 Tornado and Tornado-Driven Missiles

This section evaluates the strength and stability of the concrete cask for a maximum tornado wind loading and for the impacts of tornado-driven missiles. It also demonstrates that the concrete cask remains stable in tornado wind loading in conjunction with an impact from a high-energy tornado missile.

Concrete cask stability analysis for the maximum tornado wind loading is based on NUREG-0800, Section 3.3.1, "Wind Loadings," and Section 3.3.2, "Tornado Loadings," [16]. Loads due to tornado-driven missiles are based on NUREG-0800, Section 3.5.1.4, "Missiles Generated by Natural Phenomena."

The concrete cask stability in a maximum tornado wind is evaluated based on the design wind pressure calculated in accordance with ANSI/ASCE 7-93, [17] and using classical free body stability analysis methods.

Local damage to the concrete shell is assessed using a formula developed in NSS 5-940.1 [18]. This formula predicts the depth of missile penetration and minimum concrete thickness requirements to prevent scabbing of the concrete.

The local shear strength of the concrete shell is evaluated on the basis of ACI 349-85, Section 11.11.2.1 [5], without considering the reinforcing steel and the steel liner. The concrete shell shear capacity is also evaluated for missile loading using ACI 349-85, Section 11.7.

Tornado Wind Loading

The tornado wind velocity is transformed into an effective pressure applied to the concrete cask using procedures in ANSI/ASCE 7-93, "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures" [17]. The maximum pressure (q) is determined from the maximum tornado wind velocity as follows:

$$q = (0.00256)(K \times I \times V)2 \text{ lb/ft}^2 = (0.00256)(360)2 \times 180 = 331.8 \text{ psf}$$

where:

V = 360 mph ---------- Maximum tornado wind speed
K = 1.0 ---------- Terrain effect
I = 1.0 ---------- Importance factor

Considering that the concrete cask is small with respect to the tornado radius, the velocity pressure is assumed uniform over the projected area of the concrete cask. Because the concrete cask is vented, the tornado-induced pressure drop is equalized from inside to outside and has no effect on the concrete cask structure. The bounding total wind loading (F_w) on the projected area of the concrete cask is computed as follows.

$$F_w = q \times G \times C_f \times A_p = 36{,}003 \text{ lb} \cong 36{,}100 \text{ lb}$$

where:

q = 331.8 lb/ft^2 ---------- Maximum pressure
C_f = 0.51 ---------- Force coefficient (ASCE 7-93)
A = $H \times D_o$ = 30,637 inch^2 = 212.7 ft^2 ---- Projected area
H = 225.27 inch ---------- Concrete cask height (CC1 and CC2)
D_o = 136.0 inch ---------- Concrete cask outer diameter
G = 1.0 ---------- Gust factor

The bounding wind overturning moment (M_w) is as follows.

$$M_w = F_w \times \frac{H}{2} = 4{,}066{,}123 \text{ inch-lb} = 3.38 \times 10^5 \text{ ft-lb}$$

The stability moment (M_s) of the concrete cask (with the TSC, basket and no fuel load) about the edge of the base is as follows.

$$M_s = W_{cc} \times r_o = 13.55 \times 10^6 \text{ inch-lb} = 1.129 \times 10^6 \text{ ft-lb}$$

where:

r_{ro} = 58.915 inch ---------- Concrete cask radius of rotation

W_{cc} = 230,000 lb ---------- Lower bound concrete cask loaded weight.

ASCE 7-93 requires that the overturning moment due to wind load shall not exceed two-thirds of the dead load stabilizing moment unless the structure is anchored. Therefore, the minimum factor of safety (FS) against overturning is as follows.

$$FS = \frac{0.67M_s}{M_w} = 2.24$$

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

$$\sigma_{outer} = \frac{M_{max}c_{outer}}{I} = 19.1 \text{ psi (tension or compression)}$$

$$\sigma_{inner} = \frac{M_{max}c_{inner}}{I} = 11.7 \text{ psi (tension or compression)}$$

where:

D_o = 136.0 inches
D_i = 82.98 inches
H = 225.27 inches

$$A = \frac{\pi\left(D_o^2 - D_i^2\right)}{4} = 9{,}119 \text{ inch}^2$$

$$I = \frac{\pi\left(D_o^4 - D_i^4\right)}{64} = 14.47\times10^6 \text{ inch}^4$$

$$M_{max} = \frac{F_w \times H}{2} = 4.07\times10^6 \text{ lb-inch}$$

c_{outer} = 136.0/2 = 68.0 inches
c_{inner} = 82.98/2 = 41.49 inches

Tornado Missiles

The concrete cask is designed to withstand the effects of impacts associated with postulated tornado-driven missiles identified in NUREG-0800 [16], Section 3.5.1.4.III.4, Spectrum I missiles. These missiles are listed as follows.

- A massive high kinetic-energy missile (4,000 lb automobile, with a frontal area of 20 square feet that deforms on impact).
- A 280 lb, 8.0-inch-diameter armor piercing artillery shell.
- A 1.0-inch-diameter solid steel sphere.

All of these missiles are assumed to impact in a manner that produces the maximum damage at a velocity of 126 mph (35% of the maximum tornado wind speed of 360 mph). The concrete cask is evaluated for impact effects associated with each of the previously listed missiles.

The concrete cask has no openings except for the four air outlets at the top and four air inlets at the bottom. The outlets are configured such that a one-inch diameter solid steel missile cannot directly enter the concrete cask interior. Additionally, the basket is protected by the TSC closure lid assembly. The TSC is protected from small missiles entering the inlets by the pedestal plate; therefore, a detailed analysis of the impact of a one-inch diameter steel missile is not required.

Concrete Shell Local Damage (Penetration Missile)

Local damage to the concrete cask body is assessed by using the methodology presented by NSS 5-940.1 [18]. This method predicts the depth of penetration and minimum concrete thickness requirements to prevent scabbing. Penetration depths calculated by using this formula have been shown to provide reasonable correlation with test results. The penetration depth is as follows.

$$x = \left[4KNW\left(d^{-0.8}\right)\left(\frac{V}{1000}\right)^{1.8}\right]^{0.5} = 5.82 \text{ inch}$$

where:

d	=	8.0 inch	Missile diameter
K	=	$180/(f_c')^{1/2} = 2.92$	Coeff. depending on concrete strength
N	=	1.14	Shape factor for sharp nosed missiles
W	=	280 lb	Missile weight
V	=	126 mph = 185 ft/sec	Missile velocity
f_c'	=	3,800 psi	Concrete compressive strength at conservative 300°F

The minimum concrete shell thickness to prevent scabbing is three times the penetration depth (17.46 inch). The minimum thickness of the concrete shell is 25.25 inches (CC3). The minimum factor of safety (FS) is as follows.

$$FS = \frac{25.25}{17.46} = 1.45$$

Note that the steel liner and rebar of the concrete cask is conservatively ignored in the previously listed evaluation.

Closure Plate Local Damage (Penetration Missile)

The concrete cask is closed with a carbon steel and concrete lid assembly of varying geometry and depths depending upon the specific concrete cask design. The top plate of all lid designs is ¾-inch thick carbon steel plate. Beneath the top plate is a carbon steel clad disk of concrete varying in geometry and depth based on the specific concrete cask design. In this evaluation, only the ¾-inch thick carbon steel top plate is considered to withstand the impact of the 280-lb armor-piercing missile, impacting at 126 mph. The perforation thickness (T) of the closure steel plate is calculated by using the methodology presented in BC-TOP-9A [19].

$$T = \frac{\left(m_m V_s^2 / 2\right)^{2/3}}{672D} = 0.52 \text{ inch}$$

where:

m_m = 280 lb/32.174 ft/sec^2 ---------- 8.70 slugs (lb-sec^2/ft) missile mass
V_s = 185 ft/sec ---------- Missile velocity
D = 8 inch ---------- Missile diameter

The report recommends that the plate thickness be 25% greater than the calculated perforation thickness (T) to prevent perforation. The recommended plate thickness is as follows.

$$T = 1.25 \times 0.52 = 0.65 \text{ inch}$$

The factor of safety (FS) is as follows.

$$FS = \frac{0.75}{0.65} = 1.15$$

High-Energy Missile Impact Damage Prediction

The concrete cask is a freestanding structure. Therefore, the principal consideration in overall damage response is the potential for overturning the concrete cask as a result of the high-energy missile impact. From the principle of conservation of momentum, the impulse of the force from the missile impact on the concrete cask must equal the change in angular momentum of the concrete cask. Also, the impulse force due to the impact of the missile must equal the change in linear momentum of the missile. These relationships may be expressed as follows:

Change in momentum of the missile, during the deformation phase

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

where:

F ---------- Impact impulse force on missile

m_m = 4,000 lb/g = 124 slugs/12 = 10.4 (lb sec^2 /inch)
---------- Missile mass
t_1 ---------- Time at missile impact
t_2 ---------- Time at conclusion of deformation phase
v_1 = 126 mph = 185 ft/sec ---------- Missile velocity at impact
v_2 ---------- Velocity of missile at time t_2

The change in angular momentum of the concrete cask, about the bottom outside edge/rim, opposite the side of impact is as follows.

$$\int_{t_1}^{t_2} M_c(dt) = \int_{t_1}^{t_2} (H)(F)(dt) = I_m(\omega_1 - \omega_2)$$

Substituting,

$$\int (F)(dt) = m_m(v_2 - v_1) = \frac{I_m(\omega_1 - \omega_2)}{H}$$

where:

M_c ---------- Moment of the impact force on the concrete cask
I_m ---------- Concrete cask mass moment of inertia, about point of rotation on the bottom rim
ω_1 ---------- Angular velocity at time t_1
ω_2 ---------- Angular velocity at time t_2
m_c = 230,000/32.174 = 7,149 slugs/12 = 596 lb sec^2 /inch
---------- Mass of concrete cask
I_{mx} = $1/12(m_c)(3r^2 + H^2)$ = 3.21×10^6 lb-sec^2-inch
I_m = $I_{mx} + (m_c)(d_{CG})^2$ = 12.75×10^6 lb-sec^2-inch
r = 68.0 inches ---------- Concrete cask radius
r_{ro} = 58.915 inches ---------- Concrete cask radius of rotation
H = 225.27 inches ---------- Concrete cask height
d_{CG} = $\sqrt{112^2 + 58.915^2}$ = 126.55 inches ---- Distance from CG to rotation point

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

$m_m(v_2 - v_1) = I_m(\omega_1 - \omega_2)/H$
at time t_1, v_1 = 185 ft/sec and ω_1 = 0 rad/sec
at time t_2, v_2 = 0 ft/sec

During the restitution phase, the final velocity of the missile depends upon the coefficient of restitution of the missile, the geometry of the missile and target, the angle of incidence, and on the amount of energy dissipated in deforming the missile and target. On the basis of tests conducted by EPRI, the final velocity (v_f) of the missile following the impact is assumed to be zero. This conservatively assumes that all of the missile energy is transferred to the concrete

cask. Equating the impact force on the missile to the impulse force on the concrete cask yields the following.

$$(10.4)(v_2 - 185(12)) = 12.75\times10^6\ (0 - \omega_2)/225.27$$

Setting $v_2 = 0$ and solving for ω_2

$$\omega_2 = 0.408 \text{ rad/sec}$$

The distance (Z) from the point of missile impact to the point of concrete cask rotation is as follows.

$$Z = \sqrt{126.9^2 + 225.27^2} = 258.6 \text{ inch}$$

And the impulse velocity is as follows.

$$v_2 = Z \times \omega_2 = (258.6)(0.408) = 105.5 \text{ inch/sec}$$

The line of missile impact is conservatively assumed normal to the concrete cask. Equating the force on the missile during restitution to the impulse of the force on the concrete cask yields the following.

$$-[m_m(v_f - v_2] = I_m\ (\omega_f - \omega_2)/Z$$

$$-[10.4(0 - 105.5)] = 12.75\times10^6(\omega_f - 0.408)/258.6$$

$$\omega_f = 0.430 \text{ rad/sec}$$

where:

v_f = 0
v_2 = 105.5 inch/sec
ω_2 = 0.408 rad/sec

Thus, the final energy (E_k) of the concrete cask following the impact is as follows.

$$E_k = (I_m)(\omega_f)^2/(2) = 1.179\times10^5 \text{ inch-lb}$$

The change in potential energy (E_p) of the concrete cask due to rotating it until its center of gravity is above the point of rotation is calculated. The height of the center of gravity has increased by the distance, $h_{PE} = d_{cg} - h_{cg}$.

$$E_p = (W_{cc})(h_{PE})$$

$$E_p = 230{,}000 \text{ lb}\times14.55 \text{ inch}$$

$$E_p = 3.347\times10^6 \text{ inch-lb}$$

The massive high kinetic-energy tornado-driven missile imparts less kinetic energy to the concrete cask than the change in potential energy of the concrete cask to reach the tip-over point. Therefore, concrete cask overturning from missile impact will not occur. The factor of safety (FS) against overturning is as follows.

$$FS = \frac{3.347 \times 10^6}{1.179 \times 10^6} = 2.84$$

Combined Tornado Wind and Missile Loading (High-Energy Missile)

The concrete cask rotation due to the heavy missile impact is as follows.

$$h_{KE} = \frac{E_k}{W_{CC}} = \frac{1.179 \times 10^6}{230{,}000} = 5.13 \text{ inch}$$

The rotation after impact is as follows.

$$\theta = \alpha - \beta = 27.75 - 22.24 = 5.51°$$

where:

$$\cos\beta = \frac{h_{cg} + h_{KE}}{d_{cg}} = \frac{112 + 5.13}{126.55} = 0.9256$$

$$\beta = 22.24°$$

$$\cos\alpha = \frac{h_{cg}}{d_{cg}} = \frac{112}{126.55} = 0.8850$$

$$\alpha = 27.75°$$

$$e = d_{cg} \sin\beta = 134.2 \times \sin(22.24°) = 47.9 \text{ inch}$$

The available gravity restoration moment after missile impact is as follows.

$$M_{rst} = W_{cc}e = 230{,}000 \times 47.9 = 11.0 \times 10^6 \text{ inch-lb} = 9.18 \times 10^5 \text{ ft-lb}$$

The tornado wind moment is 3.38×10^5 ft-lb; therefore, the factor of safety (FS) is as follows.

$$FS = \frac{0.67(9.18 \times 10^5)}{3.38 \times 10^5} = 1.82$$

Therefore, the concrete cask will not overturn due to the combined effect of tornado wind loading and high-energy missile impact.

Local Shear Strength Capacity of Concrete Shell (High-Energy Missile)

This section evaluates the punching shear strength of the concrete shell when impacted by a high-energy missile. The high-energy missile is equivalent to a 20-ft^2 cross-sectional area object moving at 185 ft/sec, weighing 4,000 lb, having proportions of 2 horizontal to 1 vertical. The missile is assumed to impact flush with the top of the concrete shell. The concrete area required to resist the high-energy missile impact is conservatively calculated based on the concrete cask configuration with the thinnest concrete shell (CC3) as follows.

$$A = 2b \times b = 2(11.41)^2 = 260.4 \text{ inch}^2 = 1.8 \text{ ft}^2 < 20 \text{ ft}^2$$

where:

Setting the factored shear force, V_u, equal to the force of the high kinetic-energy missile, F_u, the leg dimension, b, of the equivalent impacting area is as follows.

$$V_u = F_u \Rightarrow \phi V_c = F_u \Rightarrow \phi 4\sqrt{f_c'}\, b_o d = F_u \Rightarrow \phi 4\sqrt{f_c'}\,(4b + 50.5)d \Rightarrow b = 11.41 \text{ inch}$$

and

$$V_c = \left(2 + \frac{4}{\beta_c}\right)\sqrt{f_c'}\,(b_o d) = 4\sqrt{f_c'}\,(b_o d)$$ ------- Concrete punching shear strength capacity [5, Eq. 11-36]

β_c = 2/1 = 2 ---------- Ratio of long side to short side
d = 25.25 inch ---------- Concrete thickness
f_c' = 3,800 psi ---------- Concrete strength, 300°F
b_o = (2b+d) + 2(b+d/2) = 4b + 50.5 -------- Perimeter of punching shear area at approximately d/2 from the missile contact area
ϕ = 0.85 ---------- Strength reduction factor [5]
F_u = LF × F = 508.8 kip ---------- Force of high kinetic energy missile with load factor [19]
F = 0.625(v)(W_m) = 462.5 kip ---------- Force of high-energy missile [19]
v = 185 ft/sec ---------- Velocity of the missile
W_m = 4,000 lb ---------- Weight of high-energy missile
LF = 1.1 ---------- 10% load factor

Therefore, the concrete shell alone has sufficient capacity to resist the high-energy missile impact force.

3.7.3.3 Flood

This section will verify the stability of the concrete cask against overturning during a design basis flood accident, and ensure that the design is adequate to withstand stresses induced by the flood.

Overturning of the concrete cask due to the drag force of the flood water flow is resisted by the weight of the loaded cask. Assuming a full submersion and steady-state flow conditions, the drag force (F_D) on the concrete cask is calculated using classical fluid mechanics for turbulent flow conditions. The resultant drag force acts horizontally through the CG of the cask. The effective weight of the concrete cask acts vertically downward through the CG. The tendency of the concrete cask to overturn is determined by comparing the moment of the drag force about a point on the bottom edge of the concrete cask to the moment of effective concrete cask weight about the same point.

The effective weight of the fully submerged concrete cask is the actual weight minus the buoyancy force due to the displaced water. The bounding condition for buoyancy occurs for the concrete cask configuration with the greatest volume to weight ratio. Thus, for conservatism, the concrete cask is assumed to be empty.

The capacity of the concrete cask to react to the stresses induced by the flood water flow drag forces is evaluated using the methodology described in ACI 349-85 [5]. For conservatism, only the concrete shell is considered.

Assuming a hollow cylinder, the volume of the concrete cask (V_{cc}) is as follows.

$$V_{cc} = \frac{\pi}{4}\left(D_o^{\,2} - D_i^{\,2}\right)h = \frac{\pi}{4}\left(136.0^2 - 79.48^2\right)225.27 = 2{,}154{,}777 \text{ inch}^3$$

where:

D_o = 136.0 inches ---------- Concrete cask outer diameter
D_i = 79.48 inches ---------- Concrete cask inner diameter
h = 225.27 inches ---------- Concrete cask height

The buoyancy force (F_b) is equal to the weight of water (62.4 lb/ft^3) displaced by the fully submerged concrete cask.

$$F_b = \frac{V_{cc}}{12^3} W_{h20} = \frac{2{,}154{,}777}{12^3} 62.4 \approx 77{,}800 \text{ lb}$$

Assuming complete submersion and steady-state flow for a rigid cylinder, the drag force (F_{D15}) of the water on the concrete cask is as follows.

$$F_{D15} = C_D \rho V^2 \left(\frac{A}{2}\right) = 0.7 \times 1.94 \times 15.0^2 \left(\frac{212.7}{2}\right) \approx 32{,}500 \text{ lb} \qquad [20]$$

where:

C_D = 0.7 ---------- Drag coefficient [20]
ρ = 1.94 slugs/ft^3 ---------- Density of water
V = 15 ft/sec ---------- Flow velocity
A = H × D_o = 30,637 inch^2 = 212.7 ft^2 ---- Projected area
H = 225.27 inches ---------- Concrete cask height
D_o = 136.0 inches ---------- Concrete cask outer diameter

The force (F_D) required to overturn the concrete cask is determined by summing the moments of the drag force and the submerged concrete cask about a point on the bottom of the concrete cask. Assuming an empty concrete cask, the minimum required overturning force is as follows.

$$F_D = \frac{(W_{CC} - F_b) r_{ro}}{h/2} = \frac{(200{,}000 - 77{,}800)58.915}{225.27/2} = 63{,}918 \text{ lb}$$

where:

W_{cc} = 200,000 lb ---------- Conservatively defined minimum empty concrete cask weight
r_{ro} = 58.915 inches ---------- Concrete cask rotation radius
h = 225.27 inches ---------- Concrete cask height

The water velocity (V) required to overturn the concrete cask is as follows.

$$V = \sqrt{\frac{2F_D}{C_D \rho A}} = \sqrt{\frac{2 \times 63{,}918}{0.7 \times 1.94 \times 212.7}} = 21.0 \text{ ft/sec}$$

Therefore, the factor of safety (FS) is as follows.

$$FS = \frac{21.0}{15.0} = 1.4$$

The stresses in the concrete due to the drag force (F_D) are conservatively calculated by considering the concrete cask to be fixed.

$\sigma_{v\ outer}$ = M / S_{outer} = 17.2 psi (tension or compression)

$\sigma_{v\ inner}$ = M / S_{inner} = 10.5 psi (tension or compression)

where:

D_o = 136.0 inches

D_i = 82.98 inches
h = 225.27 inchs
A = $\pi (D_o^2 - D_i^2) / 4 = 9{,}119$ inch^2
I = $\pi (D_o^4 - D_i^4) / 64 = 14.47 \times 10^6$ inch^4
S_{outer} = $2I/D_o = 212{,}794$ inch^3
S_{inner} = $2I/(D_i) = 348{,}759$ inch^3
w = $F_{D15}/h = 144.3$ lb/inch
M = w (h)2 / 2 = 3.66 × 106 inch-lb

3.7.3.4 Earthquake

The maximum horizontal acceleration at the surface of the concrete storage pad due to an earthquake is evaluated. Per 10 CFR 72.102 [1], the required minimum earthquake ground acceleration is 0.25g. This evaluation will show that MAGNASTOR is stable during a 0.37g earthquake horizontal acceleration (including a 1.1 factor of safety). The vertical acceleration is defined as two-thirds of the horizontal acceleration in accordance with ASCE 4-86 [21].

This calculation determines the effects of ground accelerations (components a_x, a_y and a_z) on the concrete cask for tip-over. The peak ground acceleration is associated with a safe shutdown earthquake. For this evaluation, the maximum overturning moment is compared to the restoring moment required to keep the concrete cask in a stable upright position (i.e., a concrete cask will not tip over due to the earthquake). The maximum ground accelerations and overturning/ restoring forces and moment are calculated for both empty and fully loaded concrete cask configurations.

In the event of earthquake, there exists a base shear force or overturning force due to the horizontal ground acceleration, and a restoring force due to the net force of vertical ground acceleration and gravity. This ground motion tends to rotate the concrete cask about its bottom corner at the point of rotation (at the chamfer). The horizontal moment arm is from the center of gravity (CG) toward the outer radius of the concrete cask. The vertical moment arm is from the CG to the bottom of the concrete cask. If the overturning moment is greater than the restoring moment, the concrete cask may tip over. Using the geometry of the concrete cask design, the maximum horizontal and vertical ground accelerations that the concrete cask can safely withstand without becoming unstable are identified.

The two orthogonal horizontal acceleration components (a_x and a_z) are combined for maximum horizontal acceleration magnitude. The result is applied simultaneously with the vertical component to statically evaluate the overturning force and moment. Upward ground acceleration reduces the vertical force that restores the cask to its undisturbed vertical position. Based upon the requirements presented in NUREG-0800 [16], the static analysis method is considered

applicable if the natural frequency of the structure is greater than 33 cps. The natural frequency of the MAGNASTOR concrete cask is 138 Hz for CC1 and CC2, which bounds the natural frequency of CC4, and 127 Hz for CC3. During the design basis earthquake event, a factor of safety of 1.1 against tip-over of the concrete cask must be maintained.

Tip-Over Evaluation

To maintain the concrete cask in equilibrium, the restoring moment, M_R, must be greater than, or equal to, the overturning moment, M_o. The combination of horizontal and vertical acceleration components is based on the 100-40-40 approach of ASCE 4-86 [21], which considers that when the maximum response from one component occurs, the responses from the other two components are 40% of the maximum. The vertical component of acceleration can be obtained by scaling the corresponding ordinates of the horizontal components by two-thirds. The vertical component is conservatively considered to be the same as the horizontal component.

Let:

$a_x = a_z = a$ ---------- Horizontal acceleration components
$a_y = a$ ---------- Vertical acceleration component
G_h ---------- Vector sum of two horizontal acceleration components
G_v ---------- Vertical acceleration component

Two cases are analyzed:

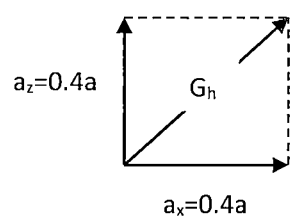
Case 1) The vertical acceleration, a_y, is at its peak:

($a_y = 1.0a$, $a_x = 0.4a$, and $a_z = 0.4a$)

$G_h =$

$$\sqrt{a_x^2 + a_z^2} = \sqrt{(0.4a)^2 + (0.4a)^2} = 0.566a$$

$G_v =$ $1.0a_y = 1.0a$



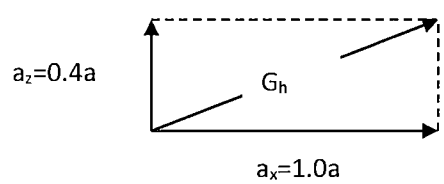
Case 2) One horizontal acceleration, a_x, is at its peak:

($a_y = 0.4 \times a$, $a_x = a$, and $a_z = 0.4a$)

$G_h =$

$$\sqrt{a_x^2 + a_z^2} = \sqrt{(1.0a)^2 + (0.4a)^2} = 1.077a$$

$G_v =$ $0.4a_y = 0.4a$



For the cask to resist overturning, the restoring moment (M_R) about the point of rotation must be greater than the overturning moment (M_o).

$M_R \geq M_O$, or $F_r b \geq F_o d \Rightarrow (W \times 1 - W \times Gv) \times b \geq (W \times Gh) \times d$

d	----------	Vertical distance measured from the base of the concrete cask to the center of gravity
b	----------	Horizontal distance measured from the point of rotation to the C.G.
W	----------	Weight of the concrete cask
F_o	----------	Overturning force
F_r	----------	Restoring force

Substituting for G_y and G_x gives:

Case 1

$$(1-a)\frac{b}{d} \geq 0.566a$$

$$a \leq \frac{b/d}{0.566 + b/d}$$

Case 2

$$(1-0.4a)\frac{b}{d} \geq 1.077a$$

$$a \leq \frac{b/d}{1.077 + 0.4\, b/d}$$

Empty concrete cask:

Case 1

$$a \leq \frac{58.92/113}{0.566 + 58.9/113} = 0.479$$

Case 2

$$a \leq \frac{58.92/113}{1.077 + 0.4\,(58.9/113)} = 0.406$$

where:

b = 58.92 inch
d = 113 inch

Loaded concrete cask:

Case 1

$$a \leq \frac{58.69/113}{0.566 + 58.69/113} = 0.479$$

Case 2

$$a \leq \frac{58.69/113}{1.077 + 0.4\,(58.69/113)} = 0.404$$

where:

d = 113 inch
b = 58.92 – x = 58.92 – 0.23 = 58.69 inches

$$e = \frac{73.44 - 72.0}{2} = 0.72 \text{ inch} \text{ ---------- TSC CG shift}$$

$$x = \frac{W_{can} e}{W_{CC}} = \frac{105{,}500 \times 0.72}{324{,}500} = 0.23 \text{ inch -- Loaded concrete cask CG shift}$$

The minimum acceleration is 0.404g. A factor of safety of 1.1 is required for an earthquake evaluation; therefore, the maximum allowable horizontal acceleration (a_{max}) at the top of the concrete pad that will preclude a cask tip-over is as follows.

$$a_{max} = \frac{0.404}{1.1} = 0.37g$$

Concrete Cask Stress

To demonstrate the ability of the concrete cask to withstand earthquake loading conditions, the fully loaded cask is conservatively evaluated for seismic loads of 0.5g in the horizontal and 0.5g in the vertical direction. These accelerations reflect a more rigorous seismic loading and, therefore, bound the design basis earthquake. No credit is taken for the concrete cask steel liner. The highest concrete compressive stresses due to the design basis seismic load are shown to occur in the CC3 concrete cask. Although CC3 is the shortest concrete cask, it is the heaviest configuration and its concrete shell has a larger inside diameter than the other concrete cask configurations and, thus, the lowest section modulus.

The maximum compressive stresses at the concrete shell outer and inner surfaces are conservatively calculated by considering the cask as a cantilever beam with its bottom end fixed. The maximum compressive stresses are as follows.

$$\sigma_{v\ outer} = \frac{M}{S_{outer}} + \frac{(1 + a_y)W_{CC}}{A} = 147 \text{ psi}$$

$$\sigma_{v\ inner} = \frac{M}{S_{inner}} + \frac{(1 + a_y)W_{CC}}{A} = 114 \text{ psi}$$

where

a_x = 0.50g ---------- Horizontal direction
a_y = 0.50g ---------- Vertical direction
W_{cc} = 340,000 lb ---------- Bounding weight of concrete cask
D_o = 136.0 inches
D_i = 85.5 inches
A = $\pi (D_o^2 - D_i^2) / 4 = 8{,}785 \text{ inch}^2$
I = $\pi (D_o^4 - D_i^4) / 64 = 14.17 \times 10^6 \text{ inch}^4$

S_{outer} = $2I/D_o$ = 208,382 inch^3
S_{inner} = $2I/(D_i)$ = 331,461 inch^3
w = $(a_x \times W_{cc}) / 218.3$ = 778.7 lb-inch
M = $(w \times 218.3^2)/2 = 1.855 \times 10^7$ lb-inch

3.7.3.5 Concrete Cask Combined Stresses

The load combinations described in Table 2.3-1 are used to evaluate the concrete cask for accident events of storage. The bounding stresses for all storage cask configurations are summarized in Table 3.7.3-1 and Table 3.7.3-2 for the loading combination Nos. 4, 5, 7, and 8. Loading combination No. 6 corresponds to drop accidents, 24-inch end drop and tip-over, which are evaluated in Section 3.7.3.6 and Section 3.7.3.7, respectively.

As shown in Table 3.7.3-1, the maximum concrete compressive stress is 1,801 psi; therefore, the minimum compressive factor of safety (FS) for accident events is as follows.

$$FS = \frac{S_{con}}{S_c} = \frac{2{,}660}{1{,}801} = 1.48$$

where:

$S_{con} = \phi F_c = 0.7 \times 3{,}800 = 2{,}660$ psi---------- Concrete compressive allowable

From Section 3.7.3.1, the maximum tensile stress in the concrete due to the accident thermal load is 0.138 ksi. The factor of safety (FS) for concrete tensile stress is as follows.

$$FS = \frac{S_{tc}}{S_t} = \frac{0.213}{0.138} = 1.54$$

where:

$S_{tc} = 0.08 \times S_{con} = 0.08 \times 2660 = 213$ psi or 0.213 ksi..... Concrete ultimate strength

From Section 3.7.3.1, the maximum rebar tensile stress (S_{rb}) due to accident thermal load is 22.7 ksi. The factor of safety (FS) for the rebar tensile stress is as follows.

$$FS = \frac{S_{rebar}}{S_{rb}} = \frac{54.0}{22.7} = 2.38$$

where:

$S_{rebar} = \phi F_r = 0.9 \times 60.0 = 54.0$ ksi---------- Rebar stress allowable

3.7.3.6 Concrete Cask 24-inch Drop

Evaluation of the Concrete Cask

During the 24-inch bottom-end drop of the concrete cask, the cylindrical portion of the concrete is in contact with the steel bottom plate that is a part of the base weldment. The plate is assumed to be part of an infinitely rigid storage pad. No credit is taken for the crush properties of the storage pad or the underlying soil layer. Therefore, energy absorbed by the crushing of the cylindrical concrete region of the concrete cask equals the product of the compressive strength of the concrete, the crush depth of the concrete, and the projected area of the concrete cylinder. Crushing of the concrete continues until the energy absorbed equals the potential energy of the cask at the initial drop height. The TSC is not rigidly attached to the concrete cask, so it is not considered to contribute to the concrete crushing. The energy balance equation is as follows.

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

where:

h	=	24.0 inches	Drop height
δ			The crush depth of the concrete cask
P_o	=	3,800 psi	Compressive strength of the concrete, 300°F
A	=	$\pi(R_2^2 - R_1^2) = 9{,}119$ inch^2	Area of the concrete shield wall
R_1	=	41.49 inches	Inside radius of the concrete
R_2	=	68 inches	Outside radius of the concrete
w	=	185,000 lb	Bounding weight of concrete, rebar, and lid assembly

It is assumed that the maximum force that can be exerted on the concrete cask is the compressive strength of the concrete multiplied by the area of the concrete being crushed. The concrete cask's steel shell will not experience any significant damage during a 24-inch drop. Therefore, its functionality will not be impaired due to the drop.

The crush distance computed from the energy balance equation is as follows.

$$\delta = \frac{hw}{P_o A - w} = \frac{(24)(185{,}000)}{(3800)(9{,}119)-(185{,}000)} = 0.13 \text{ inch}$$

Pedestal Crush Evaluation

Upon a bottom-end impact of the concrete cask, the TSC produces a force on the pedestal (base weldment) located near the bottom of the cask. The ring above the air inlets is expected to yield. To determine the resulting acceleration of the TSC and deformation of the pedestal, a LS-DYNA analysis is used. As described in Section 3.10.4.3, a quarter-symmetry finite element model of the pedestal is used for this evaluation. To ensure that maximum deformations and accelerations are determined, two analyses are performed. One analysis, which uses the upper-bound weight

of 105 kips, envelops the maximum deformation of the pedestal. The second analysis employs the lower-bound weight of 60 kips to account for maximum acceleration.

The maximum accelerations of the TSC during the 24-inch bottom-end impact are calculated to be 14.5g and 25.2g for the upper-bound weight TSC and lower-bound weight TSC, respectively. The resulting acceleration time histories of the TSC, which correspond to a filter frequency of 200 Hz, are shown in Figure 3.7.3-1 for the analysis using the upper-bound weight model and Figure 3.7.3-2 for the lower-bound weight model. The dynamic load factor (DLF) for the TSC is calculated to be 1.35 for the upper-bound weight TSC and 0.95 (consider 1.0) for the lower-bound weight TSC, based on the response of one-degree systems subjected to a triangular load pulse [22]. Therefore, the accelerations for the upper-bound weight and lower-bound weight TSC are 19.6g and 25.2g, respectively.

The maximum strain in the pedestal is 15.4%. Since the ultimate strain of A36 steel is greater than 25%, the pedestal is not subject to failure. The maximum vertical displacement of the air inlet is calculated to be 1.46 inches for the upper-bound and lower-bound weight TSC. The original opening is 4.4 inches. Since the maximum displacement is 1.46 inches, the minimum air inlet opening is 2.9 inches (4.4 – 1.16), which is approximately 66% of the original air inlet opening. This condition is bounded by the consequences of the loss of one-half of the air inlets off-normal event.

3.7.3.7 Concrete Cask Tip-Over

Tip-over of the concrete cask is a nonmechanistic, hypothetical accident condition that presents a bounding case for evaluation. Existing postulated design basis accidents do not result in the tip-over of the concrete cask. Functionally, the concrete cask does not suffer significant adverse consequences due to this event. The concrete cask, TSC, and basket maintain design basis shielding, geometry control of contents, and contents confinement performance requirements.

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

The MAGNASTOR concrete cask tip-over analyses are performed using LS-DYNA. LS-DYNA is an explicit finite element program for the nonlinear dynamic analysis of structures in three dimensions. Details of the finite element model are presented in Section 3.10.4.

Two geometries are considered in this evaluation. The pad width of 30 ft in the models corresponds to the typical width of a concrete storage pad. One model considers a pad length of 30 ft, while the second model referred to as the "oversized pad," employs a length of 60 feet. The second model allows the effect of the pad length used in the analysis to be assessed.

The acceleration time histories for the TSC and basket for the standard and oversized pad cases are shown in Figure 3.7.3-3 and Figure 3.7.3-4. A cut-off frequency of 200 Hz is applied to filter the analysis results and measure the peak accelerations. The following is a summary of the peak accelerations.

Location	Position from Base of Concrete Cask (in)	Acceleration Standard Pad (g)	Acceleration Oversized Pad (g)
Top of basket	177.7	26.4	26.6
Top of TSC closure lid	197.6	29.5	29.6

Using two-dimensional models of the PWR and BWR basket (similar to the models described in Sections 3.10.1 and 3.10.2, meshing density modified for modal analysis), the modal frequencies for the basket are calculated. Table 3.7.3-3 summarized the frequencies for the first mode shape for the PWR and BWR baskets in the 0° and 45° basket orientations. The dynamic load factors are determined using the response of one-degree systems subjected to a triangular load pulse [22]. The dynamic load factors and the maximum accelerations at the top of the TSC and top of the basket are summarized in Table 3.7.3-4. As the table and figures show, maximum accelerations are less than the specified design value of 40g. The acceleration results indicate that even with a 100% increase in the pad length, the resulting change in the maximum accelerations is less than 1 percent. This demonstrates that the effect of the pad size employed in the analysis has an insignificant effect on the maximum accelerations.

Figure 3.7.3-1 Acceleration Time History of the Upper-Bound Weight TSC – 24-Inch Concrete Cask Drop

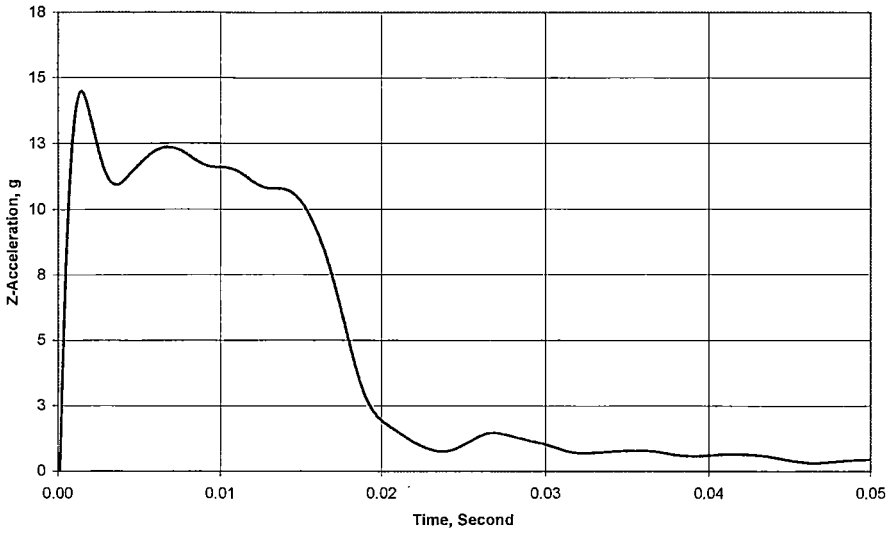


Figure 3.7.3-2 Acceleration Time History of the Lower-Bound Weight TSC – 24-Inch Concrete Cask Drop

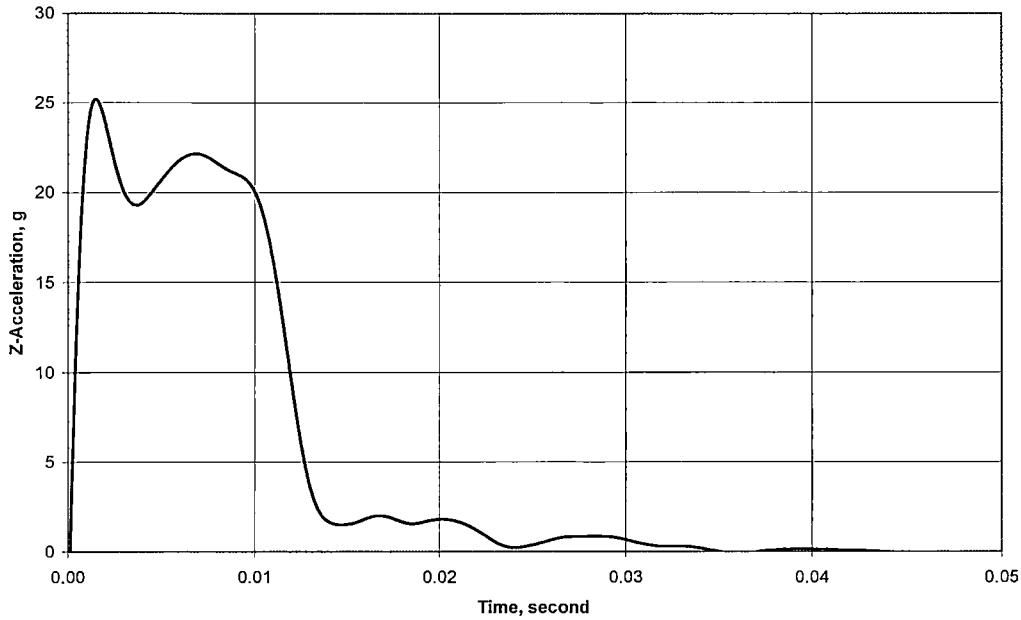


Figure 3.7.3-3 Acceleration Time History for Concrete Cask Tip-Over Condition - Standard Pad

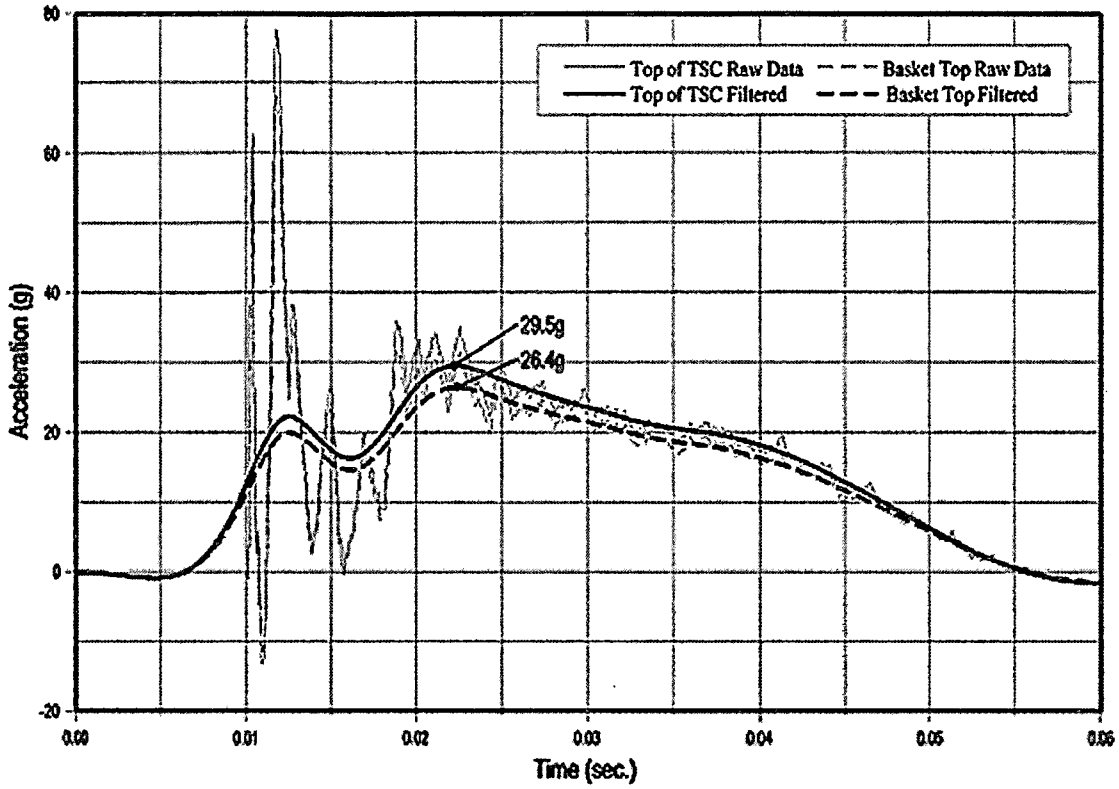


Figure 3.7.3-4 Acceleration Time History of Oversized Pad

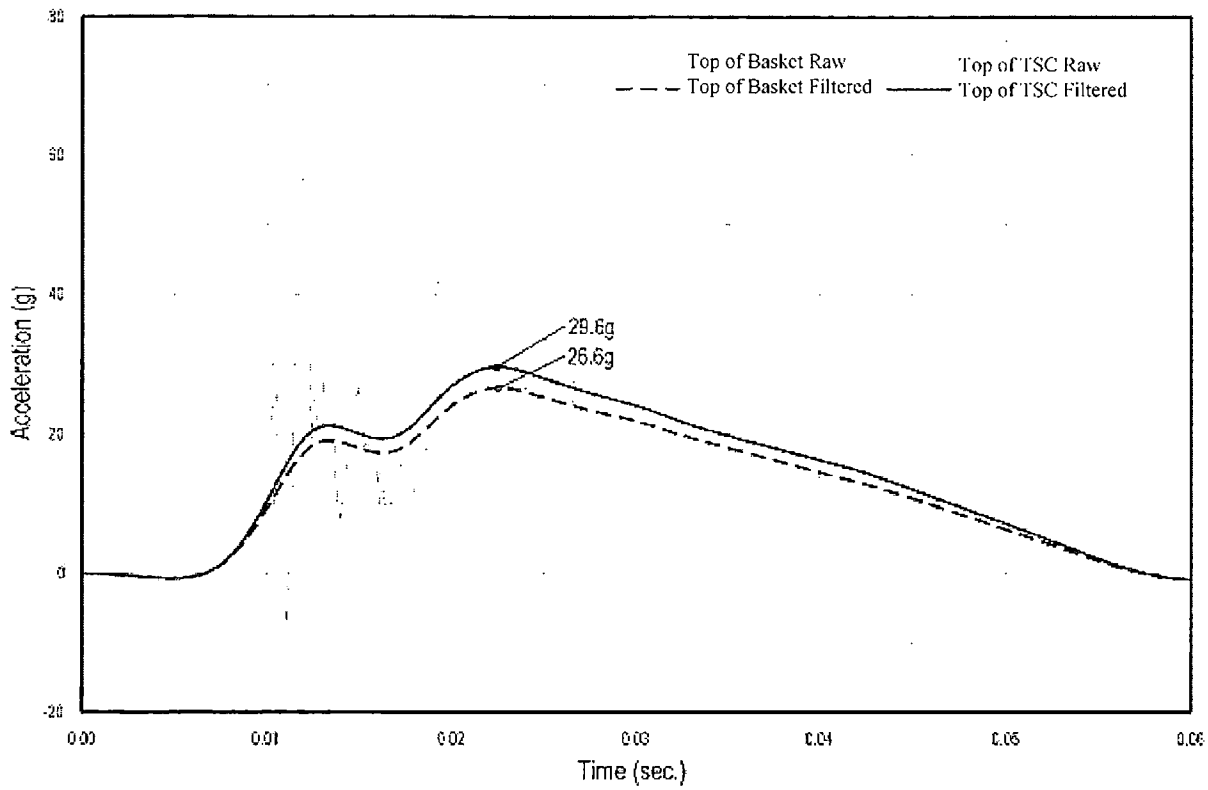


Table 3.7.3-1 Concrete Cask Vertical Stress Summary – Inner Surface, psi

Condition	Dead	Live	Wind	Thermal	Seismic	Flood	Tornado	Total
4	-28	-26	0	-1626	0	0	0	-1680
5	-28	-26	0	-1633	-114	0	0	-1801
7	-28	-26	0	-1633	0	-11	0	-1698
8	-28	-26	0	-1633	0	0	-12	-1699

Table 3.7.3-2 Concrete Cask Circumferential Stress Summary – Inner Surface, psi

Condition	Dead	Live	Wind	Thermal	Seismic	Flood	Tornado	Total
4	0	0	0	-1626	0	0	0	-1626
5	0	0	0	-1633	0	0	0	-1633
7	0	0	0	-1633	0	0	0	-1633
8	0	0	0	-1633	0	0	0	-1633

Table 3.7.3-3 Basket Modal Frequency for Concrete Cask Tip-over

Fuel Type and Basket Angle	Frequency (F), Hz
PWR-0°	269
PWR-45°	33
BWR-0°	140
BWR-45°	39

Table 3.7.3-4 DLF and Amplified Accelerations for Concrete Cask Tip-over

Fuel Type and Basket Angle	Top of TSC Lid			Top of Fuel Basket		
	Base Acceleration, g	DLF	Amplified Acceleration, g	Base Acceleration, g	DLF	Amplified Acceleration, g
PWR-0°	29.6	1.0	29.6	26.6	1.01	26.9
PWR-45°	29.6	1.0	29.6	26.6	1.21	32.2
BWR-0°	29.6	1.0	29.6	26.6	1.02	27.1
BWR-45°	29.6	1.0	29.6	26.6	1.07	28.5

3.8 Fuel Rods

This section presents an evaluation of the PWR and BWR fuel rods for the storage conditions of the MAGNASTOR system.

3.8.1 PWR Fuel Rod Buckling Evaluation

This section presents the buckling evaluation for MAGNASTOR high burnup PWR fuel (burnup greater than 45,000 MWd/MTU) having cladding oxide layers that are 80 and 120 microns thick. A reduced cladding thickness is assumed due to the cladding oxide layer. These analyses show that the maximum stresses in the high burnup PWR fuel remain below the yield strength in the design basis accident events and confirm that the fuel rods will return to their original configuration. A 24-inch end drop orientation of the concrete cask subjects the fuel rods to axial loading. The 24-inch drop evaluation employs two acceleration time histories. The 24-inch concrete cask end drop described in Section 3.10.4.3 resulted in the acceleration time history shown in Figure 3.7.3-2. The maximum acceleration for the time history shown in Figure 3.7.3-2 is 25.3g's (the strong segment of the pulse lasts for 0.015 second). A bounding triangular-shaped time history with a maximum acceleration of 45g's for a duration of 0.02 second is also used.

In the end drop orientation, the fuel rods are laterally restrained by the grids and come into contact with the fuel assembly base. The only vertical constraint for the fuel rod is the base of the assembly. As opposed to employing a straight fuel assembly in the evaluation with all the grids present, the fuel assembly is considered to be bowed, and a fuel assembly grid may be missing and still meet the acceptable configuration for undamaged fuel. The evaluation of the PWR fuel rods is based on the following representative samples.

Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)	Fuel Rod Pitch (in)	Gap Between Fuel Assembly and Fuel Tube Wall (in)
We 17×17	0.360	0.021	0.496	0.564
We 15×15	0.417	0.024	0.563	0.561
We 14×14	0.400	0.022	0.556	1.232
CE16×16	0.382	0.025	0.506	0.888
CE14×14	0.440	0.031	0.580	0.880
BW17×17	0.377	0.022	0.502	0.451
BW15×15	0.414	0.022	0.568	0.494

Review of the design basis fuel inventory indicates that the largest gap between the enveloping of the fuel rods of a straight fuel assembly and the basket fuel tube inner wall could be 1.23 inches, corresponding to a 14×14 rod array having a minimum rod pitch of 0.556 inch and a minimum rod diameter of 0.40 inch inside a maximum basket fuel cell with an inside dimension of 8.86 inches. In this evaluation, an assembly with an initial bow of 0.55 inch is permitted to displace an additional 0.68 inch to the full gap displacement of 1.23 inches. A PWR 17×17 fuel assembly with a bow of 0.55 inch (less than the gap of 0.564 inch, as shown in the preceding table) can still fit into a MAGNASTOR basket fuel tube. To implement a bow of 0.55 inch into the fuel assembly, the half-symmetry ANSYS model corresponding to a row of fuel rods (Figure 3.8.1-1) is used. The clad is modeled with shell elements (Figure 3.8.1-2). Each grid is modeled using brick elements to maintain the spacing between the fuel rods at the grid (Figure 3.8.1-2). The fuel tube is modeled using brick elements to restrict the lateral motion of the fuel assembly. Each of the fuel rods in the ANSYS model is simply supported at each end. A static force is applied to the ANSYS model at the grid nearest the axial center to develop a 0.55-inch lateral displacement. The purpose of the ANSYS model and solution is to provide the coordinates of the fuel clad for the LS-DYNA model. This is accomplished by obtaining a static solution with the ANSYS model, and then using the option to update the coordinates of the nodes based on the displacements from the solution.

Five LS-DYNA models are considered for the 24-inch cask end drop conditions. All models incorporate a bow of 0.55 inch. These cases envelop the range of the cross-sectional moments for the PWR fuel rods and the grid spacing at the bottom of the fuel assembly as summarized in the following table. Case 5 is used to confirm that the acceleration associated with the 24-inch end drop of the MAGNASTOR System provides bounding stresses.

Case	Fuel Assembly	Lowest Grid Spacing (inch)	Acceleration Definition
1	14×14	60*	45g
2	14×14	33	45g
3	17×17	60*	45g
4	17×17	33	45g
5	17×17	60*	25.3g

* The 60-inch spacing corresponds to the fuel rod configuration with two missing grids at the bottom of the fuel assembly.

In all cases, the thickness of the clad was reduced by 120 microns (0.0047 inch). Cases 1 through 4 require a separate ANSYS model and LS-DYNA model to represent unique coordinates or boundary conditions (geometry of Case 5 is the same as for Case 3). The LS-DYNA model employs the same nodes and elements as the ANSYS model (with the incorporation of the 0.55-inch bow). Elastic properties are used in the ANSYS model and the bilinear properties are employed in the LS-DYNA model. An initial downward velocity of 136 in/sec (corresponding to a 24-inch end drop for the storage condition) is assigned to all nodes in the model. The deceleration time history is applied to the nodes of the brick elements representing the fuel tube. The side walls of the fuel tube are restrained in the lateral direction to maximize the effect of the fuel rods impacting the fuel tube side wall.

The LS-DYNA analyses for Cases 1 through 4 were performed for the duration of 0.08 second to capture the response of the fuel after the 0.02 second loading duration. Post-processing each analysis result identifies the maximum shear stress occurring at the shell surface. The maximum shear stress result from LS-DYNA is factored by two to determine the maximum stress intensity.

The following table contains the maximum stress intensity for the five cases.

Maximum Stress Intensity for the Five LS-DYNA Analyses

Case	Maximum Stress Intensity (ksi)	Factor of Safety Against Yield Strength
1	25.4	3.08
2	21.8	3.59
3	41.9	1.86
4	34.7	2.25
5	22.0	3.54

The case using the 60-inch spacing in conjunction with the minimal cross-section (Case 3) is identified as the bounding case. All stresses were shown to be less than the yield strength.

The results confirm that high burnup PWR fuel with a maximum distance of 60 inches from the bottom to the first grid will remain structurally adequate for the storage design basis cask end drop load conditions.

Figure 3.8.1-1 Overall Model Plot for a Typical PWR Fuel Assembly

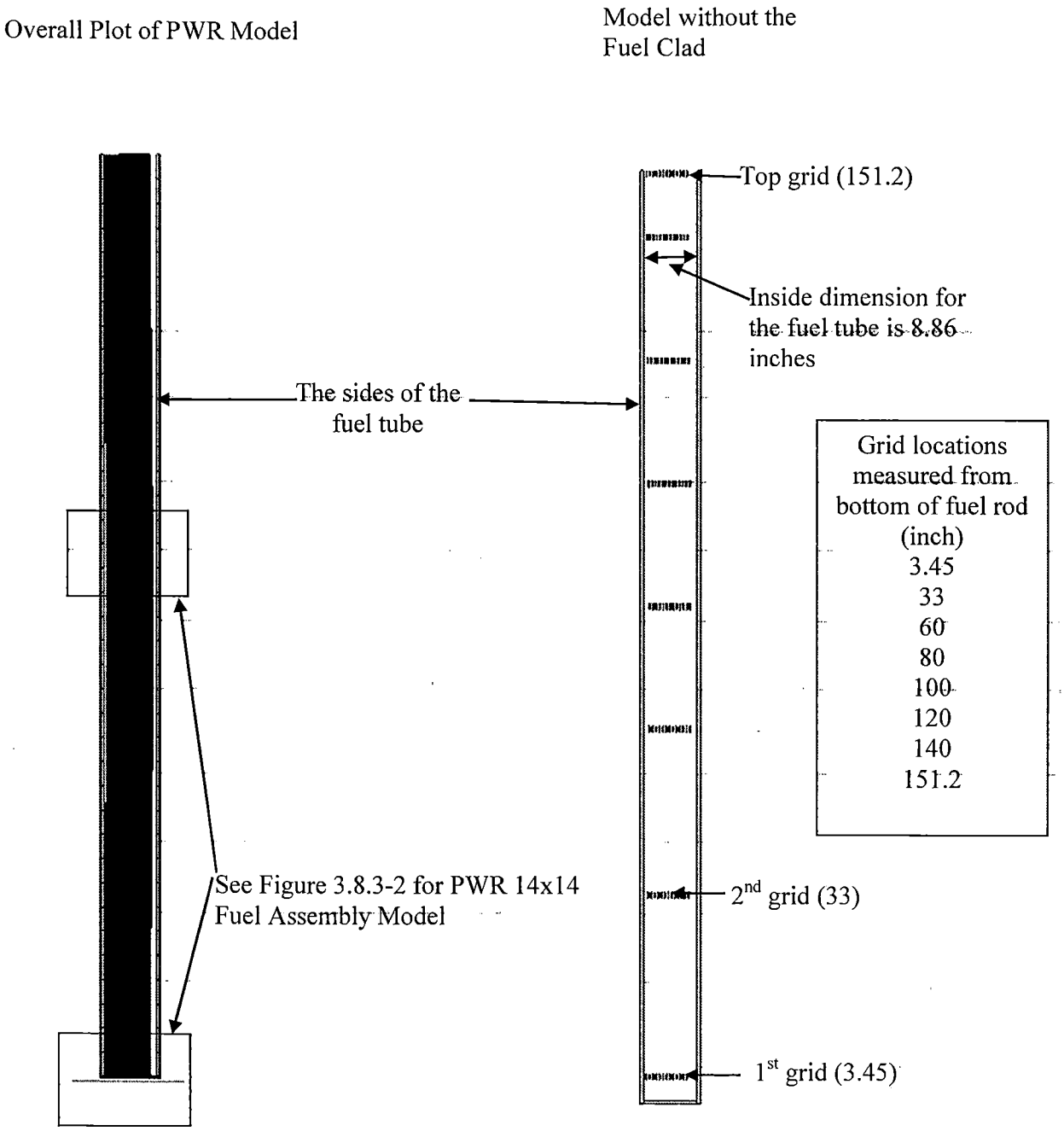
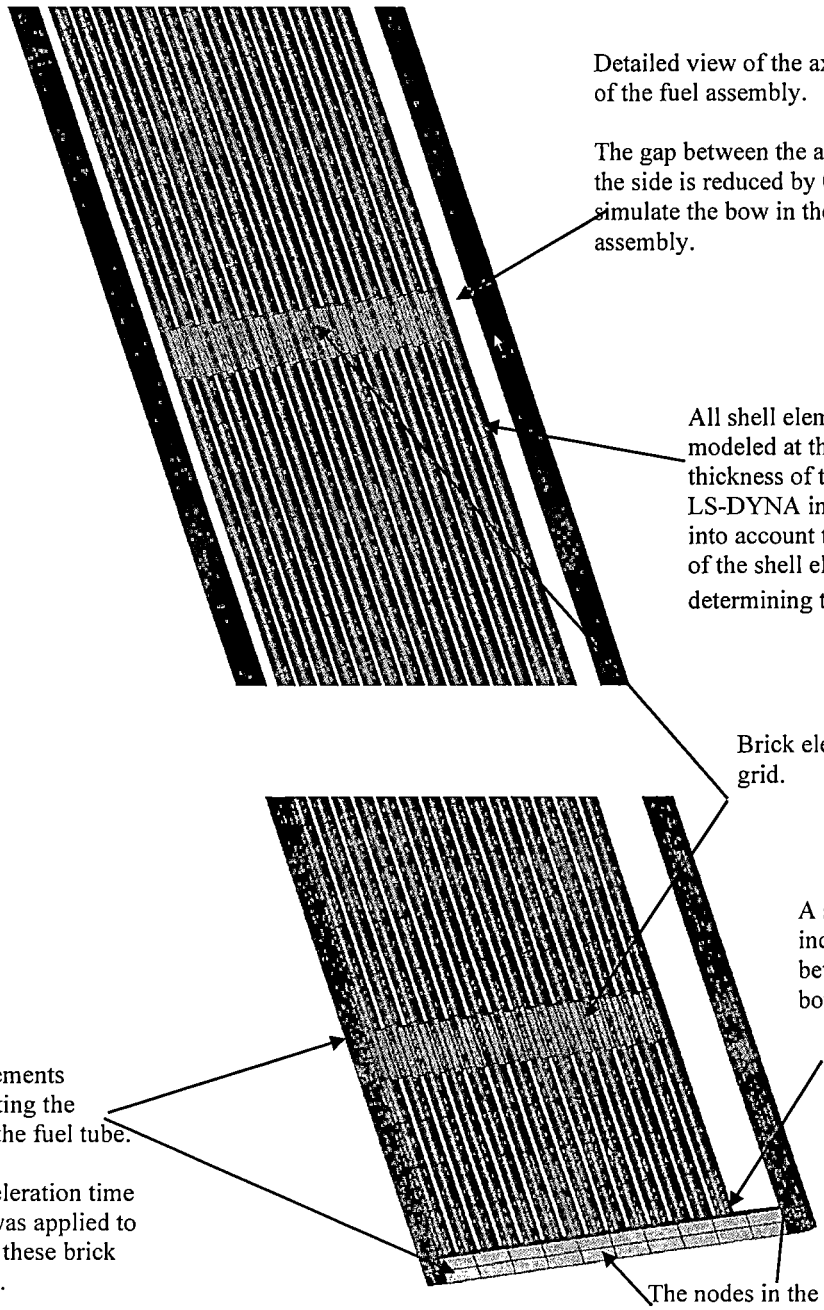


Figure 3.8.1-2 Detailed View of the PWR 14×14 Fuel Assembly



3.8.2 BWR Fuel Rod Buckling Evaluation

The evaluation of the BWR fuel rod is based on the following representative samples of BWR fuel rods.

Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)
GE 7x7	0.563	0.032
GE 8x8-2	0.483	0.032
GE 8x8-4	0.484	0.032
GE 9x9-2	0.441	0.028
GE 10x10-2	0.378	0.024

The location of the lateral constraints in the BWR fuel are: 0.00 in, 22.88 in, 43.03 in, 63.18 in, 83.33 in, 103.48 in, 122.3 in, 143.78 in, and 163.42 inches.

For the PWR fuel rod (with all grids and with the 120-micron thickness reduction), the largest ratio of unsupported length (L) to radius of gyration of the cladding cross-section (r) is:

$$L/r = \frac{33}{0.5 \times \sqrt{((0.360 - 2 \times 0.0047)/2)^2 + (0.318/2)^2}} = 279$$

The ratio (L/r) for a BWR fuel rod (with the 125-micron thickness reduction for the high burnup fuel) is:

$$L/r = \frac{22.88}{0.5 \times \sqrt{((0.378 - 2 \times 0.0049)/2)^2 + (0.330/2)^2}} = 185$$

The analysis presented in Section 3.8.1 is bounding for both PWR and BWR fuel rods because the "L/r" for the PWR fuel rod is larger than the "L/r" for the BWR fuel rod. Therefore, no further evaluation of the BWR fuel rod is required.

3.8.3 Thermal Evaluation of Fuel Rods

MAGNASTOR limits normal storage condition fuel cladding temperatures to be ≤ 400°C (752°F) in accordance with ISG-11, Rev 3. Zirconium alloy or stainless steel cladding degradation is not expected to occur below this temperature in an inert gas environment.

The fuel cladding temperature limit for short-term off-normal and accident events is 570°C (1,058°F). Refer to Chapter 4, which demonstrates that the maximum fuel cladding temperatures are well below the temperature limits for all design conditions of storage.

3.8.4 Side Drop Evaluation

The basket side drop configuration is evaluated using a uniformly applied 60g's along the length of the basket. This significantly bounds the accelerations developed in the concrete cask tip-over accident in which the accelerations vary from near-zero value at the point of rotation to a maximum acceleration reported in Section 3.7.3.7 of 26.6g's at the top of the basket. The analyzed bounding fuel rod length of 60.0 inches envelops all fuel types and includes the condition with a missing support grid in the fuel assembly. During a side drop, the maximum deflection of a fuel rod is based on the fuel rod spacing of the fuel assembly. Assuming a 17×17 array (fuel assembly with the maximum number of rods), the maximum fuel rod deflection, including the 120-micron oxide layer, is:

$$(17-1) \times (0.496-0.36+2\times120\times10^{-6}\times39.37) = 2.33 \text{ in.}$$

The side drop loading is evaluated for three fuel rods, which corresponds to the limits of the stress modulus Z (ratio of the cross-sectional moment of inertia to the maximum radius to relate the maximum fiber stress (S) to the bending moment (M), S=M/Z) and the maximum span, as shown in the following table.

Case	Rod Diameter (inches)	Clad Thickness (inches)	Z (in^3) (10^{-3})	Span (inches)
CE14×14	0.440	0.031	3.18	16.8
WE15×15	0.417	0.024	2.20	26.2
WE17×17	0.360	0.0205	1.33	20.6

ANSYS is used to perform a static analysis with a lateral loading of 60g. The model is shown in Figure 3.8.4-1. The fuel rod is modeled with beam elements, and the properties for the fuel clad take into account the reduction of the outer radius by 0.0047 inch (120 microns). The density of the beam element material was based on the zircaloy clad (0.237 lb/in^3) and the pellet density (0.396 lb/in^3). The lateral constraints show the location of the grids used in the model, and the distance from the end of the fuel rod to the first support is 60 inches. The analyses confirm that the rod lateral displacement is 2.33 inches, which results in the fuel rod being supported with the 60-inch distance between adjacent grids. Therefore, the location of the unsupported span along the fuel rod is not significant. The spacing for the adjacent grids is shown in the preceding table.

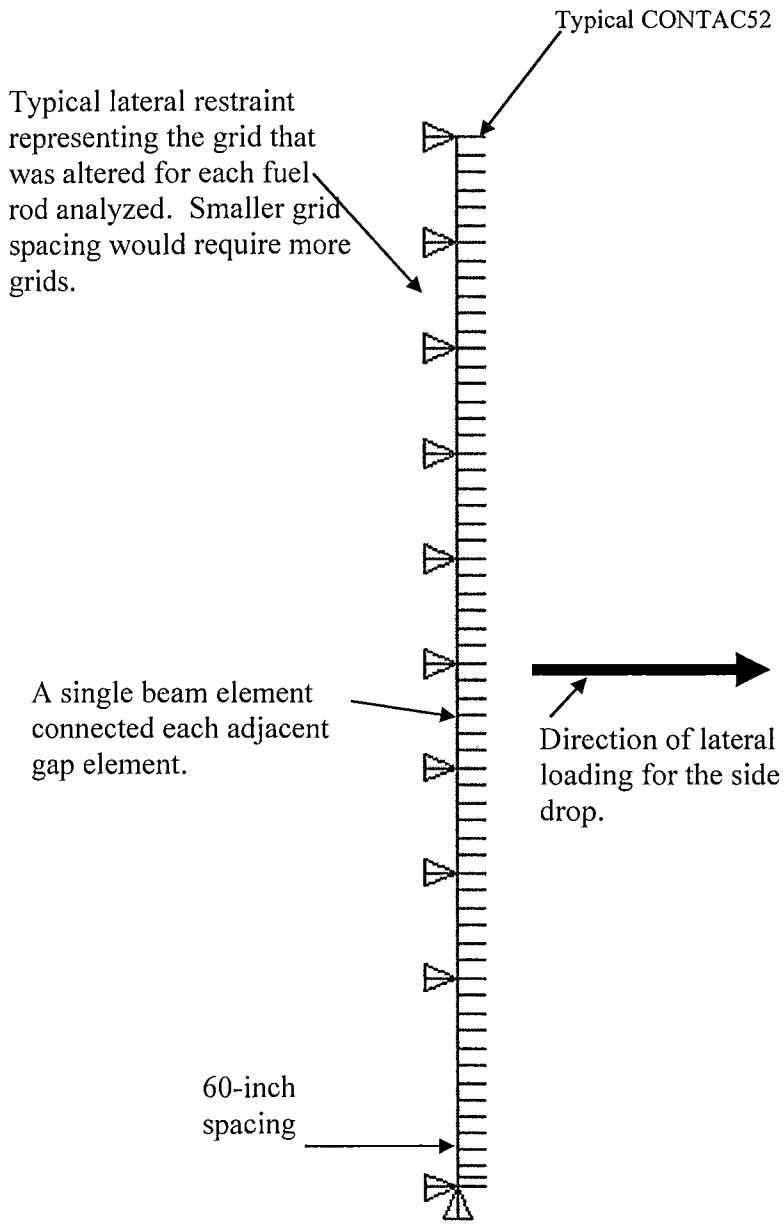
To represent the maximum gap of 2.33 inches, which the fuel rod can displace in the side drop, CONTAC52s were modeled at each node. The gap for each CONTAC52 was set to 2.33 inches

to limit the lateral displacement of the fuel rod to 2.33 inches. The gap stiffness for each CONTAC52 was defined to be 10^6 lb/in, which simulates the resistance of the basket to the lateral motion of the fuel rod. The lateral flexural stiffness of the fuel rod is considered to be insignificant compared to the stiffness of the basket. The effect of this stiffness, whether larger or smaller, would not influence the maximum stress. The maximum stress in the fuel rods is shown in the following table, and the allowable stress is the material yield strength at 752°F (69.6 ksi).

Case	Maximum Stress (ksi)	Margin of Safety Against Yield Strength
CE14×14	37.1	+0.88
WE15×15	48.1	+0.45
WE17×17	46.3	+0.50

This confirms that the PWR fuel rod subject to high burnup will remain intact for a 60g side drop condition, which bounds the tip-over accident condition.

Figure 3.8.4-1 ANSYS Model for the PWR Fuel Rod High Burnup Condition



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3.10 Structural Evaluation Detail

This section contains evaluation detail not found in the preceding sections.

3.10.1 PWR Fuel Basket Finite Element Models

3.10.1.1 Load Path Description

This section describes the load paths and interactions between basket components during storage conditions. The MAGNASTOR PWR fuel basket is designed to accommodate 37 PWR fuel assemblies. For the normal conditions of storage, the weight of the fuel assemblies is directly supported by the bottom plate of the TSC. The basket is subjected to its self-weight only. Standoffs at the ends of the fuel tubes, side weldments and corner weldments provide support of the basket in the axial direction. Standoffs for the fuel tubes are formed by extension of the fuel tube corners or use of connector pin assemblies. Bearing loads are transmitted from the basket to the TSC bottom plate. For the off-normal and accident events associated with loadings in the transverse direction of the basket (e.g., off-normal handling load, concrete cask tip-over accident), the weight of the fuel assemblies is supported by the 21 fuel tubes, side support weldments, and corner support weldments. Referring to Figure 3.10.1-1, load transfer between the fuel tubes, '1', is through contact at the tube corners. This contact consists of two types: the pins and the region between pins where the tube sections are in contact. The pin-tube slot connections at 20-inch center-to-center distance prevent the fuel tubes from sliding past each other. The shear load transmitted across the pins is reacted out in bearing in the fuel tube pin slots. The tube region between pins transmits bearing directly between fuel tubes. Shear loads between the tube corners can be transmitted by friction; however, friction is not considered in the finite element analyses of the basket. The detailed interaction between fuel tube corners, as well as a free-body diagram of a tube section, is shown in Figure 3.10.1-3. As the figure shows, the pin welded to one tube fits into the slots cut into the adjoining tube.

The connector pin-tube slot connections at the ends of the basket serve the same functions as the intermediate pin-tube slot connections for loadings in the transverse direction of the basket. Additionally, alignment pins (e.g., the drive pin of the connector pin assembly) may be inserted to the holes of the connector pins to assist basket construction.

The corner and side support weldments provide rigidity to the basket. The weldments are attached to the fuel tube array by means of bolted boss connections. Bosses welded to the fuel tubes are slotted into the weldments. Connection is made with the use of a washer and bolt combination. Figure 3.10.1-1 and Figure 3.10.1-2 show the boss connection details, '2'. To ensure the connection is in tension, the bosses are designed not to penetrate completely through the weldment wall. Therefore, once installed and preloaded, the bolts are always in tension. Shear loads are reacted out by the interaction of the bosses, boss welds, and the support

weldments, '3'. When the support weldments are in compression, bearing loads are transferred through the support weldment to the fuel tube array, '4' (Figure 3.10.1-2). Figure 3.10.1-4 shows a free-body diagram of the fuel tube interaction with the support structure.

3.10.1.2 Finite Element Model Descriptions for PWR

This section describes the finite element models for the structural evaluation for the PWR basket. The following describes the models and the applicable ASME Code section.

Finite Element Model	Analysis Usage	Loading Condition	ASME Code Section
3D Periodic Elastic Model	Off-normal handling conditions of PWR basket for translational loadings	Level C	III-NG
3D Thermal Stress Model	Thermal stress evaluation	Level A	III-NG
3D Periodic Plastic Model	Concrete cask tip-over accident evaluation	Level D	III-NG, App. F

3.10.1.2.1 PWR Basket Three-Dimensional Periodic Models

[redacted]

The corner and side support weldments are bolted to the fuel tube array at twenty locations around the circumference of the basket (ten locations in the model). The bolt/boss joints are modeled using LINK10 for the bolts and COMBIN40 elements for the bosses. The LINK10 element represents the bolt and is capable of tension loads only. Compression loads are carried by the CONTAC52 gap elements discussed above. The COMBIN40 elements represent the shear restraint provided by the bosses welded to the fuel tubes. A gap of 1/16 inch is considered on each side of the boss, as defined by the Real Constants of the COMBIN40 elements. The interaction between the corner weldment support bar and the ridge gusset is modeled using a LINK10 element capable of compression only, since there is no weld between the support bar and the gusset.

Loads and boundary conditions are discussed in Section 3.10.1.3. The weight of the neutron absorbers and the retainers, which are not included in the finite element model, are considered by adjusting the density of the carbon steel for the fuel tube sides.

3.10.1.2.2 PWR Basket Three-Dimensional Thermal Stress Model

The structural evaluation for thermal stresses is performed using a three-dimensional quarter-symmetry finite element model, as shown in Figure 3.10.1-7. The model represents the top or bottom 47 inches of the PWR basket to evaluate the bounding axial and radial thermal gradients considering the end restraint of the basket due to the connector pin assemblies. This model includes the connector pin assemblies at the end of the fuel tubes and two intermediate pin and bolt locations. The connector pin assemblies at the end of the basket are modeled with nodal constraints in the basket transverse directions at the interface of two adjacent connector pins. The modeling methodology of the model is the same as that of the three-dimensional periodic model as discussed in Section 3.10.1.2.1.

3.10.1.2.3 PWR Basket Three-Dimensional Periodic Plastic Model

The tip-over accident evaluation of the PWR basket is performed using two three-dimensional plastic periodic models for 0° and 45° basket orientations, respectively. [redacted] Also, the BEAM4 elements that are used to model the corner weldment bars in the elastic model are replaced with BEAM188 elastic-plastic elements. For all elastic-plastic materials, a bilinear kinematic material model is used with specified values for the yield stress and tangent modulus.

Loads and boundary conditions are discussed in Section 3.10.1.3.3. The weight of the neutron absorbers and the retainers, which are not included in the finite element model, are considered by adjusting the density of the carbon steel for the fuel tube sides.

3.10.1.3 Finite Element Model Boundary Conditions for PWR Basket

3.10.1.3.1 Off-Normal Handling Boundary Conditions

For off-normal handling events, the three-dimensional periodic models described in Section 3.10.1.2.1 are used to calculate the stresses due to loading in the transverse direction of the basket. The gap between the basket and the transfer cask is 0.62 inch (0.12-inch basket-TSC and 0.50-inch TSC-cask). To represent the loads from the fuel assemblies, a bounding pressure load of 1.2 psi is applied to the fuel tubes.

The boundary conditions for 0° and 45° basket orientations are shown in Figure 3.10.1-9 and Figure 3.10.1-10, respectively. For off-normal events, an inertia load of 0.707g (resultant of 0.5g loading in the two transverse directions) is applied in the transverse direction of the basket. Applied pressure loads for fuel assemblies are also multiplied by 0.707g.

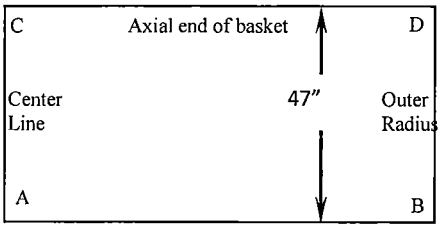
The 0° and 45° basket orientations are critical for the PWR basket for loading in the transverse direction. The 0° basket orientation maximizes the stresses in the fuel tube sidewalls and the 45° basket orientation maximizes the bending stresses in the tube corners. Intermediate basket orientations are bounded by the 0° and 45° orientations. Therefore, the basket evaluation is performed using two half-symmetry models for the 0° and 45° basket orientations, respectively. Symmetry boundary conditions are applied at the plane of symmetry. Symmetry boundary conditions are also applied to both ends of the finite element model to represent a periodic section of the basket. CONTAC52 elements are used at the periphery of the basket to represent the interface of the basket and the canister shell inside the transfer cask. Outer nodes of the CONTAC52 elements are fixed. For off-normal events, material properties at 100°F are conservatively used (using the modulus of elasticity for carbon steel at lower temperature results in slightly higher stress results.)

3.10.1.3.2 Thermal Stress Analysis Boundary Conditions

The three-dimensional quarter-symmetry model described in Section 3.10.1.2.1 is used to calculate the thermal stress due to the thermal expansion. As shown in the following table, a total of five cases of temperature boundary conditions are defined that envelop the maximum temperature gradients (ΔT) in the axial and radial directions of the basket for all conditions of

storage and transfer. Prior to performing the thermal stress analysis, the steady-state temperature distribution in the model is determined by a thermal conduction analysis. The SOLID45, SHELL43 and BEAM4 structural elements were converted to SOLID70, SHELL57 and LINK33 thermal elements, respectively, for the thermal conduction solution.

Thermal Boundary Temperatures – PWR Basket (°F)



Case	A	B	C	D
1	600	440	360	300
2	680	500	580	440
3	640	520	700	590
4	430	380	210	260
5	700	500	550	400

Symmetry boundary conditions are applied at the planes of symmetry. In the basket axial direction, the model is restrained at one end.

3.10.1.3.3 Concrete Cask Tip-Over Accident Boundary Conditions

The concrete cask tip-over is evaluated as a side impact for the basket. During the concrete cask tip-over event, acceleration varies from 1g at the bottom of the concrete cask to a maximum acceleration at the top of the TSC. The three-dimensional plastic model is used for the evaluation of the basket (Section 3.10.1.2.3). A bounding acceleration of 35g is applied to the basket models in the transverse direction. The 35g acceleration bounds the maximum acceleration in the basket, including the dynamic load factor for the concrete cask tip-over accident.

Pressure loads are applied to the PWR basket models to represent the fuel assembly weight with a 35g acceleration.

For the tip-over accident (loading in the transverse direction), the 0° and 45° basket orientations are critical for the PWR basket as discussed in Section 3.10.1.2.3. Therefore, the basket is evaluated using models corresponding to the 0° and 45° basket orientations. Symmetry boundary conditions are applied at the plane of symmetry. Symmetry boundary conditions are also applied to both ends of the three-dimensional periodic finite element model. CONTAC52 elements are used to represent the interface of the basket and the canister shell inside the concrete cask. The location of the outer nodes of the gap elements at the basket periphery incorporates the canister shell displacements during the concrete cask tip-over accident. The canister shell displacement at approximately mid-height (100 inches from canister bottom) of the canister shell is used. This

is conservative since the g-load at this location is significantly lower than the bounding g-load used in the basket analysis (35g). The boundary conditions for these models are shown in Figure 3.10.1-9 and Figure 3.10.1-10. For accident conditions, material properties at 500°F are used.

The fuel assembly weight used in the 3D periodic model and 3D periodic plastic model is 1,680 pounds for a total contents weight of 37 × 1,680 or 62,160 pounds. Since the basket response is controlled by the total contents weight, the maximum contents weight in each storage location is 1,765 pounds (5% increase from 1,680 pounds) while constraining the maximum total basket contents weight to 62,160 pounds. The small variation in the weight in each storage location of the model has a negligible effect on the basket stresses.

3.10.1.4 Post-Processing Finite Element Analysis Results

3.10.1.4.1 Maximum Stresses for Off-Normal Handling Condition

The post-processing of the finite element analysis results from the periodic model for the off-normal event is performed by taking section cuts at various locations in the model.

The fuel tube section cuts are divided into two regions. Region 1 is the region between the pin supports. For the periodic model, this region is defined from the base of the model (mid-distance between pins) to the base of the pin. Region 2 is the pin region. This region starts at the base of the pin and extends to the top of the finite element model (mid-plane of pin). For both regions, the region just above and below the pin cutout (±0.25 inch) is omitted from the section cuts to eliminate stress concentrations in the model. The membrane stresses are calculated by taking a section cut at the center of the tube thickness. The membrane plus bending stress is calculated by taking the maximum of the stresses calculated at the inner or outer surface of the fuel tube. Refer to Figure 3.10.1-11 and Figure 3.10.1-12 for the tube identification and the locations of the section cuts.

The maximum stresses for the corner support weldments are calculated by taking section cuts along the length of the weldment (ten inches for the periodic model). Refer to Figure 3.10.1-13 and Figure 3.10.1-14 for the locations of the section cuts.

The maximum stresses for the side weldments are calculated taking section cuts along the length of the weldment (ten inches for the periodic model). The membrane stresses are calculated by taking a section cut at the mid-thickness of the weldment. The membrane plus bending stress is calculated by taking the maximum of the stresses calculated at the inner or outer surface of the weldment. Refer to Figure 3.10.1-15 and Figure 3.10.1-16 for the locations of the section cuts.

The bolt tensile loads are obtained from the LINK10 element results. The boss shear loads are extracted from the COMBIN40 element results.

3.10.1.4.2 Maximum Thermal Stresses

The post-processing of the finite element analysis results for the thermal stress evaluation is performed by extracting the maximum nodal stress intensities from the model. The maximum nodal stress is obtained for two separate regions: (1) fuel tubes and (2) corner and side support weldments. The bolt tensile loads are extracted from the LINK10 elements, and the boss shear loads are extracted from the COMBIN40 elements.

3.10.1.4.3 Maximum Stresses for Concrete Cask Tip-Over Accident

The post-processing of finite element analysis results for the basket tip-over accident using the three-dimensional plastic model is performed by extracting stresses in the basket for the 0° and 45° basket orientations.

For the fuel tube stresses, the primary membrane stresses are calculated by extracting the maximum nodal stress at the mid-thickness of the tube wall. Based on the differences in stress criterion summarized from the plastic finite element results [i.e., $(\sigma + 3\ \tau)^{1/2}$] and the ASME Code, Section III stress criterion [i.e., $(\sigma + 4\ \tau)^{1/2}$], calculated membrane stress results are conservatively increased by a factor of $(4/3)^{1/2}$. The primary membrane plus bending stresses are evaluated by extracting the maximum stress intensity results of each fuel tube.

The stresses for the corner and side support weldments are calculated using the three-dimensional plastic models. The maximum primary membrane plus bending stress intensity for the corner and side weldments are extracted from the model. The maximum primary membrane plus bending stress intensity is compared to the membrane allowable to obtain a conservative bounding factor of safety.

3.10.1.5 Finite Element Models for PWR DF Basket

This section describes the finite element models used for the structural evaluation for the PWR DF basket assembly. The following describes the models and the applicable ASME Code section.

Finite Element Model	Analysis Usage	Loading Condition	ASME Code Section
3D Periodic Elastic Model	Off-normal TSC handling conditions (loads in basket in transverse direction)	Level C	III-NG
3D Thermal Stress Model	Thermal stress evaluation	Level A	III-NG
3D Periodic Plastic Model	Concrete cask tip-over accident evaluation	Level D	III-NG, App. F

3.10.1.5.1 Periodic Elastic Model

The three-dimensional periodic elastic models are constructed based on the periodic elastic basket models presented in Section 3.10.1.2.1 for the PWR basket, with a modification of the corner support weldment region to reflect the DF basket design. The models are shown in Figure 3.10.1-17 and Figure 3.10.1-18 for the 0° and 45° basket orientation, respectively. The DFC corner weldment plates are modeled with ANSYS SOLID45 elements. The ridge gussets are modeled with SHELL63 elements. The boundary conditions are defined using the same method presented in Section 3.10.1.3.1. CONTAC52 elements are used at the periphery of the basket to represent the interface of the basket and canister shell inside the transfer cask. For the off-normal loading event, an inertia load of 0.707g (resultant of 0.5g loading in the two orthogonal directions) is applied to the model in the transverse direction of the basket. Applied pressure loads for basket content (fuel assemblies and DFC) are also multiplied by 0.707g.

3.10.1.5.2 Thermal Stress Model

The thermal stress model is similar to the quarter-symmetry thermal stress model presented in Section 3.10.1.2.2 (Figure 3.10.1-7). The model is constructed based on the 0° basket periodic elastic model for the PWR DF basket and represents the top or bottom 56 inches of the basket. The boundary conditions for this model are identical to those presented in Section 3.10.1.3.2, which includes five cases of boundary conditions to envelop the maximum temperature gradients (ΔT) in the axial and radial directions of the basket for all conditions of storage and transfer. These temperatures are applicable to the PWR DF basket since the thermal analysis for the PWR configuration with DF basket is bounded by those for the PWR standard configuration as discussed in Chapter 4.

3.10.1.5.3 Periodic Plastic Model

The tip-over accident evaluation of the PWR DF basket is performed using two 3-dimensional plastic periodic models for 0° and 45° basket orientations, respectively. The models are the same as the periodic elastic models used for the off-normal handling evaluations except that the elastic material properties are replaced with elastic-plastic material properties for the fuel tubes, pins, corner weldments, and side weldments. Also, the SHELL63 elements that are used to model the corner weldment ridge gussets in the elastic model are replaced with SHELL43 elastic-plastic elements. For all elastic-plastic materials, a bilinear kinematic material model is used with specified values for the yield stress and tangent modulus. The boundary conditions are defined using the same method presented in Section 3.10.1.3.3. CONTAC52 elements are used at the periphery of the basket to represent the interface of the basket and canister shell inside the concrete cask. A bounding acceleration of 35g is applied to the models in the transverse direction for both the 0° and 45° basket orientations. Pressure loads are applied to the basket models to represent the weight of the fuel assemblies and DFC with a 35g acceleration.

The maximum allowed contents weight in each storage location of the DF basket is 1,765 pounds and the maximum allowed contents weight of the basket is 61,184 pounds. The fuel assembly weight used in the periodic elastic model and periodic plastic model is 1,680 pounds per storage location except for the four DFC locations (1,814 pounds) equivalent to a total model contents weight of 62,696 pounds, which bounds the maximum allowed contents weight of 61,184 pounds. Since the basket response is controlled by the total contents weight, the small variation of the weight used in 33 storage locations of the model (1,680 is 5% less of 1,765 pounds) will have a negligible effect on the basket stresses.

3.10.1.5.4 Post-processing Finite Element Model Results

For the thermal stress evaluation, the post-processing of the finite element analysis results is performed using the same method as shown in Section 3.10.1.4.2. Maximum nodal stress intensities are extracted from the analysis results. For the off-normal and tip-over accident conditions, the post-processing methods as discussed in Section 3.10.1.4.1 and Section 3.10.1.4.3 are used. Critical stresses at various sections of the basket structure are calculated using the ANSYS post-processor for the PWR DF basket. Locations of the sections for the fuel tubes, the corner support weldment plates and the ridge gussets are shown in Figure 3.10.1-19 through Figure 3.10.1-23.

Figure 3.10.1-1 Expanded View of PWR Basket

[redacted]

Figure 3.10.1-2 Bolted Attachment Details

[redacted]

Figure 3.10.1-3 Free-Body Diagram of PWR Basket Fuel Tube Detail

[redacted]

Figure 3.10.1-4 Free-Body Diagram of Basket Support Structure

[redacted]

Figure 3.10.1-5 PWR Basket Periodic Model – 0° Basket Orientation

[redacted]

Figure 3.10.1-6 PWR Basket Periodic Model – 45° Basket Orientation

[redacted]

Figure 3.10.1-7 Thermal Stress Evaluation Model

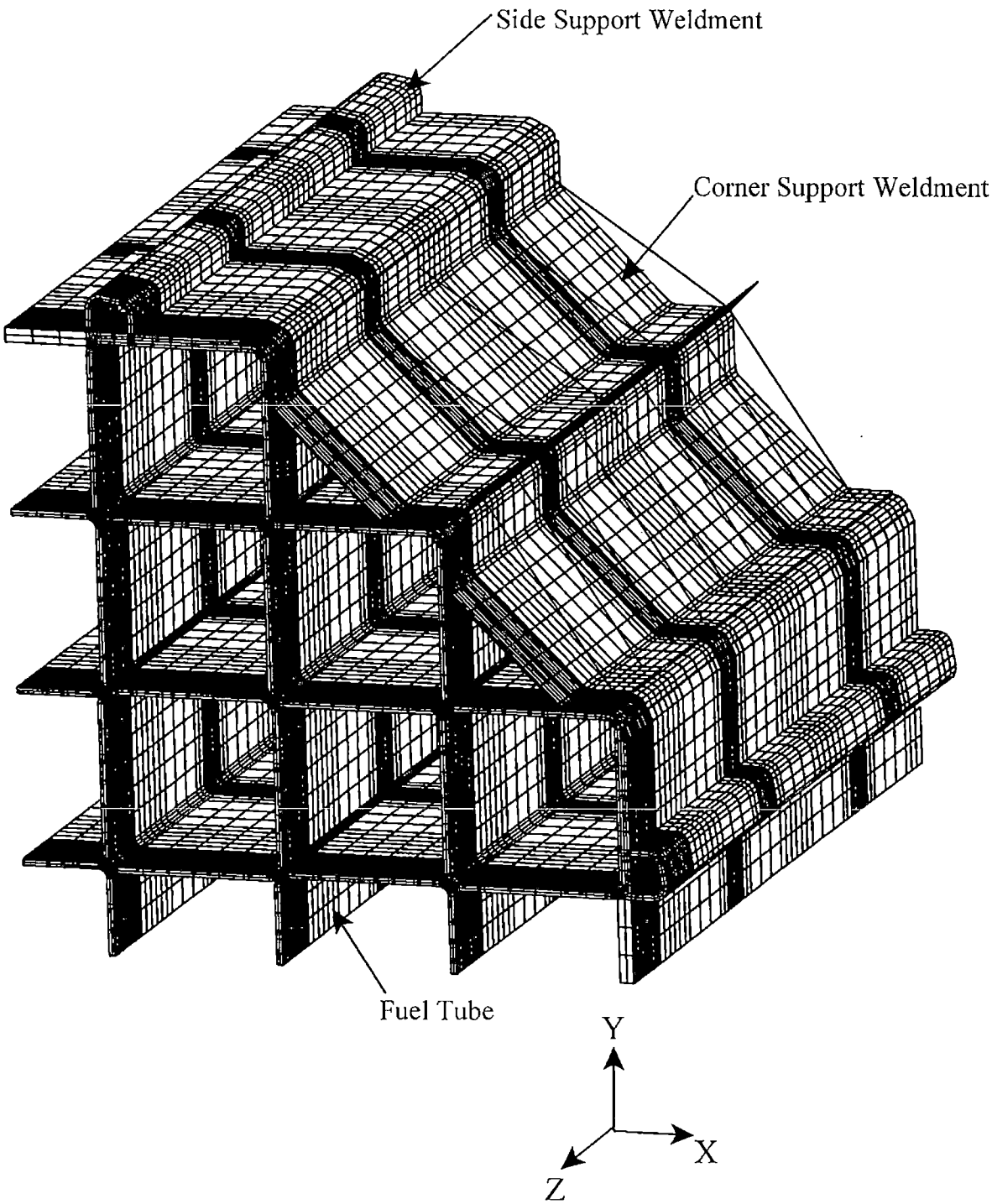


Figure 3.10.1-8 PWR Fuel Tube Pin Finite Element Model Details

[redacted]

Figure 3.10.1-9 PWR Basket Model Boundary Conditions for a Transverse Loading - 0° Basket Orientation

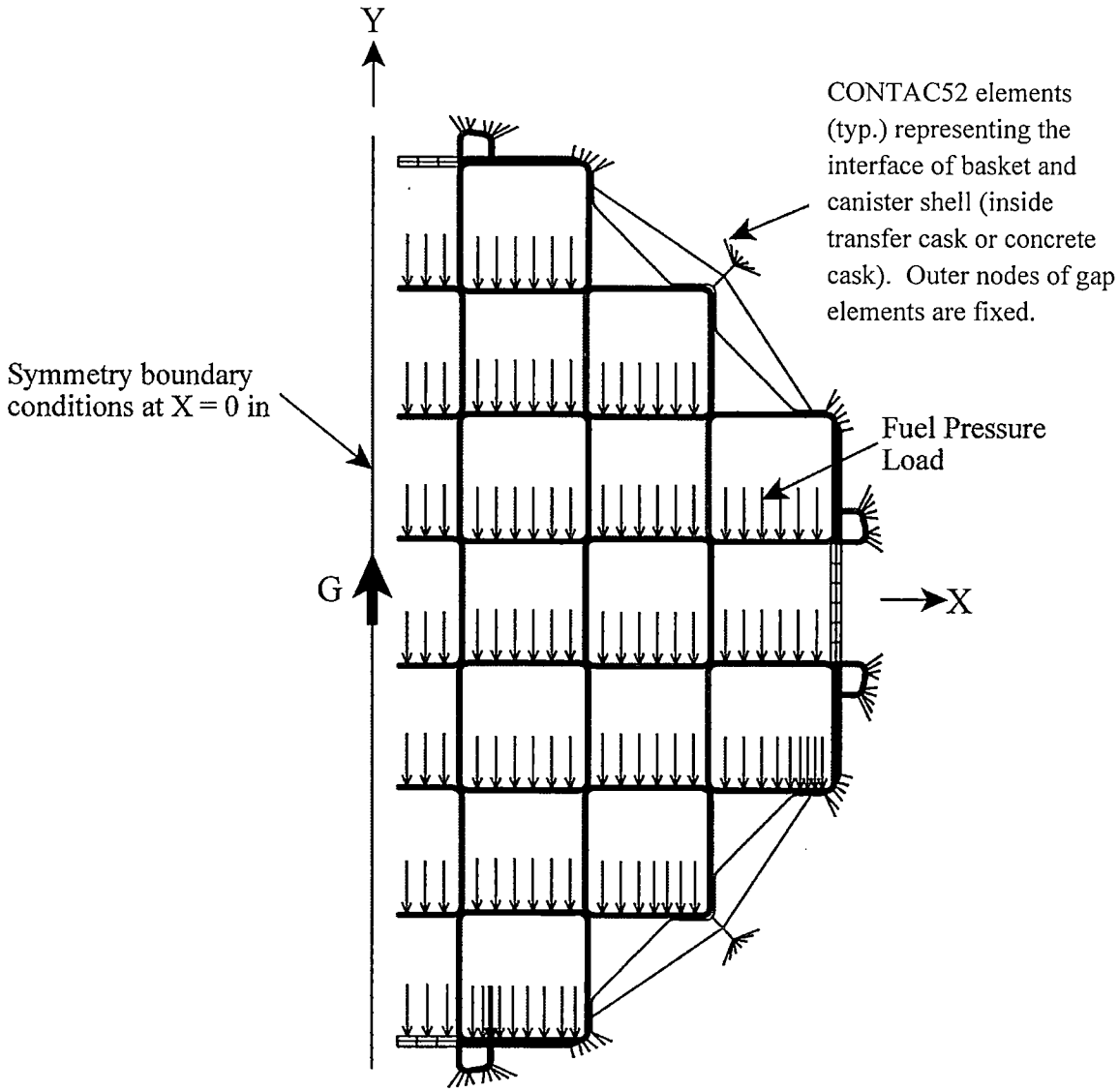


Figure 3.10.1-10 PWR Basket Model Boundary Conditions for a Transverse Loading - 45° Basket Orientation

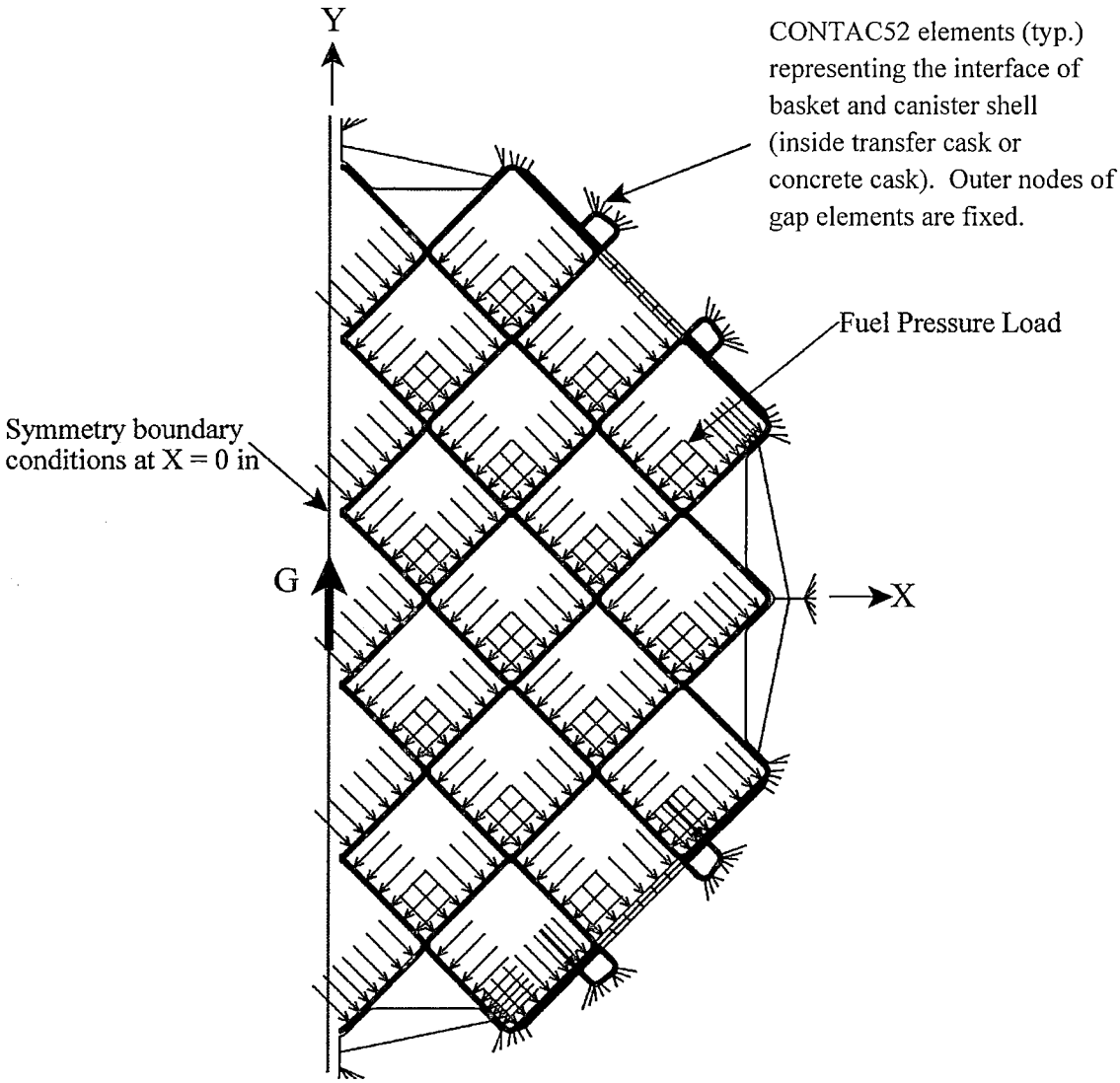


Figure 3.10.1-11 PWR Fuel Tube Array and Section Cuts - 0° Orientation

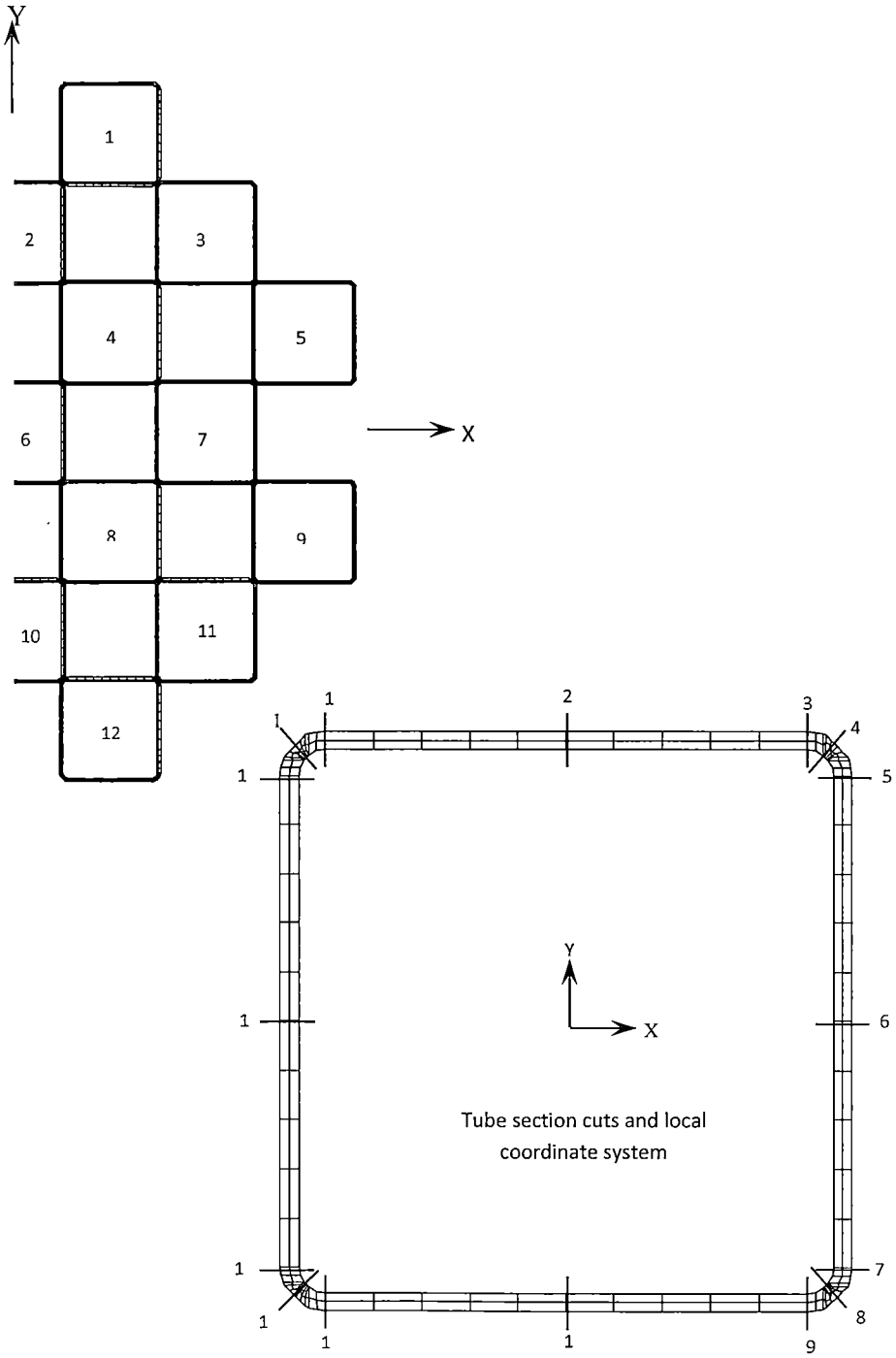


Figure 3.10.1-12 PWR Fuel Tube Array and Section Cuts - 45° Basket Orientation

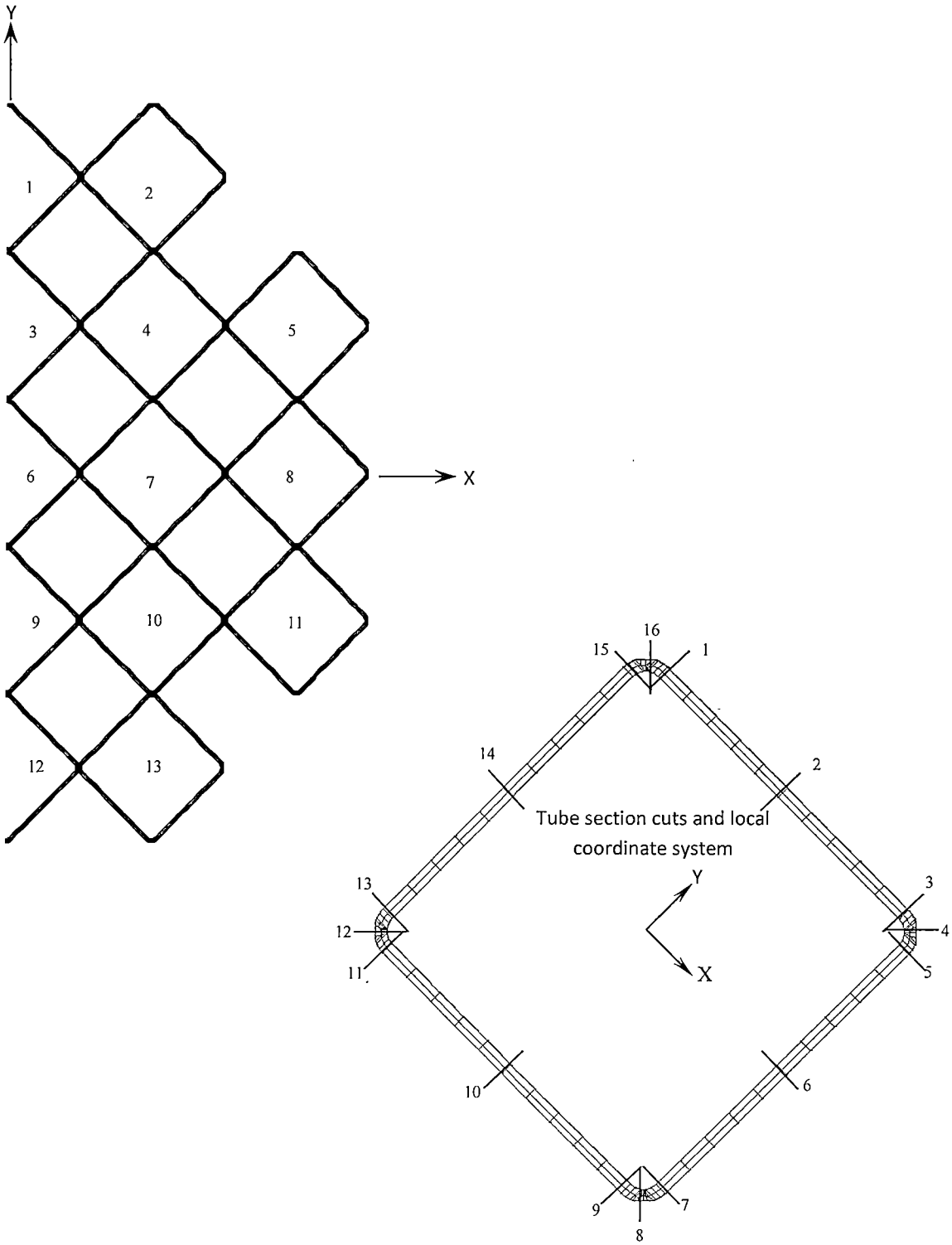


Figure 3.10.1-13 PWR Corner Support Weldment Section Cuts – 0° Basket Orientation

[redacted]

Figure 3.10.1-14 PWR Corner Support Weldment Section Cuts – 45° Basket Orientation

[redacted]

Figure 3.10.1-15 PWR Side Support Weldment Section Cuts – 0° Basket Orientation

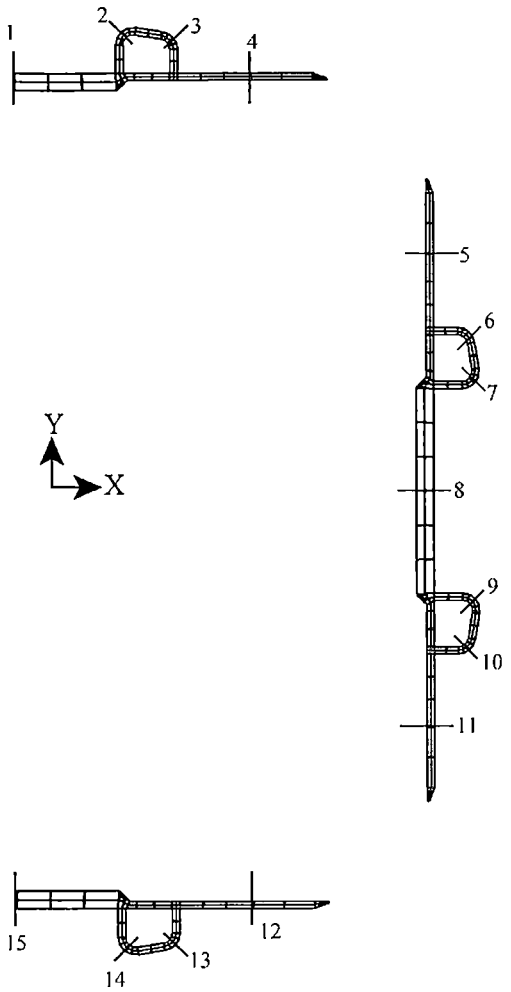


Figure 3.10.1-16 PWR Side Support Weldment Section Cuts – 45° Basket Orientation

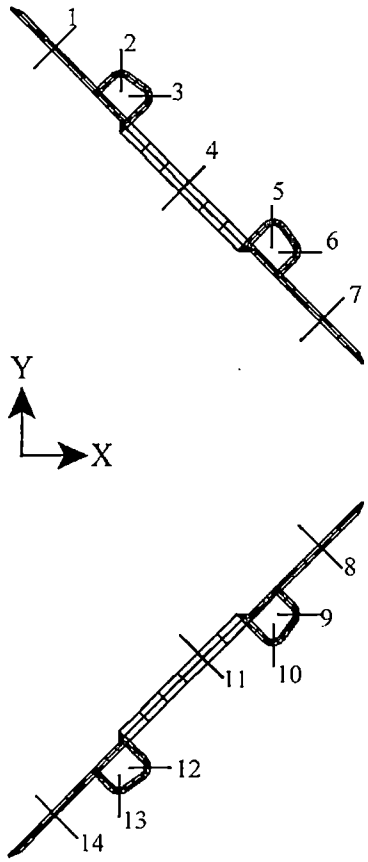


Figure 3.10.1-17 Finite Element Model for PWR DF Basket – 0° Basket Orientation

[redacted]

Figure 3.10.1-18 Finite Element Model for PWR DF Basket – 45° Basket Orientation

[redacted]

Figure 3.10.1-19 PWR DF Basket Fuel Tube Array and Section Cuts – 0° Basket Orientation

[redacted]

Figure 3.10.1-20 PWR DF Basket Fuel Tube Array and Section Cuts – 45° Basket Orientation

[redacted]

Figure 3.10.1-21 PWR DF Basket Corner Support Weldment Section Cuts – 0° Basket Orientation

[redacted]

Figure 3.10.1-22 PWR DF Basket Corner Support Weldment Section Cuts – 45° Basket Orientation

[redacted]

Figure 3.10.1-23 PWR DF Basket Ridge Gusset Locations Section Cuts

[redacted]

3.10.2 BWR Fuel Basket Finite Element Models

3.10.2.1 Load Path Description

This section explains the load paths in the basket that ensure the structural integrity of the BWR MAGNASTOR during all conditions of storage. The MAGNASTOR BWR fuel basket is designed to accommodate up to 87 BWR fuel assemblies. For normal conditions of storage, the weight of the fuel assemblies is directly supported by the bottom plate of the TSC. The basket is subjected to its self-weight only. Standoffs at the ends of the fuel tubes, side weldments and corner weldments provide support of the basket in the axial direction. Bearing loads are transmitted from the basket to the TSC bottom plate. [redacted] For the off-normal and accident conditions associated with loadings in the transverse direction of the basket (e.g. off-normal handling load, concrete cask tip-over accident), the weight of the fuel assemblies is supported by the 45 fuel tubes, side support weldments, and the corner support weldments. Referring to Figure 3.10.2-1, load transfer between the fuel tubes, '1', is through bearing contact at the corners. The bearing contact consists of two load paths: the pin-slot connections transmit load directly between each fuel tube; and where the tubes are in contact, bearing loads are transmitted. The shear load transmitted across the pins is reacted out in bearing in the pin slots. The detailed interaction between fuel tube corners is shown in Figure 3.10.2-2 and Figure 3.10.2-3. As the figures show, the pins welded to one tube mate to the slots cut into the adjoining tube. Figure 3.10.2-3 shows a free-body diagram of the fuel tube pin joint. Frictional forces are not considered in the finite element analysis of the basket.

The connector pin-tube slot connections at the ends of the basket serve the same functions as the intermediate pin-tube slot connections for loadings in the transverse direction of the basket. Additionally, alignment pins may be inserted to the holes of the connector pins to assist basket construction. For the BWR basket, the alignment pins shall be removed after final assembly.

The corner and side support weldments provide rigidity to the basket. The weldments are attached to the fuel tube array by means of bolted boss connections. Bosses welded to the fuel tubes are slotted in to the weldments. Connection is made with the use of a washer and bolt combination. Referring to Figure 3.10.2-1 and Figure 3.10.2-2, the bolted joints, '2', are designed to transmit tensile loads. Therefore, once installed and preloaded the bolts are always in tension. Shear loads are reacted out by interaction of the bosses, boss welds, and the support weldments, '3'. If the support weldments are bearing on the fuel tube array, the load is transferred through the bearing contact, '4', of the support weldments and fuel tube array (Figure

3.10.2-2). Figure 3.10.2-4 shows a free-body diagram of the fuel tube interaction with the basket support structure.

3.10.2.2 Finite Element Model Descriptions

This section describes the finite element models used in the BWR basket structural evaluation. The following table describes the finite element models and the applicable ASME Code section.

Finite Element Model	Analysis Usage	Loading Condition	ASME Code Section
3D Periodic Model	Off-normal TSC handling conditions (loads in basket in transverse direction)	Level C	III-NG
3D Thermal Stress Model	Thermal stress evaluation	Level A	III-NG
3D Periodic Plastic Model	Concrete cask tip-over accident evaluation	Level D	III-NG, App. F

3.10.2.2.1 BWR Basket Three-Dimensional Periodic Model

Two three-dimensional periodic half-symmetry models of the BWR basket are used to calculate the stresses in the basket due to transverse loading during the off-normal TSC handling conditions. These models correspond to the critical basket orientations, 0° and 45°, as shown in Figure 3.10.2-5 and Figure 3.10.2-6. The fuel tube support pins are spaced on 10.0-inch centers; therefore, the periodic model extends from the axial center of a tube pin to the axial center of the next tube pin, a 10.0-inch segment.

The basket finite element models are constructed using SOLID45, SHELL43, BEAM4, Link10, COMBIN14, COMBIN40 and CONTAC52 elements. The fuel tube assemblies, pins, corner weldment plates and side support weldments are modeled using SOLID45 elements. SHELL43 elements are used to model the support plates at the corner assemblies and BEAM4 elements are used to provide moment continuity at the interface between the SOLID45 and SHELL43 elements. COMBIN14 spring elements are used to connect the pins to one of the two adjacent fuel tubes. The interaction between the fuel tubes, pins, corner support weldment and side support weldment is modeled with CONTAC52 gap elements. These gap elements allow the transfer of loads between the basket structural components.

For the basket structural evaluation, the TSC is not modeled. CONTAC52 gap elements are used to model the gap between the BWR basket and the TSC. These gap elements represent the clearance around the circumference between the side and corner weldments of the basket and the ID of the TSC.

The corner support and side support assemblies are bolted to the fuel tube array at twenty four locations around the circumference of the basket. The bolt/boss joints are modeled using LINK10 tension only elements for the bolts and COMBIN40 elements for the boss. The COMBIN40 elements represent the shear restraint generated by the bosses welded to the fuel tubes.

Loads and boundary conditions are discussed in Section 3.10.2.3.1. The weight of the neutron absorbers and the retainers, which are not included in the finite element model, are considered by adjusting the density of the carbon steel for the fuel tube sides.

3.10.2.2.2 BWR Basket Three-Dimensional Thermal Stress Model

The structural evaluation for thermal stresses is performed using the same three-dimensional periodic half-symmetry model detailed in Section 3.10.2.2.1 for the 0° orientation. A thermal conduction analysis is first performed by converting the structural elements to their corresponding thermal elements (ANSYS elements types SOLID70, SHELL57, and LINK33 are used). Temperature boundary conditions are applied as discussed in Section 3.10.2.3.2. The computed nodal temperatures from the conduction analysis are then imported into the structural model to determine the thermal stresses. Note that the periodic model is adequate to evaluate the thermal stresses in the basket, which mainly result from thermal expansion of the basket in the radial and circumferential directions. Thermal stress due to thermal expansion in the axial direction is negligible since the basket components are free to expand axially.

3.10.2.2.3 BWR Basket Three-Dimensional Periodic Plastic Model

The evaluation of the BWR basket for the cask tip-over event is performed using two three-dimensional plastic periodic models, as shown in Figure 3.10.2-8 and Figure 3.10.2-9. The models are similar to the periodic model presented in Section 3.10.2.2.1. Elastic-plastic material properties are used for all basket components in the model, except for the bolts. A typical model detail for the pin-slot connections is shown in Figure 3.10.2-10.

Loads and boundary conditions are discussed in Section 3.10.2.3.3. The weight of the neutron absorbers and the retainers, which are not included in the finite element model, are considered by adjusting the density of the carbon steel for the fuel tube sides.

3.10.2.3 Finite Element Model Boundary Conditions

3.10.2.3.1 Off-Normal Handling Boundary Conditions

The three-dimensional periodic models as described in Section 3.10.2.2.1 are used to calculate the stresses due to loading in the transverse direction of the basket for off-normal handling conditions. The gap between the basket and the transfer cask is 0.62 inch (0.12-inch basket-TSC and 0.50-inch TSC-cask). To represent the loads from the fuel assemblies, a bounding pressure load is applied to the fuel tubes.

The boundary conditions are the models for 0° and 45° basket orientations, as shown in Figure 3.10.2-11 and Figure 3.10.2-12, respectively. For off-normal events, an inertia load of 0.707g (resultant of 0.5g acceleration applied in the two transverse directions) is applied in the transverse direction of the basket. Applied pressure loads for fuel assemblies are also multiplied by 0.707g.

The 0° and 45° basket orientations are governing for the BWR basket for loading in the transverse direction. The 0° basket orientation maximizes the stresses in the fuel tube sidewalls and the 45° basket orientation maximizes the bending stresses in the tube corners. Intermediate basket orientations are bounded by the 0° and 45° orientations. Therefore, the basket evaluation is performed using two half-symmetry models for the 0° and 45° basket orientations, respectively. Symmetry boundary conditions are applied at the plane of symmetry. Symmetry boundary conditions are also applied to both ends of the finite element model to represent a periodic section of the basket. CONTAC52 elements are used to represent the interface of the basket and the canister shell inside the transfer cask. Outer nodes of gap elements are fixed. For off-normal events, material properties at 100°F are conservatively used (using the modulus of elasticity for carbon steel at lower temperature results in slightly higher stress results.)

3.10.2.3.2 Thermal Stress Boundary Conditions

The three-dimensional model described in Section 3.10.2.2.2 is used to calculate the thermal stress due to the thermal expansion. The applied temperatures are conservatively selected to envelop the maximum temperature gradients (ΔT) of the basket for all conditions of storage and transfer. The basket temperature gradient is obtained by a thermal conduction analysis of the BWR thermal model. The bounding temperatures for the thermal analysis are 725 °F at the center and 400 °F along the outer edge as shown in Figure 3.10.2-7. For the thermal stress structural analysis, the temperature profile calculated by the thermal conduction solution is used.

Symmetry boundary conditions are applied at the planes of symmetry. In the basket axial direction, the model is restrained at one end.

3.10.2.3.3 Concrete Cask Tip-Over Accident Boundary Conditions

The concrete cask tip-over is evaluated as a side impact for the basket. During the concrete cask tip-over event, the acceleration varies from 1g at the bottom of the concrete cask to a maximum acceleration at the top of the TSC. The three-dimensional plastic model is used for the evaluation of the BWR basket (see Section 3.10.2.2.3). A bounding acceleration of 35g is applied to the BWR models. The 35g acceleration bounds the maximum acceleration in the basket, including dynamic load factor, for the concrete cask tip-over accident.

Pressure loads are applied to the BWR basket models to represent the fuel assembly weight with a 35g acceleration.

For the tip-over accident (loading in the transverse direction), the 0° and 45° basket orientations are governing for the BWR basket as discussed in Section 3.10.2.3.1. Therefore, the basket is evaluated using models corresponding to the 0° and 45° basket orientations. Symmetry boundary conditions are applied at the plane of symmetry. Symmetry boundary conditions are also applied to both ends of the three-dimensional periodic finite element model. CONTAC52 elements are used to represent the interface of the basket and the canister shell inside the concrete cask. The location of the outer nodes of the gap elements at the basket periphery incorporates the canister shell displacements during the concrete cask tip-over accident. The boundary conditions are shown in Figure 3.10.2-11 and Figure 3.10.2-12 for the tip-over basket evaluation. For accident conditions, material properties at 500°F are conservatively used.

3.10.2.4 Post-Processing Finite Element Analysis Results

3.10.2.4.1 Maximum Stresses for Off-Normal Handling Condition

The post-processing of the finite element analysis results from the periodic model for the off-normal handling event is performed by taking section cuts at various locations in the model. The region just above and below the pin cutout (±0.25 inch) is omitted from the section cuts to eliminate local stress concentrations in the model. The membrane stresses are calculated by taking a section cut at the center of the tube thickness. The membrane plus bending stress is calculated by taking the maximum of the stresses calculated at the inner or outer surface of the fuel tube. Refer to Figure 3.10.2-13 through Figure 3.10.2-16 for tube identification and the locations of the section cuts.

The maximum stresses for the corner support weldments are calculated by taking section cuts along the length of the weldment (ten inches for the periodic model). Since the corner weldment is modeled using SHELL43 elements; the membrane stresses are calculated at the midplane of the element, and the membrane plus bending stresses are calculated using the maximum stresses

of either the inner or outer surface of the element. Refer to Figure 3.10.2-17 and Figure 3.10.2-18 for the locations of the section cuts.

The maximum stresses for the side weldments are calculated taking section cuts along the length of the weldment (ten inches for the periodic model). The membrane stresses are calculated by taking a section cut at the mid-thickness of the weldment. The membrane plus bending stress is calculated by taking the maximum of the stresses calculated at the inner or outer surface of the weldment. Refer to Figure 3.10.2-19 and Figure 3.10.2-20 for the locations of the section cuts. The bolt tensile loads are obtained from the LINK10 element results. The boss shear loads are extracted from the COMBIN40 element results.

3.10.2.4.2 Maximum Thermal Stresses

The post-processing of the finite element analysis results for thermal stress evaluation is performed by extracting the maximum membrane plus bending stress intensities from the thermal stress model. The maximum stress is obtained for the fuel tubes, the side support weldment and the corner support weldment.

3.10.2.4.3 Maximum Stresses for Concrete Cask Tip-over Accident

The post-processing of finite element analysis results for the basket tip-over accident using the three-dimensional plastic model is performed by extracting stresses in the basket for the 0° and 45° basket orientations. Both elastic and plastic stress results are calculated. Plastic stresses are obtained by finding the maximum equivalent plastic stress at each section cut location for membrane and membrane plus bending stresses.

The primary membrane stresses are calculated by extracting the maximum nodal stress at the mid-thickness of the tube wall. Based on the differences in stress criterion summarized from the plastic finite element results [i.e., $(\sigma + 3\ \tau)^{1/2}$] and the ASME Code, Section III stress criterion [i.e., $(\sigma + 4\ \tau)^{1/2}$], calculated membrane stress results are conservatively increased by a factor of $(4/3)^{1/2}$. The maximum membrane plus bending plastic equivalent stresses are generally not increased by this factor. However, if the adjusted membrane stress is higher than the membrane plus bending value, then the membrane plus bending stress is also increased by $(4/3)^{1/2}$ for consistency. If yielding has not occurred along a section, the averaged membrane or membrane plus bending stress intensities are reported.

Figure 3.10.2-1 Expanded View of BWR Basket

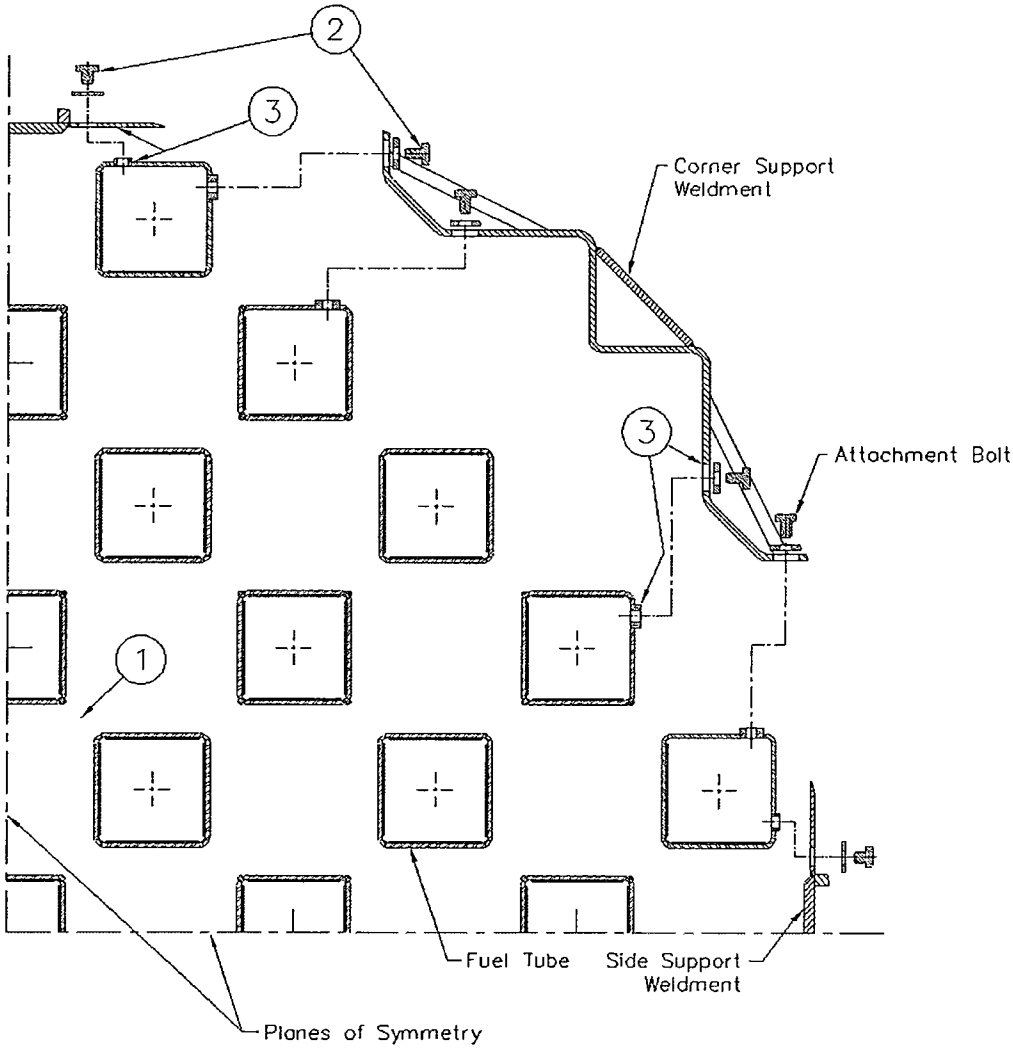


Figure 3.10.2-2 Bolted Attachment Details

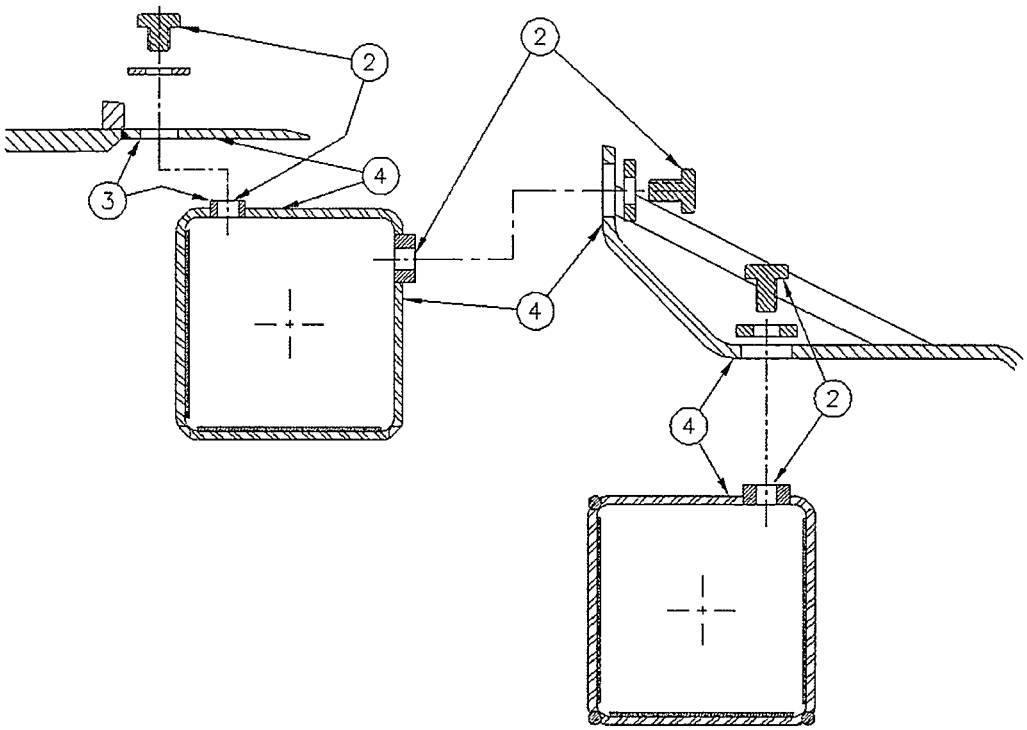
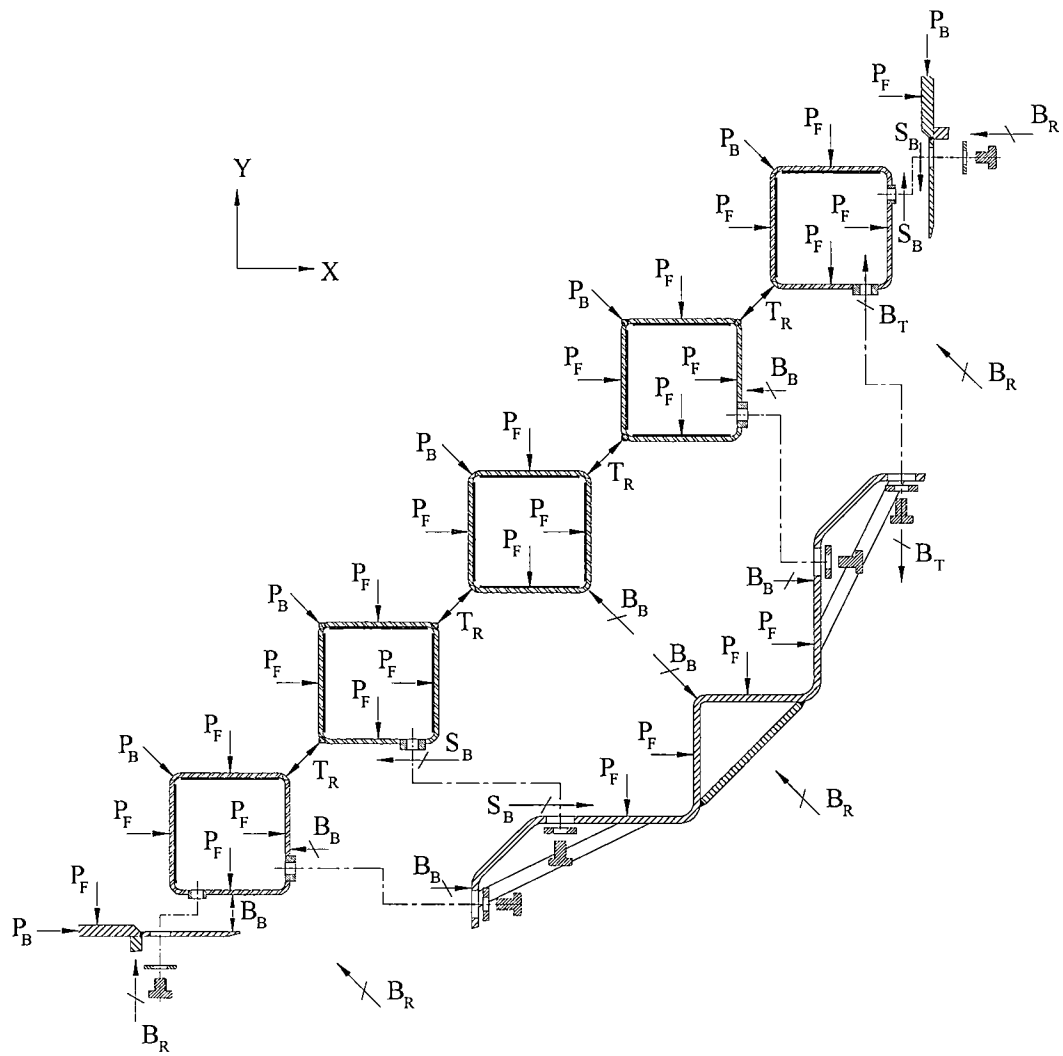


Figure 3.10.2-3 Free-Body Diagram of BWR Basket Fuel Tube Detail

[redacted]

Figure 3.10.2-4 Free-Body Diagram of Basket Support Structure



P_B	Loads due to adjacent basket structure
P_F	Local load due to fuel assembly
B_R	Basket reaction with TSC shell locations
B_T	Tensile load at bolt and tube boss (typical)
B_B	Bearing reaction between tube sidewall and support structure (typical)
S_B	Shear reaction between support structure and tube boss (typical)
T_R	Reactions between tubes detailed in Figure 3.10.2-3

Figure 3.10.2-5 BWR Basket Periodic Model – 0° Basket Orientation

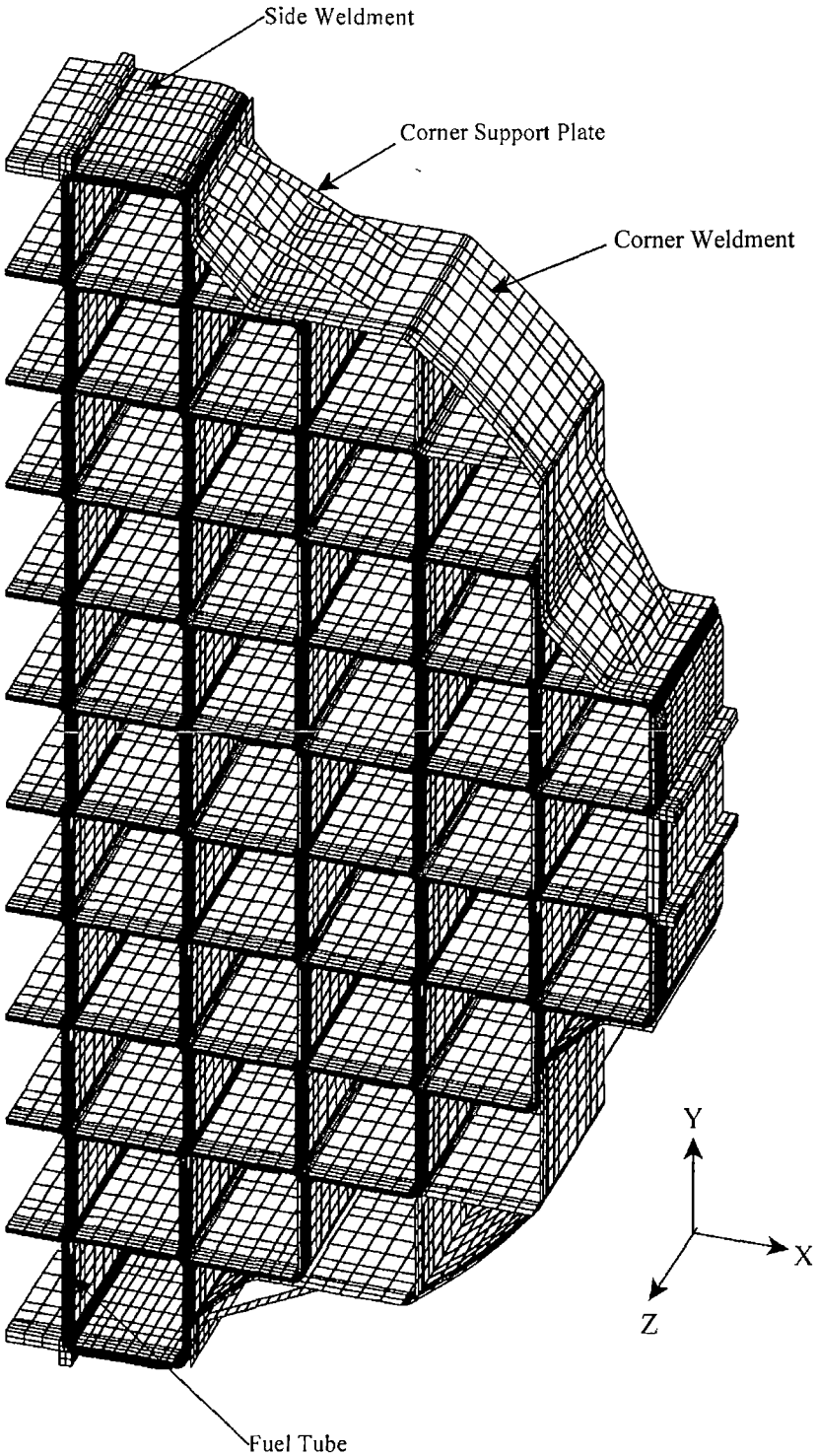


Figure 3.10.2-6 BWR Basket Periodic Model – 45° Basket Orientation

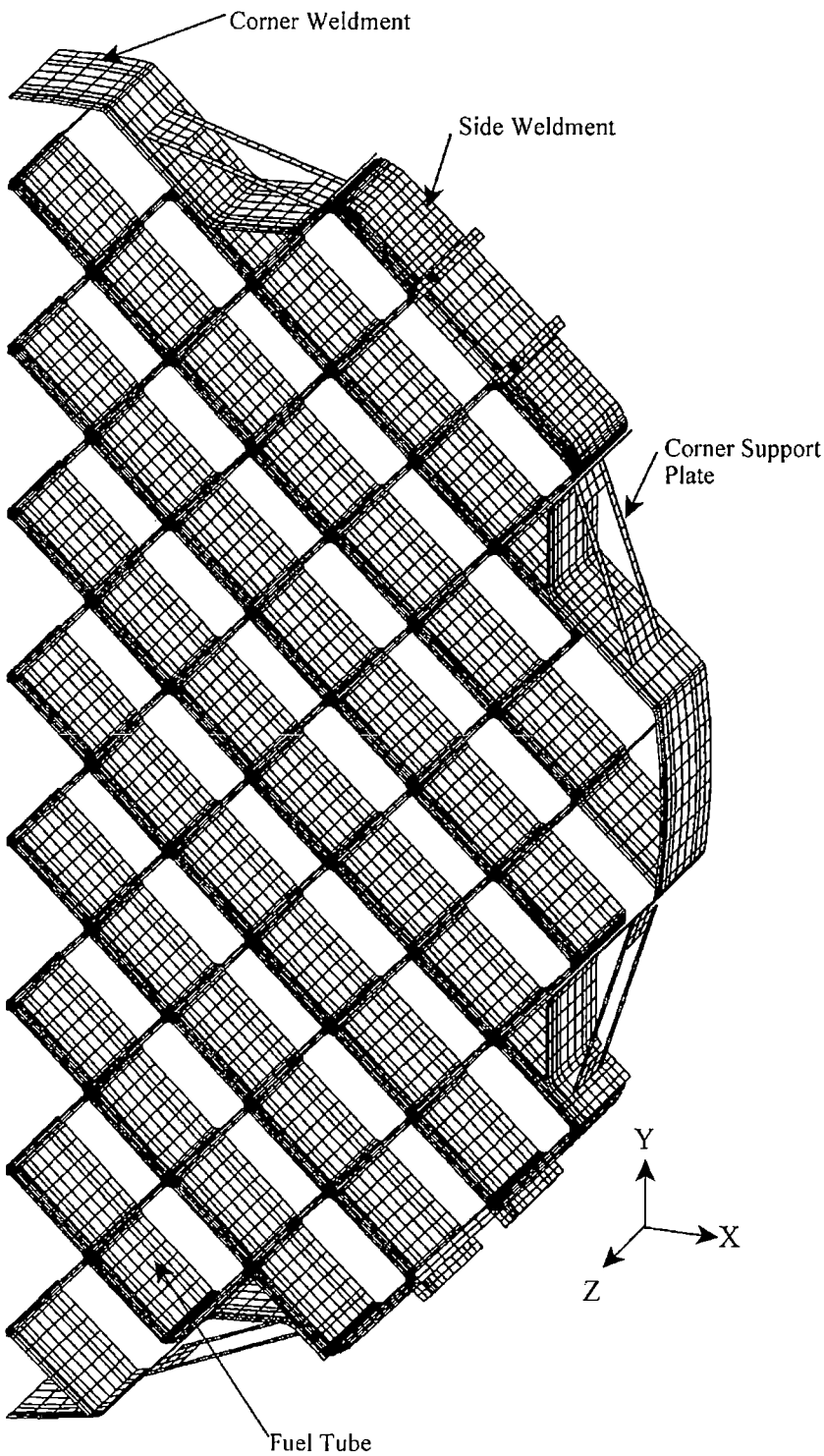


Figure 3.10.2-7 Thermal Stress Evaluation Model

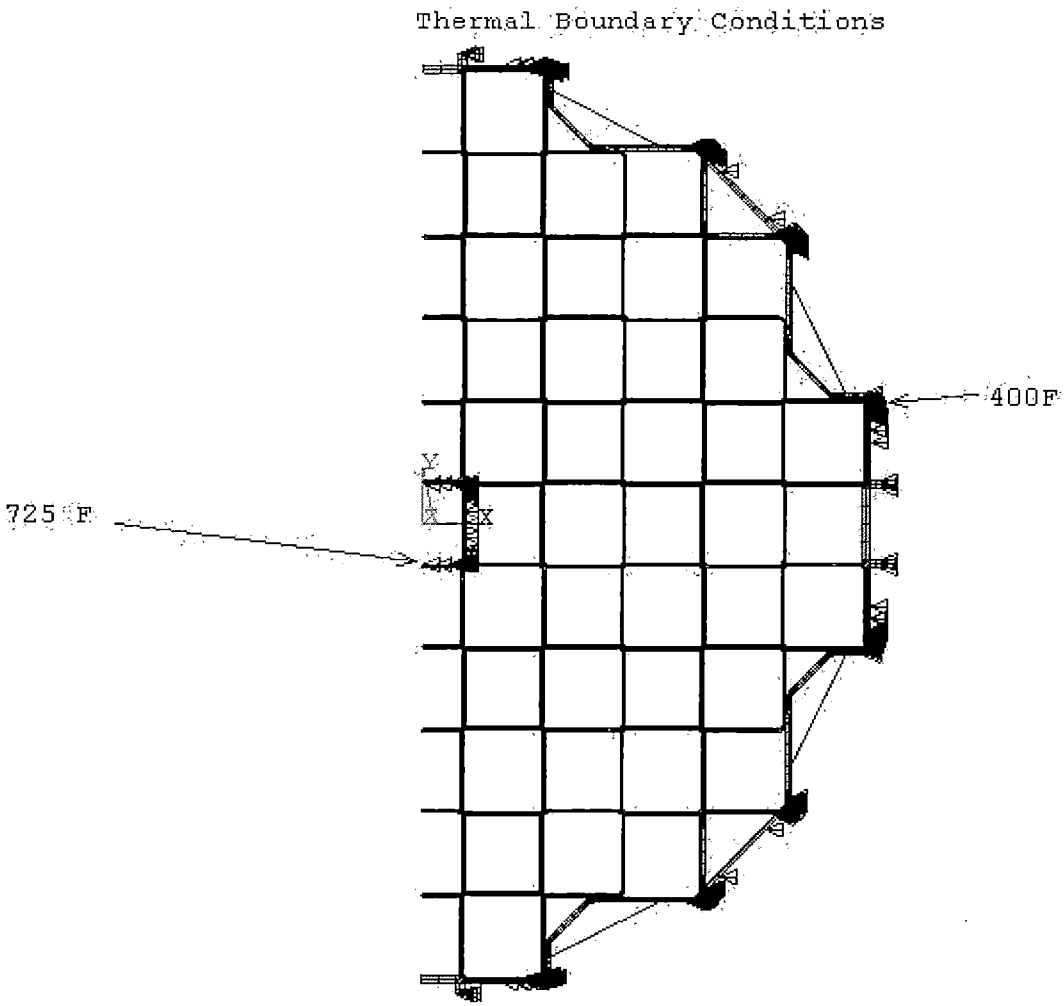


Figure 3.10.2-8 BWR Basket Plastic Model - 0° Basket Orientation

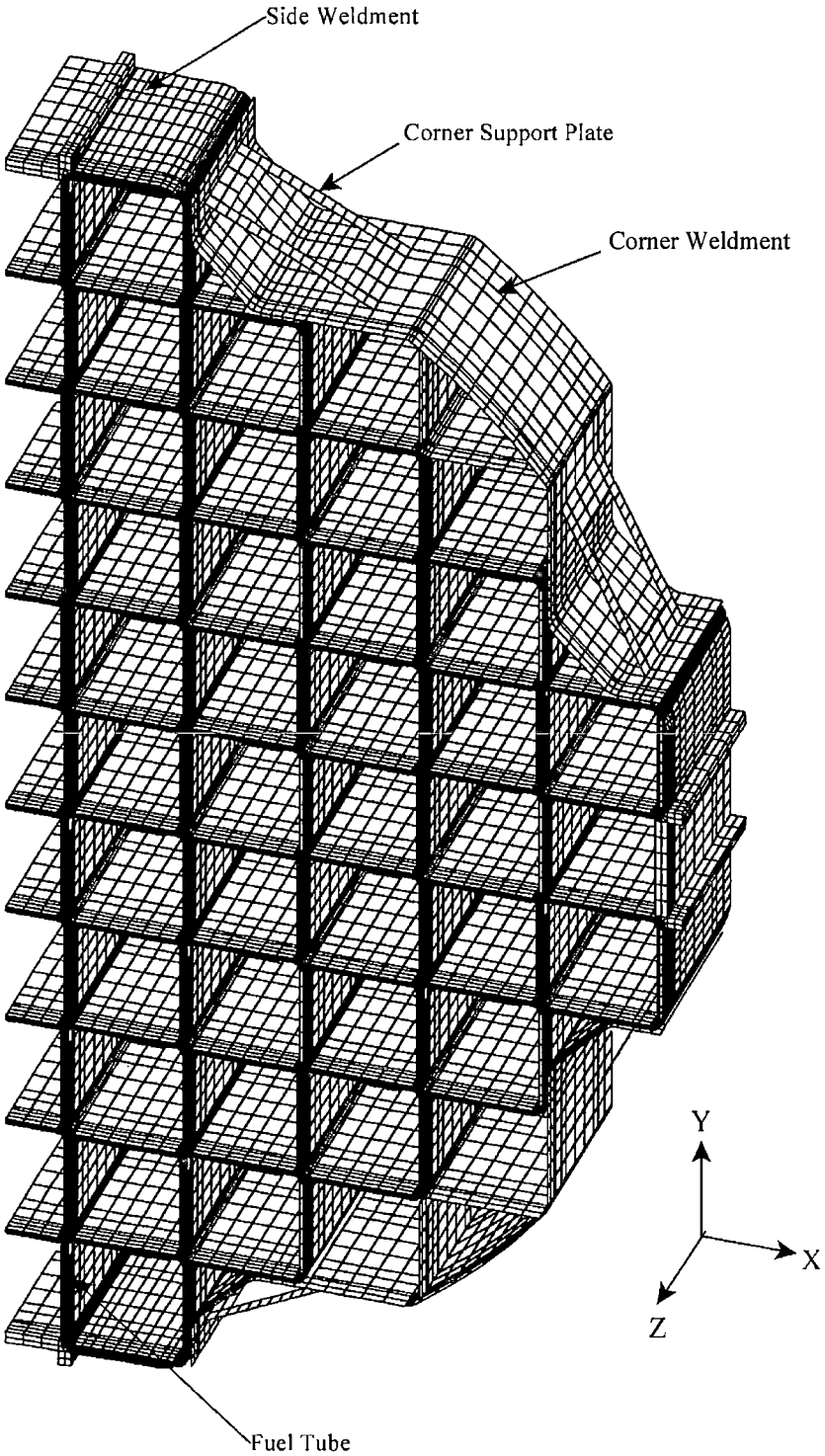


Figure 3.10.2-9 BWR Basket Plastic Model - 45° Basket Orientation

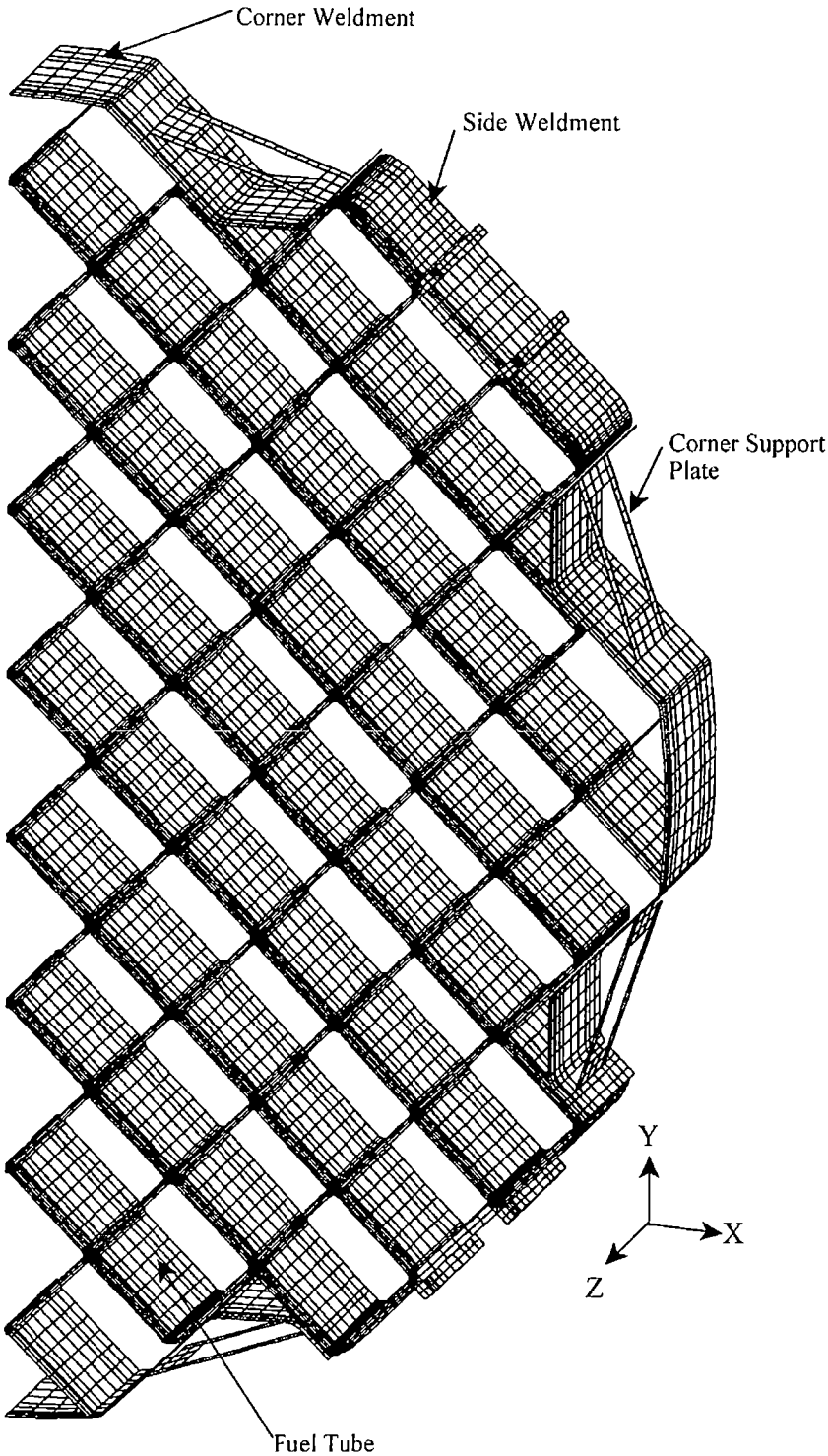


Figure 3.10.2-10 Typical BWR Fuel Tube Pin Finite Element Model Details

[redacted]

Figure 3.10.2-11 BWR Basket Model Boundary Conditions for a Transverse Loading – 0° Basket Orientation

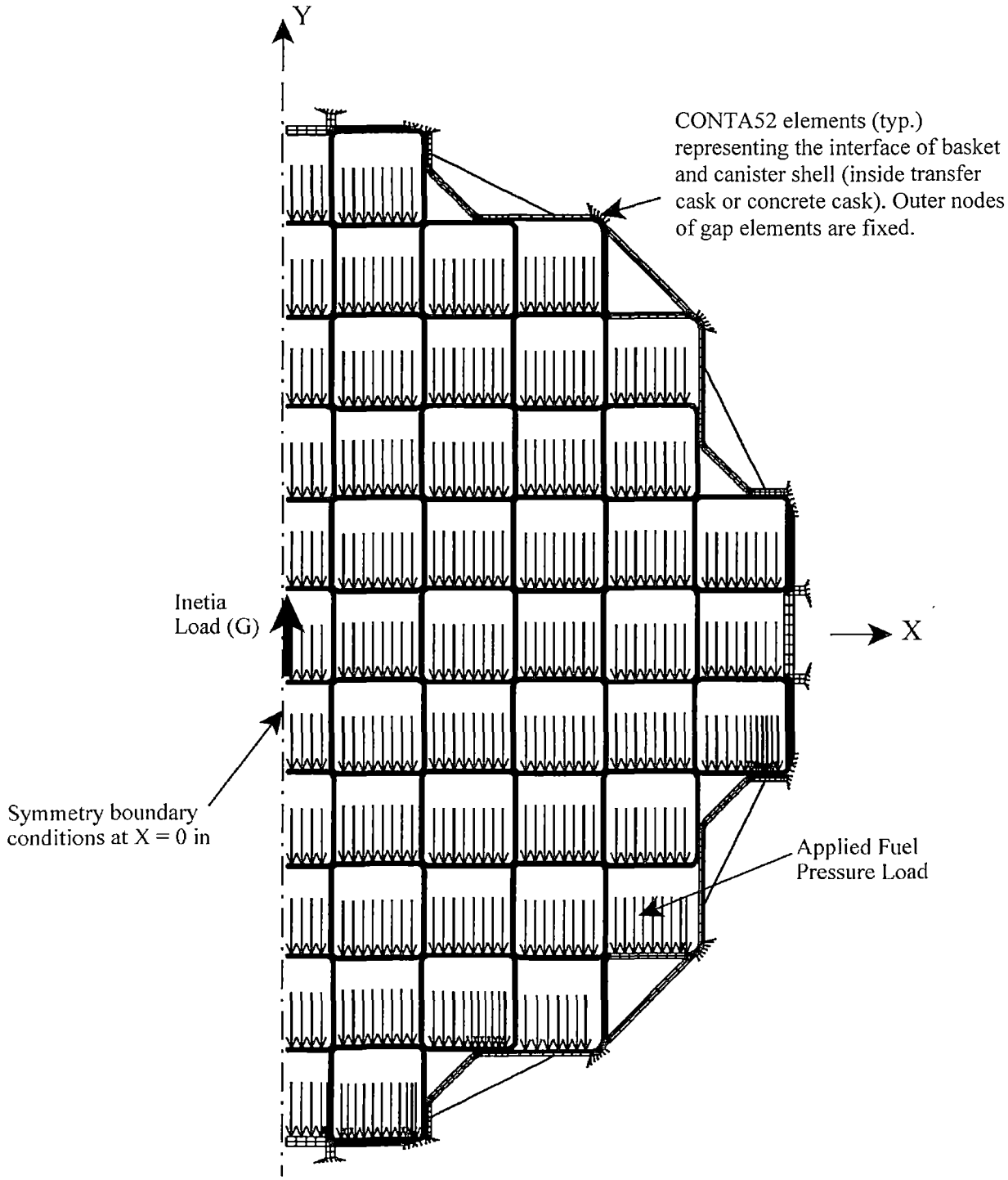


Figure 3.10.2-12 BWR Basket Model Boundary Conditions for a Transverse Loading – 45° Basket Orientation

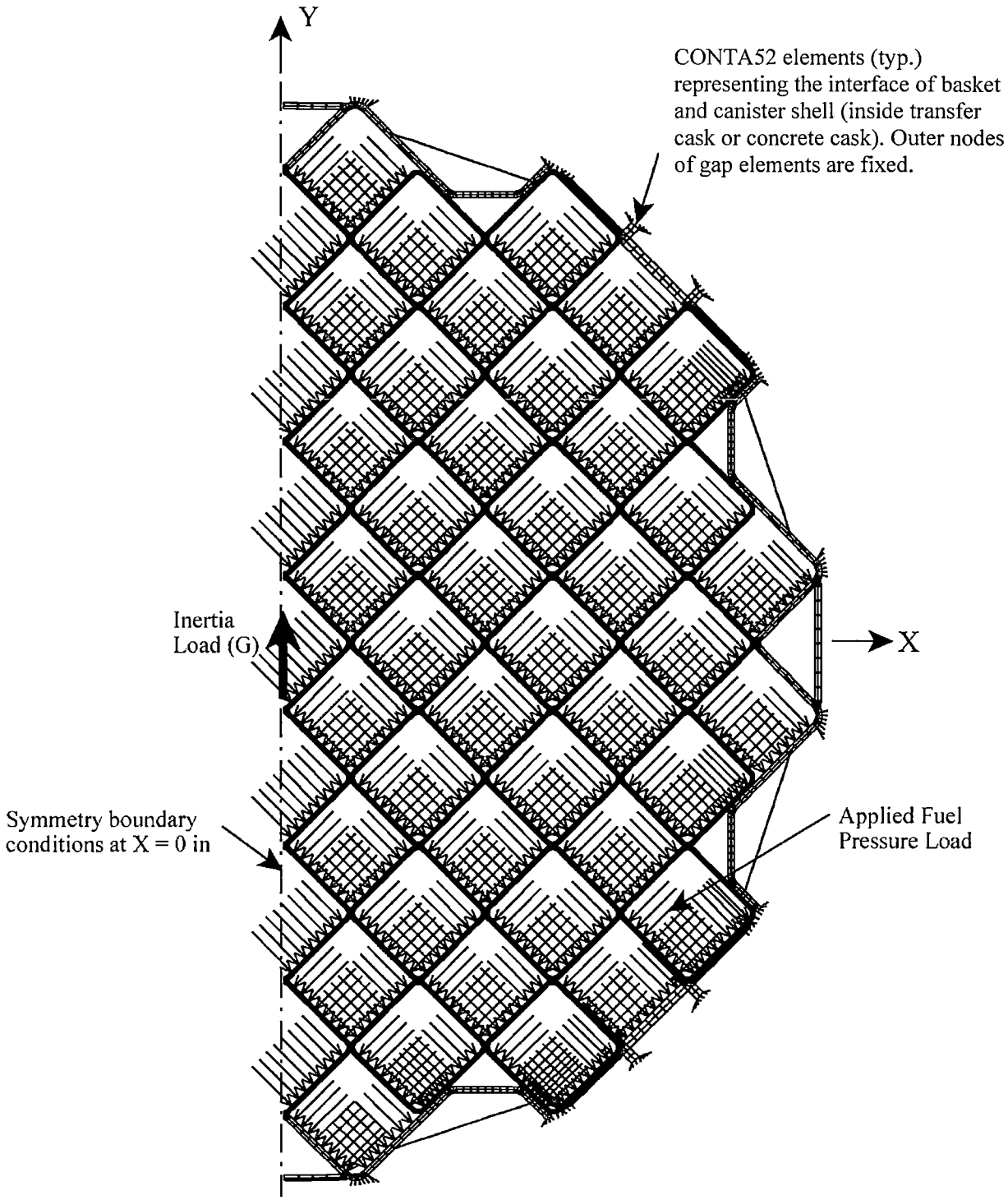


Figure 3.10.2-13 BWR Fuel Tube Array – 0° Basket Orientation

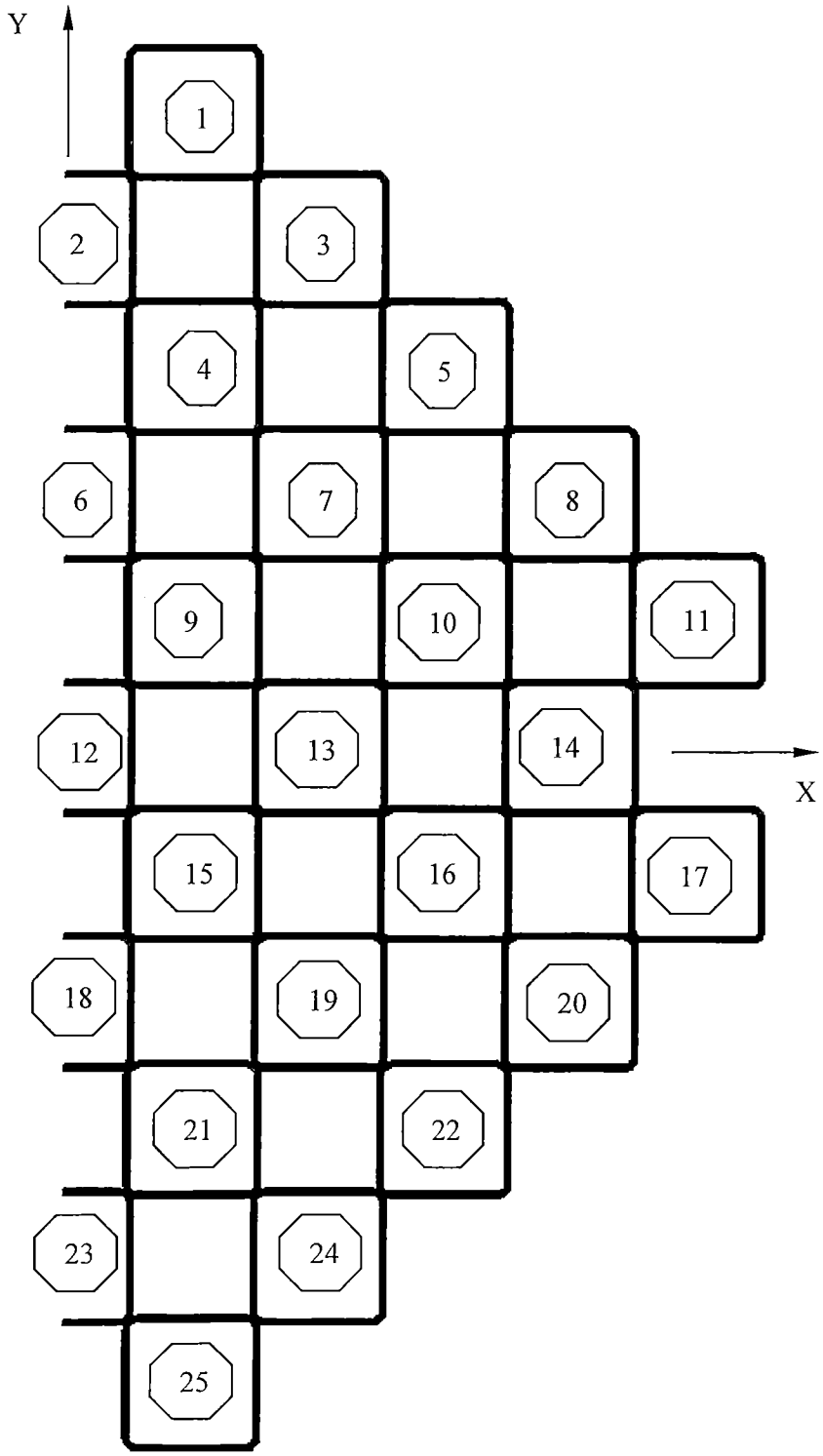


Figure 3.10.2-14 BWR Fuel Tube Section Cuts – 0° Basket Orientation

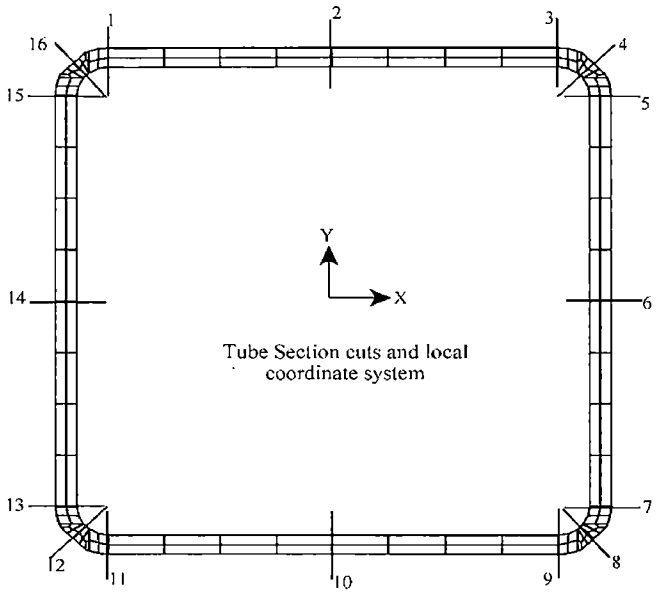


Figure 3.10.2-15 BWR Fuel Tube Array – 45° Basket Orientation

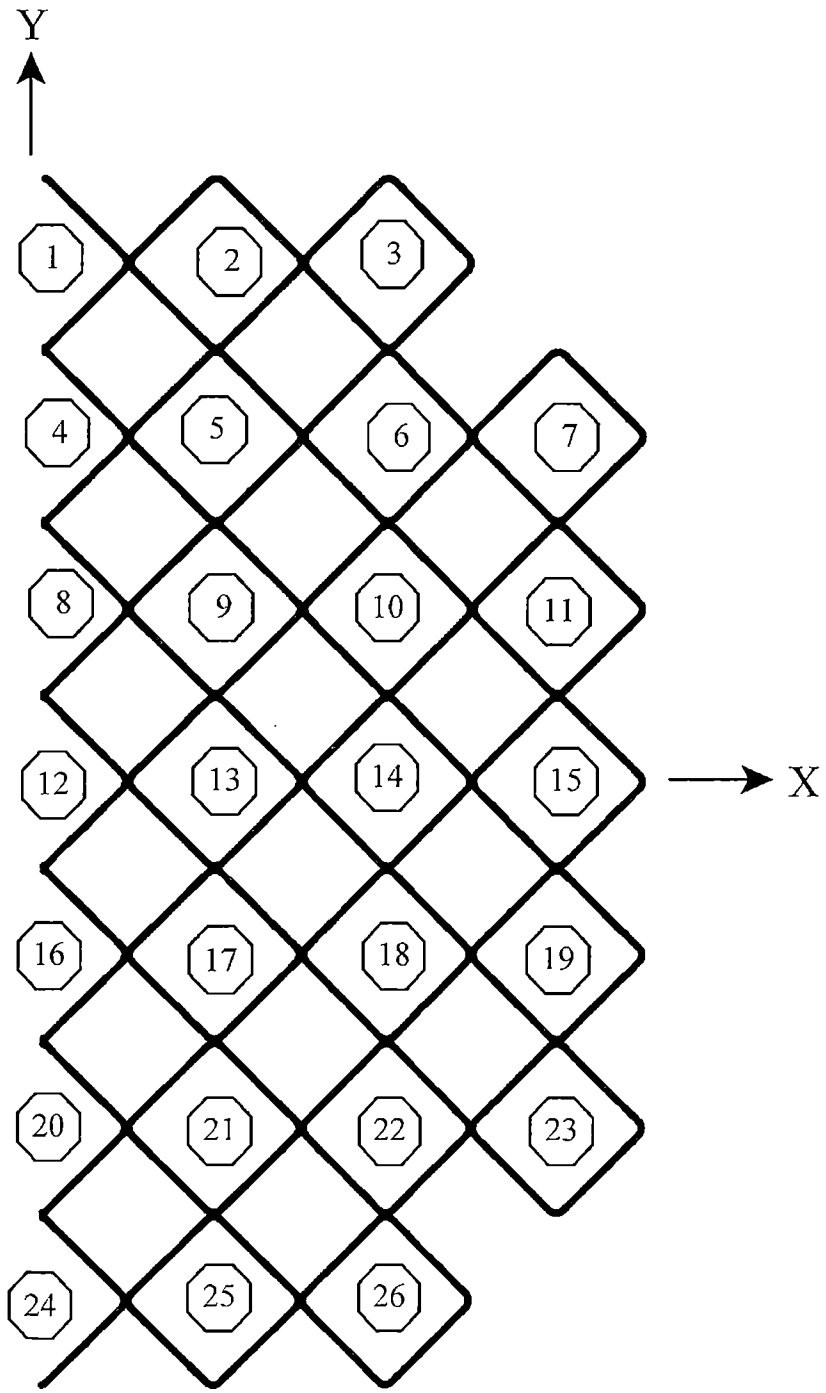


Figure 3.10.2-16 BWR Fuel Tube Section Cuts – 45° Basket Orientation

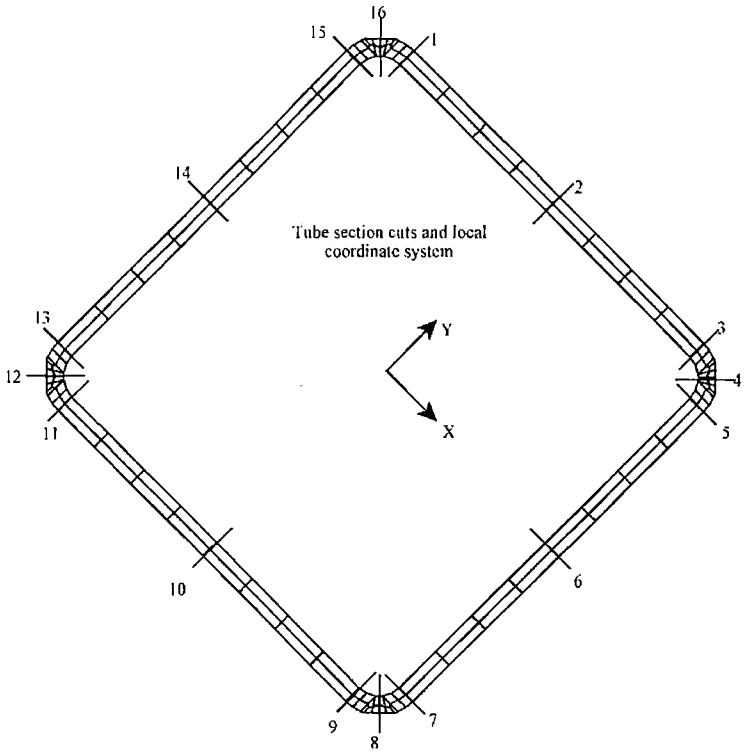


Figure 3.10.2-17 BWR Corner Support Weldment Section Cuts – 0° Basket Orientation

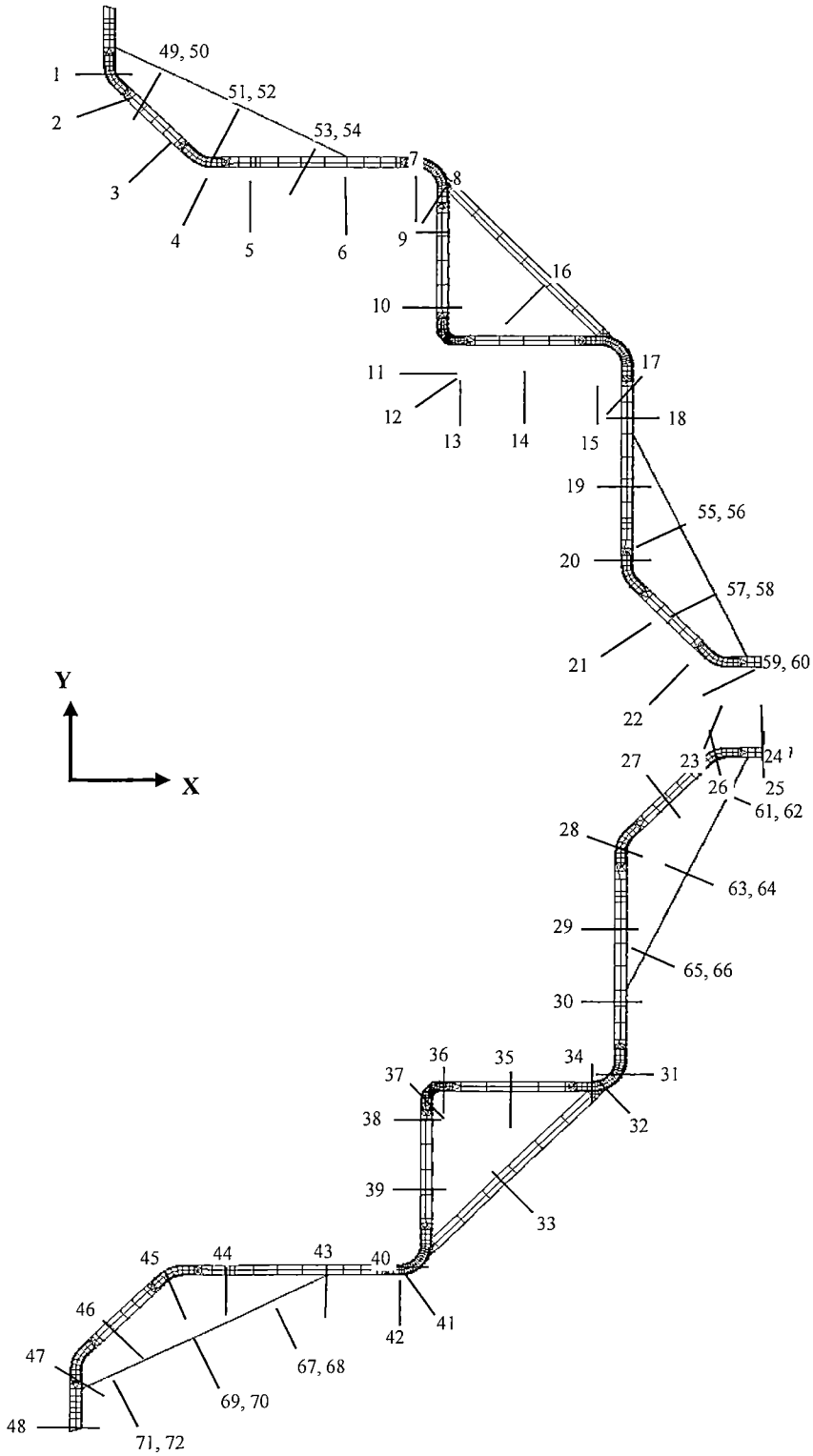


Figure 3.10.2-18 BWR Corner Support Weldment Section Cuts – 45° Basket Orientation

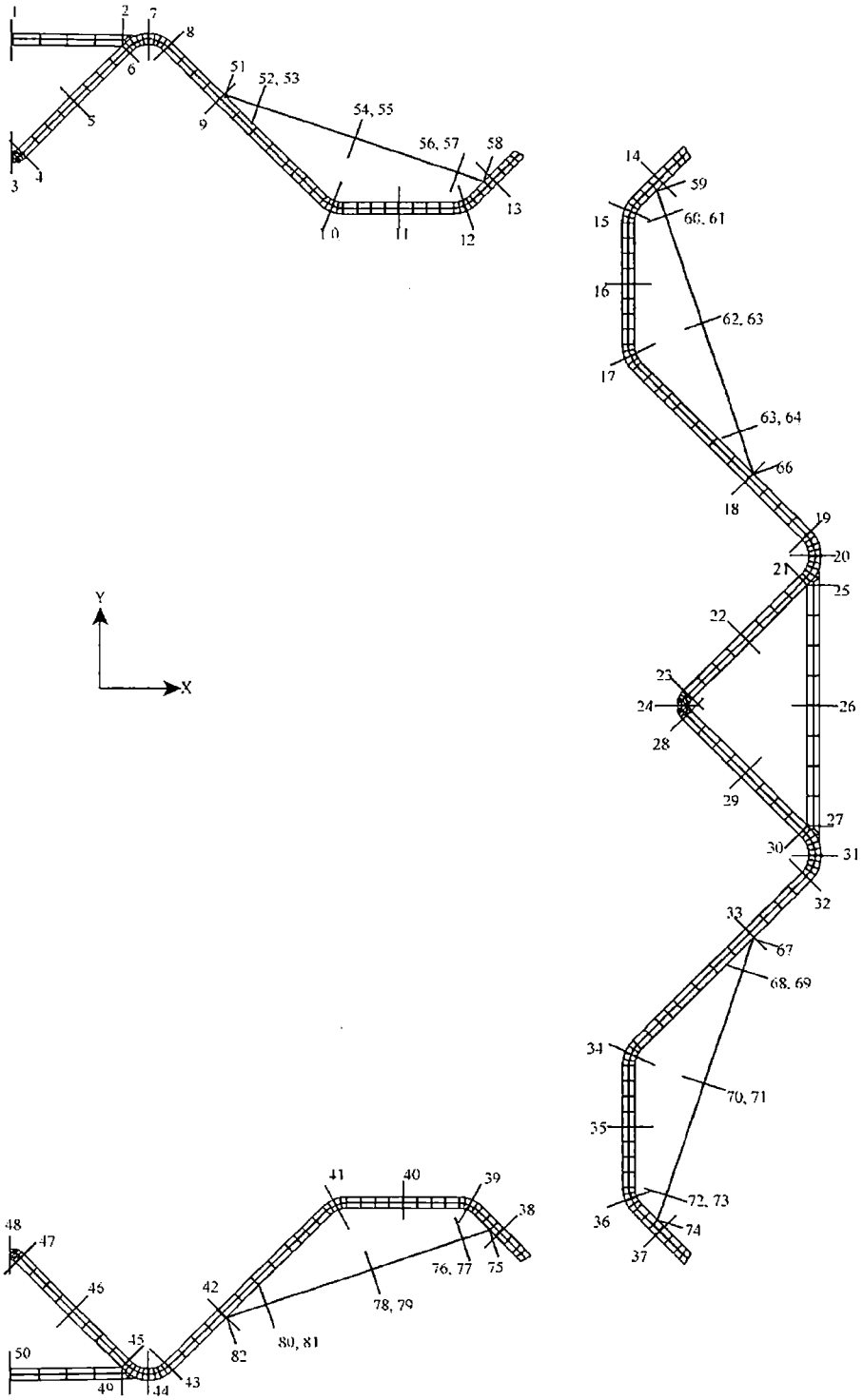


Figure 3.10.2-19 BWR Side Support Weldment Section Cuts – 0° Basket Orientation

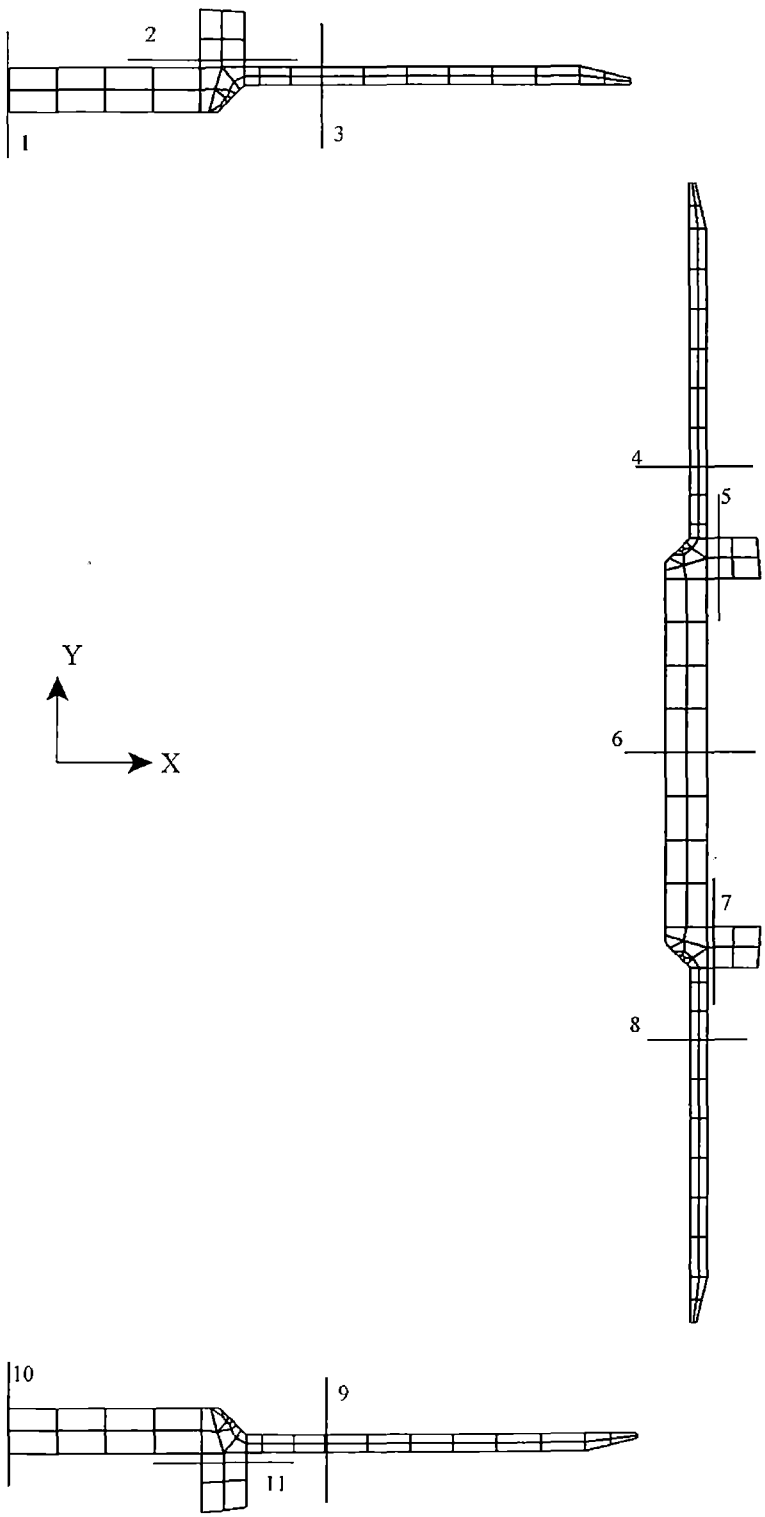
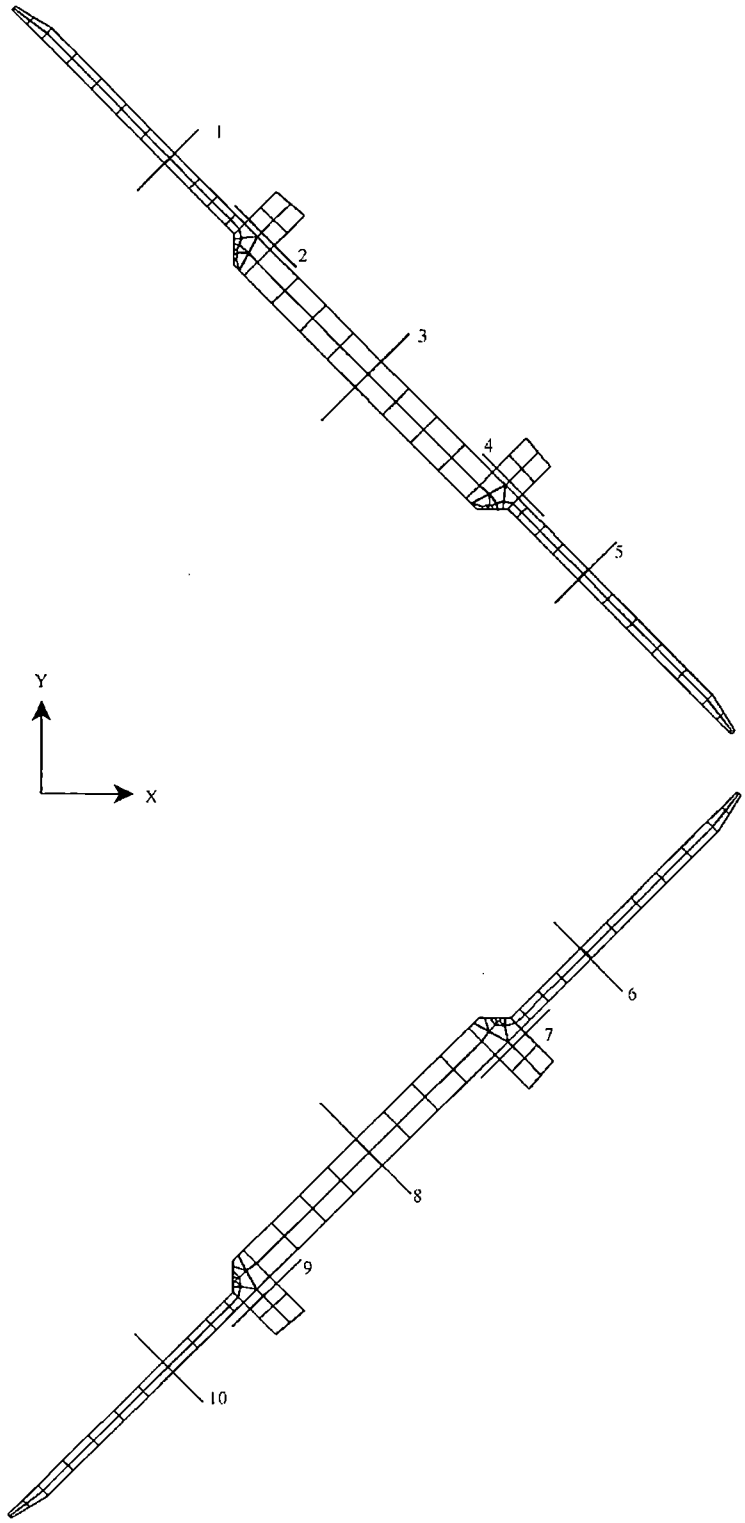


Figure 3.10.2-20 BWR Side Support Weldment Section Cuts – 45° Basket Orientation



3.10.3 TSC Finite Element Models

This section presents details on the TSC finite element models used in the structural evaluation of the different TSC configurations for lift, normal conditions and off-normal or accident events of storage. The finite element model used for the structural evaluation of the TSC configurations with the single-piece closure lid assembly design (i.e., TSC1 and TSC2) is described in Section 3.10.3.1. The finite element models used for the structural evaluation of the TSC configurations with the composite closure lid assembly design (i.e., TSC3 and TSC4) are described in Section 3.10.3.2.

3.10.3.1 TSC1/TSC2 Finite Element Model Description

The three-dimensional finite element model of the TSC configuration with the single-piece closure lid assembly (i.e., TSC1 and TSC2) is constructed using ANSYS SOLID45 elements. By taking advantage of the symmetry of the TSC, the model represents one-half (180° section) of the TSC, including the TSC shell, bottom plate, and closure lid. The finite element model of the TSC is shown in Figure 3.10.3-1. ANSYS CONTAC52 elements are used to model the interaction between the closure lid and the TSC shell. Gap elements are also used to simulate the interaction with the concrete cask inner liner standoffs or transfer cask inner shell during a side impact and pedestal during an end impact. The size of the CONTAC52 gaps is determined from nominal dimensions of contacting components. Due to the relatively large gaps resulting from the nominal geometry, these gaps remain open during all loadings considered. All gap elements are assigned a stiffness of 1×10^8 lb/in.

This model represents a "bounding" combination of geometry and loading that envelops all MAGNASTOR PWR and BWR TSC configurations with single-piece lids (i.e., TSC1 and TSC2 configurations). Specifically, the longest TSC is modeled in conjunction with a conservative fuel and basket combination. By using the longest TSC with the conservative content weight, bending stresses are maximized at the junction of the shell and lid. Thus, the analysis yields conservative results relative to the expected performance of the actual TSC configurations.

Boundary Conditions for TSC Lift

The lifting configuration for the TSC consists of six hoist rings bolted to the closure lid at equally spaced angular intervals. To simulate the lifting of the TSC, nodes representing the hoist rings on the closure lid are constrained in the Y-direction. For heavy lift evaluation, only three of the hoist rings are considered. Due to the symmetry of the model, only the nodes at 60° and 180° are constrained. Symmetry boundary conditions are applied at the plane of symmetry of the model. Pressure representing the weight of the fuel and basket is applied to the TSC bottom. A 1.1g inertia load is applied in the axial direction.

Boundary Conditions for Normal Conditions and Off-normal or Accident Events

Model Constraints

The model is constrained in the global Z-direction for all nodes in the plane of symmetry. Other constraints for different loading conditions are summarized below. The directions of the coordinate system are shown in Figure 3.10.3-1.

Model Constraint Summary

Condition	Constraint
Dead Weight	Y-direction at TSC bottom
Normal Handling	Y-direction – lift points in TSC lid
Off-normal Handling - axial	Y-direction – lift points in TSC lid
Off-normal Handling – lateral	Gap elements at TSC shell in radial direction
24-inch drop	Y-direction at TSC bottom
Tip-over	Gap elements at TSC shell in radial direction

Inertial Load

Inertial loads resulting from the weight of the TSC and contents are considered by applying an appropriate deceleration factor (g-load). Inertial loads are summarized below.

Inertial Load Summary

Condition	Inertial Load
Dead Weight	1g – axial
Normal Handling	1.1g – axial
Off-normal Handling	1.5g – axial, 0.707g – lateral
24-inch drop	60g – axial
Tip-over	Tapered 40g – lateral (40g at top of TSC closure lid, 1g at base of concrete cask)

Pressure Load – Internal Pressure

A uniform pressure is applied to all internal surfaces of the TSC shell, bottom plate and closure lid. The TSC pressures used for the normal condition (110 psig), off-normal (130 psig) and accident events (250 psig) bound all pressure conditions.

Pressure Load – Dead Load, Handling, and 24-inch Drop

For the dead load, handling, and 24-inch drop analyses, the inertial load produced by the contents weight is considered to be uniformly distributed on the inner surface of TSC bottom plate. Based on the contents weight of 90,000 lb and the TSC inside radius of 35.5 inches, the pressure corresponding to the contents weight is as follows.

$$p = \frac{90{,}000}{\pi\left(35.5^2\right)} = 22.7 \text{ psi}$$

The pressure load is multiplied by appropriate inertia loading (1g, 1.1g and 60g for dead load, handling, and 24-inch drop, respectively).

Pressure Load—Off-Normal Handling

For the off-normal handling analysis, the inertial load produced by the contents weight is considered to be uniformly distributed on the inner surface of TSC bottom plate multiplied by 1.5g for the axial component of off-normal handling. For the lateral component of the off-normal handling, the content weight is represented as an equivalent static pressure, with 0.707g, applied on the interior surface of the TSC shell. The pressure is uniformly applied to the canister shell along the TSC cavity length, and is applied in the circumferential direction as a cosine distribution over a 21° arc from the impact centerline in the half-symmetry model.

Pressure Load—Tip-Over

The inertial load produced by the 90,000 lb (45,000 lb for the half-symmetry model) content weight is represented as an equivalent static pressure applied on the interior surface of the TSC shell. The pressure is uniformly tapered along the cavity length based on a tapered inertia load of 40g at the top of the canister closure lid and 1g at the base of the concrete cask, and is applied in the circumferential direction as a cosine distribution over a 21° arc from the impact centerline.

Temperatures for Thermal Stress Analysis

The finite element thermal stress analysis is performed with TSC temperatures that envelop the TSC temperature gradients for normal (76°F ambient temperature) and off-normal storage (106°F and -40°F ambient temperatures), and transfer conditions for all TSC configurations. Prior to performing the thermal stress analysis, the steady-state temperature distribution is determined using bounding temperature data from the storage and transfer thermal analyses. This is accomplished by converting the SOLID45 structural elements of the TSC model to SOLID70 thermal elements to perform a thermal conduction analysis. Nodal temperatures are applied at key locations for the thermal analysis: top-center of the closure lid, top-outer diameter of the closure lid, bottom-center of the closure lid assembly, bottom-center of the bottom plate, bottom-outer diameter of the bottom plate, and the TSC shell where the maximum temperature occurs.

The temperature distribution used in the structural analyses envelops the temperature gradients experienced by all PWR and BWR TSC configurations under storage and transfer conditions.

The temperatures at the key locations are listed below. Temperatures locations (A through F) are defined in Figure 3.10.3-2. The temperatures for all nodes in the TSC model are obtained by the solution of the steady-state thermal conduction analysis.

Top-center of the closure lid (C)	=	510°F
Top-outer diameter of the closure lid (F)	=	430°F
Bottom-center of the closure lid (B)	=	570°F
Bottom-center of the bottom plate (A)	=	350°F
Bottom-outer diameter of the bottom plate (D)	=	240°F
Canister shell at 166 inches from TSC bottom (E)	=	510°F

Post-Processing

The stress evaluation for the TSC1/TSC2 configuration is performed in accordance with the ASME Code, Section III, Subsection NB, by comparing the linearized sectional stresses against allowable stresses. The sectional stresses at 15 locations of the TSC1/TSC2 model are obtained for each 3° angular division of the model at the stress locations shown in Figure 3.10.3-2. The allowable stresses for normal conditions and off-normal or accident events are taken from Subsection NB.

Bounding temperatures that envelop the maximum temperatures experienced by TSC components during storage and transfer conditions are used to determine allowable stress values. Temperatures used at each stress section are given in Figure 3.10.3-2. Allowable stress values at temperatures are determined based on mechanical properties for SA-240 Type 304 stainless steel. All stress components are reported in the global cylindrical coordinate system (X = Radial, Y = Circumferential, Z = Axial). Additionally, in accordance with ISG 15, Revision 0, an 0.8 weld reduction factor is applied to the allowable stresses for the closure lid weld (Section 11 of Figure 3.10.3-2).

TSC Analysis Result Details

Table 3.10.3-1 through Table 3.10.3-17 present detailed analyses results for the TSC1/TSC2 for normal conditions and off-normal and accident events of storage. Refer to Figure 3.10.3-2 for section cut locations.

Figure 3.10.3-1 MAGNASTOR TSC1/TSC2 Finite Element Model

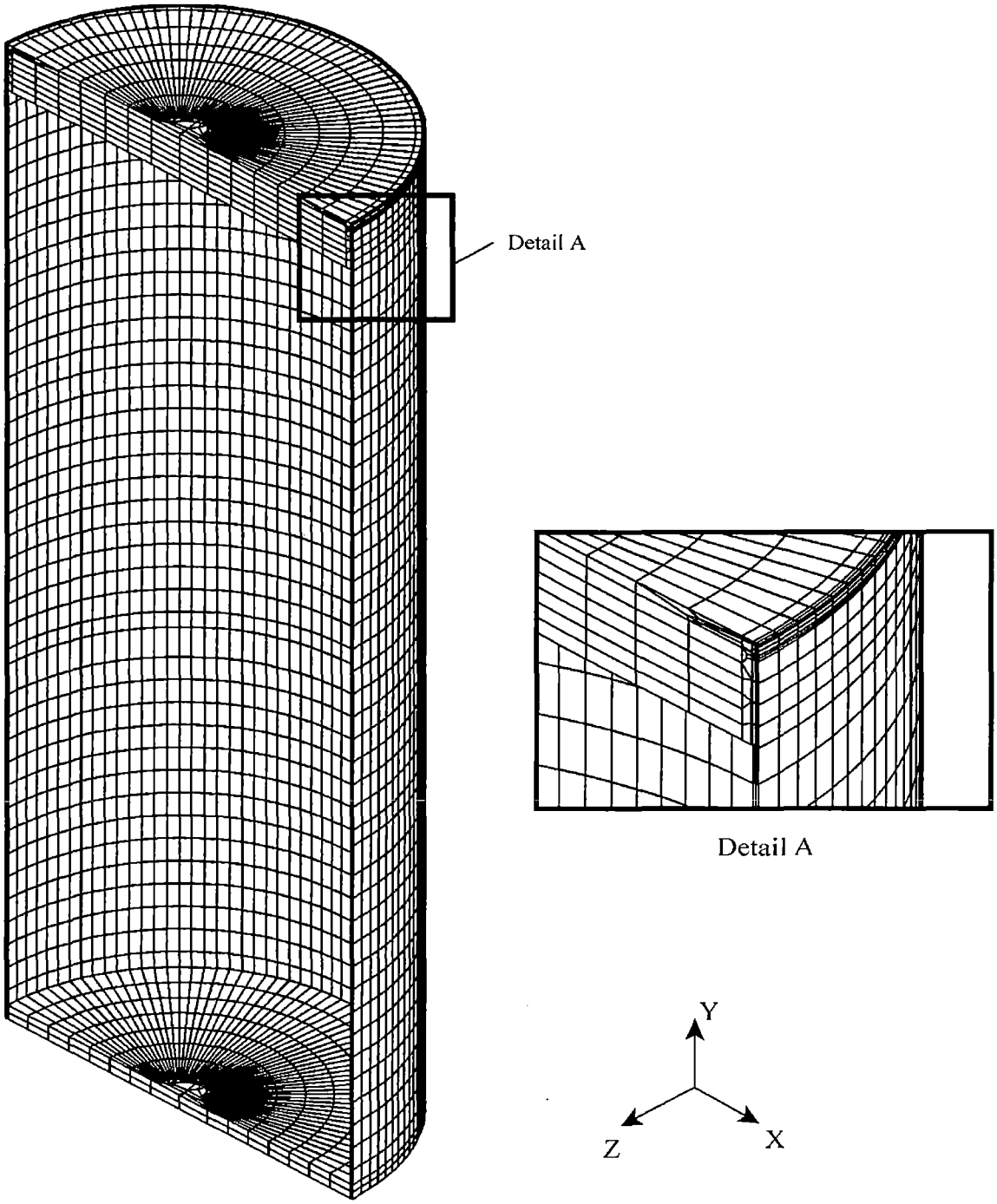
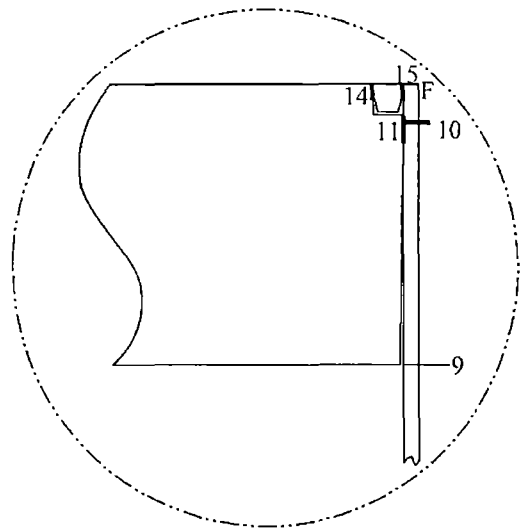


Figure 3.10.3-2 Identification of Sections for Evaluating Linearized Stresses in TSC1/TSC2



Weld Detail

Section Cut	Temperature Allowable (F)	Section Coordinates			
		Node 1		Node 2	
		X	Z	X	Z
1	225	35.50	0.00	35.50	2.75
2	225	35.50	2.75	36.00	2.75
3	250	35.50	5.75	36.00	5.75
4	400	35.50	41.42	36.00	41.42
5	425	35.50	69.58	36.00	69.58
6	470	35.50	94.92	36.00	94.92
7	500	35.50	112.75	36.00	112.75
8	500	35.50	148.42	36.00	148.42
9	450	35.50	182.75	36.00	182.75
10	450	35.50	190.50	36.00	190.50
11	450	35.50	190.25	35.50	190.75
12	250	0.00	0.00	0.00	2.75
13	450	0.00	182.75	0.00	191.75
14	450	34.5	191.50	34.5	191.75
15	450	35.5	191.5	35.5	191.75

Note: Dimensions in inches

Table 3.10.3-1 TSC1/TSC2 Normal Pressure plus Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-0.12	1.60	4.36	-0.04	0.05	-0.18	4.50	20.00	4.44
2	0.92	-9.06	-1.29	-0.22	0.01	-0.66	10.17	20.00	1.97
3	-0.58	-9.49	4.83	-0.19	-0.03	1.01	14.51	20.00	1.38
4	-0.02	7.81	4.78	-0.21	0.00	0.00	7.84	18.70	2.39
5	-0.04	7.81	4.78	-0.20	0.00	0.00	7.86	18.40	2.34
6	-0.04	7.81	4.77	-0.21	0.00	0.00	7.86	17.86	2.27
7	-0.05	7.81	4.76	-0.21	0.00	0.00	7.86	17.50	2.23
8	-0.05	7.80	4.74	-0.21	0.00	0.00	7.86	17.50	2.23
9	-0.07	7.70	4.72	-0.20	0.00	0.03	7.78	18.10	2.33
10	-0.35	1.26	1.08	0.00	0.00	0.07	1.62	18.10	large
11	-0.09	1.15	0.38	-0.01	0.00	-0.85	1.89	14.48[b]	7.66
12	0.25	0.29	-0.65	0.00	1.26	-1.41	3.90	20.00	5.13
13	0.03	0.03	-0.06	0.00	-0.05	0.05	0.17	18.10	large
14	0.49	1.59	-0.04	0.02	-0.05	-0.13	1.67	18.10	large
15	0.18	1.51	0.08	0.00	0.00	-0.10	1.50	18.10	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-2 TSC1/TSC2 Normal Pressure plus Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-0.96	-5.82	11.51	-0.09	-0.02	-0.25	17.33	30.00	1.73
2	2.84	-14.16	-1.29[b]	0.00	0.00	-1.19	17.32	30.00	1.73
3	-0.25	-4.94	19.45	-0.08	-0.04	1.27	24.48	30.00	1.23
4	-0.05	7.92	4.82	-0.21	0.00	0.01	7.98	28.05	3.52
5	-0.06	7.94	4.81	-0.21	0.00	-0.02	8.02	27.60	3.44
6	-0.07	7.95	4.81	-0.21	0.00	0.00	8.03	26.79	3.34
7	-0.07	7.96	4.80	-0.21	0.00	0.00	8.04	26.25	3.26
8	-0.08	7.94	4.78	-0.21	0.00	0.00	8.03	26.25	3.27
9	-0.05	8.12	6.32	-0.21	0.00	0.01	8.18	27.15	3.32
10	-0.78	1.13	1.11	0.00	0.00	0.89	2.60	27.15	large
11	-0.14	1.54	2.05	0.00	0.00	-1.18	3.23	21.72[c]	6.72
12	24.66	23.52	2.96	0.75	1.07	-1.42	22.26	30.00	1.35
13	2.87	2.85	0.04	0.00	-0.06	0.04	2.82	27.15	9.63
14	0.61	1.66	-0.07	0.04	-0.09	-0.12	1.77	27.15	large
15	-0.59	1.25	-0.15	0.00	0.05	0.06	1.85	27.15	large

[a] See Figure 3.10.3-2 for section locations.
[b] Localized bending stresses are secondary and are excluded from evaluation.
[c] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-3 TSC1/TSC2 Normal Pressure plus Handling, P + Q, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	0.68	12.71	-2.73	-0.02	-0.01	-0.05	15.44	60.00	3.89
2	2.82	-11.18	-19.61	0.00	0.00	-1.19	22.56	60.00	2.66
3	-0.29	-3.60	19.95	0.00	0.04	1.22	23.63	60.00	2.54
4	-0.06	8.18	4.84	-0.21	0.01	0.01	8.25	56.10	6.80
5	-0.07	8.29	4.84	-0.21	0.00	-0.02	8.37	55.20	6.59
6	-0.08	8.33	4.82	-0.21	0.00	0.00	8.42	53.58	6.36
7	-0.08	8.37	4.84	-0.22	0.00	0.00	8.46	52.50	6.21
8	-0.08	8.30	4.84	-0.21	0.00	0.00	8.39	52.50	6.26
9	-0.07	7.92	6.29	0.00	0.00	0.00	7.99	54.30	6.80
10	-0.89	2.51	0.39	0.00	-0.01	1.13	4.06	54.30	large
11	-0.24	2.34	-1.52	0.04	0.01	-0.55	4.06	43.44[b]	large
12	-41.04	-37.90	-8.45	-1.25	-0.15	-1.51	33.17	60.00	1.81
13	-13.65	-12.13	-3.78	-0.26	0.64	0.28	9.99	54.30	5.44
14	0.06	3.03	-0.40	0.00	0.00	-0.10	3.45	54.30	large
15	-1.13	3.57	-0.13	0.09	-0.01	-0.02	4.70	54.30	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-4 TSC1/TSC2 Normal Pressure, P_m, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
1	-0.10	1.33	3.61	-0.03	0.04	-0.17	3.73
2	0.79	-7.22	-1.16	0.18	-0.01	-0.55	8.17
3	-0.50	-6.93	3.91	0.13	0.02	0.85	11.01
4	-0.03	7.81	3.86	-0.21	0.00	0.00	7.84
5	-0.04	7.81	3.85	-0.21	0.00	0.00	7.86
6	-0.04	7.81	3.85	-0.21	0.00	0.00	7.86
7	-0.05	7.80	3.85	-0.21	0.00	0.00	7.86
8	-0.05	7.80	3.85	-0.21	0.00	0.00	7.86
9	-0.06	7.73	3.85	-0.20	0.00	0.04	7.81
10	-0.40	0.77	0.59	-0.03	0.01	0.27	1.24
11	-0.11	0.95	0.83	-0.03	-0.01	-0.60	1.53
12	0.19	0.23	-0.63	0.00	0.98	-1.13	3.11
13	0.04	0.04	-0.06	0.00	-0.04	0.04	0.15
14	0.31	1.06	-0.09	-0.02	0.00	-0.07	1.16
15	0.09	1.04	0.16	-0.02	-0.01	-0.04	0.97

[a] See Figure 3.10.3-2 for section locations.

Table 3.10.3-5 TSC1/TSC2 Normal Pressure, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
1	-0.75	-4.52	9.51	0.07	0.02	-0.22	14.03
2	2.37	-11.47	-16.71	0.00	0.00	-0.99	19.19
3	-0.20	-3.23	15.78	0.04	0.03	1.07	19.08
4	-0.06	7.90	3.89	-0.21	0.00	0.01	7.96
5	-0.07	7.90	3.87	-0.21	0.00	-0.02	7.98
6	-0.07	7.90	3.87	-0.21	0.00	0.00	7.98
7	-0.07	7.90	3.87	-0.21	0.00	0.00	7.98
8	-0.08	7.89	3.87	-0.21	0.00	0.00	7.98
9	-0.05	8.19	5.53	0.00	0.00	0.01	8.24
10	-0.75	0.37	-0.33	-0.03	0.02	1.02	2.08
11	0.07	1.40	2.30	-0.04	-0.01	-0.90	2.87
12	19.64	18.71	2.15	0.59	0.79	-1.14	17.91
13	2.24	2.22	0.03	0.00	-0.04	0.04	2.21
14	0.43	1.14	-0.08	-0.02	0.02	-0.05	1.22
15	-0.46	0.84	-0.06	-0.03	-0.01	0.02	1.30

[a] See Figure 3.10.3-2 for section locations.

Table 3.10.3-6 TSC1/TSC2 Thermal Stresses, Q, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
1	-0.05	3.72	0.05	0.00	0.00	0.04	3.79
2	-0.20	2.82	-0.25	-0.08	0.00	-0.01	3.08
3	0.09	1.06	-0.51	0.00	-0.01	-0.03	1.57
4	0.00	-0.27	-0.15	0.01	0.00	0.00	0.27
5	0.00	-0.36	-0.20	0.02	0.00	0.00	0.36
6	0.00	-0.42	-0.21	0.02	0.00	0.00	0.42
7	0.00	-0.43	-0.23	0.02	0.00	0.00	0.43
8	-0.01	-0.44	-0.20	0.02	0.00	0.00	0.43
9	-0.02	-0.57	-0.20	0.03	0.00	-0.01	0.55
10	-0.12	1.37	-0.74	0.00	-0.01	0.24	2.20
11	-0.33	1.63	0.01	0.01	0.00	0.07	1.98
12	-16.87	-14.95	-4.20	-0.50	-1.60	-0.10	13.05
13	-10.85	-9.35	-3.62	-0.26	0.69	0.22	7.38
14	-0.25	1.60	-0.07	0.00	0.00	0.01	1.86
15	-0.49	2.39	0.17	-0.05	0.01	0.02	2.88

[a] See Figure 3.10.3-2 for section locations.

Table 3.10.3-7 TSC1/TSC2 Off-Normal Pressure plus Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-0.14	1.84	5.02	-0.05	0.06	-0.21	5.18	22.00	4.25
2	1.07	-10.37	-1.51	-0.26	0.01	-0.76	11.66	22.00	1.89
3	-0.67	-10.75	5.54	-0.21	-0.03	1.16	16.51	22.00	1.33
4	-0.03	9.23	5.48	-0.24	0.00	0.00	9.27	20.57	2.22
5	-0.04	9.23	5.48	-0.24	0.00	0.00	9.28	20.24	2.18
6	-0.05	9.23	5.47	-0.24	0.00	0.00	9.29	19.65	2.11
7	-0.05	9.23	5.46	-0.24	0.00	0.00	9.29	19.25	2.07
8	-0.06	9.22	5.44	-0.24	0.00	0.00	9.29	19.25	2.07
9	-0.08	9.11	5.42	-0.24	0.00	0.04	9.20	19.91	2.16
10	-0.42	1.41	1.20	0.00	0.00	0.11	1.84	19.91	large
11	-0.11	1.32	0.53	-0.01	0.00	-0.96	2.13	15.93[b]	7.48
12	0.28	0.33	-0.76	0.00	1.44	-1.62	4.47	22.00	4.92
13	0.04	0.04	-0.07	0.00	-0.06	0.06	0.20	19.91	large
14	0.54	1.79	-0.06	0.02	-0.05	-0.14	1.88	19.91	large
15	0.20	1.70	0.11	0.00	0.00	-0.11	1.67	19.91	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-8 TSC1/TSC2 Off-Normal Pressure plus Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-1.10	-6.64	13.23	-0.10	-0.03	-0.28	19.88	33.00	1.66
2	3.27	-16.24	-23.02	0.00	0.00	-1.37	26.44	60.00[b]	2.27
2	3.27	-16.24	-1.51[c]	0.00	0.00	-1.37	19.87	33.00	1.66
3	-0.28	-5.53	22.31	0.00	0.00	1.47	27.94	33.00	1.18
4	-0.06	9.36	5.52	-0.25	0.00	0.01	9.43	30.86	3.27
5	-0.07	9.38	5.51	-0.25	0.00	-0.03	9.47	30.36	3.21
6	-0.08	9.39	5.51	-0.25	0.00	0.00	9.49	29.47	3.11
7	-0.09	9.39	5.50	-0.25	0.00	0.00	9.49	28.88	3.04
8	-0.09	9.38	5.48	-0.25	0.00	0.00	9.48	28.88	3.05
9	-0.06	9.62	7.34	0.00	0.01	0.01	9.68	29.87	3.09
10	-0.92	1.19	1.05	0.00	0.00	1.08	2.92	29.87	large
11	-0.13	1.79	2.47	0.00	0.00	-1.35	3.75	23.89[d]	6.37
12	28.23	26.93	3.35	0.86	1.22	-1.62	25.52	33.00	1.29
13	3.27	3.25	0.05	0.00	-0.06	0.05	3.23	29.87	9.25
14	0.68	1.87	-0.09	0.04	-0.09	-0.13	1.99	29.87	large
15	-0.67	1.41	-0.16	0.00	0.05	0.07	2.09	29.87	large

[a] See Figure 3.10.3-2 for section locations.
[b] Bending stresses are considered secondary, P+Q stress allowable used.
[c] Localized bending stresses are secondary and are excluded from evaluation.
[d] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-9 TSC1/TSC2 Off-Normal Pressure plus Handling, P + Q, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	0.78	14.01	-3.15	-0.02	-0.01	-0.07	17.16	60.00	3.50
2	3.26	-13.26	-22.64	0.00	0.00	-1.37	26.04	60.00	2.30
3	-0.32	-4.19	22.81	0.00	0.04	1.41	27.09	60.00	2.21
4	-0.07	9.61	5.55	-0.25	0.01	0.01	9.69	55.20	5.62
5	-0.08	9.72	5.55	-0.25	0.00	-0.02	9.82	53.58	5.43
6	-0.09	9.77	5.53	-0.25	0.00	0.00	9.87	53.58	5.43
7	-0.09	9.80	5.54	-0.25	0.00	0.00	9.91	52.50	5.30
8	-0.09	9.74	5.55	-0.25	0.00	0.00	9.85	52.50	5.33
9	-0.08	9.41	7.30	0.00	-0.01	0.00	9.49	54.30	5.72
10	-1.03	2.58	0.32	0.00	-0.01	1.31	4.41	54.30	large
11	-0.29	2.43	-1.64	0.04	0.01	-0.61	4.30	43.44[b]	large
12	-44.54	-41.22	-9.07	-1.36	0.06	-1.71	36.12	60.00	1.66
13	-14.05	-12.53	-3.80	-0.26	0.63	0.29	10.36	54.30	5.24
14	0.43	3.48	-0.16	0.04	-0.09	-0.13	3.66	54.30	large
15	-1.21	3.72	-0.14	0.10	-0.01	-0.01	4.94	54.30	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-10 TSC1/TSC2 Normal Pressure plus Off-Normal Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-1.64	1.20	4.54	0.20	0.04	-0.35	6.23	24.75	3.97
2	1.20	-10.15	-1.07	0.26	-0.14	-0.70	11.57	24.75	2.14
3	-0.60	-10.57	5.42	0.01	-0.10	1.06	16.17	24.50	1.52
4	-0.12	7.94	5.63	0.08	0.00	0.00	8.06	22.50	2.79
5	-0.12	7.89	5.63	0.07	0.00	0.00	8.00	22.12	2.77
6	-0.12	7.88	5.59	0.06	0.00	0.00	8.00	21.45	2.68
7	-0.13	7.88	5.57	0.07	0.00	0.00	8.01	21.00	2.62
8	-0.15	7.95	5.45	0.09	0.01	0.00	8.09	21.00	2.60
9	-0.08	7.91	4.90	0.03	-0.08	0.03	7.98	21.75	2.73
10	-6.14	-0.11	0.89	0.66	-0.18	-0.64	7.27	21.75	2.99
11	-4.94	0.30	-0.34	0.75	-0.22	-1.44	6.10	17.40[b]	2.85
12	0.24	0.32	-0.65	0.00	1.37	-1.51	4.18	24.50	5.86
13	0.02	0.04	-0.06	0.00	-0.06	0.05	0.17	21.75	large
14	-1.58	1.35	-0.21	0.47	0.03	0.07	3.08	21.75	7.06
15	-3.66	0.93	-0.20	0.67	-0.28	-0.27	4.87	21.75	4.47

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-11 TSC1/TSC2 Normal Pressure plus Off-Normal Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-1.04	-6.70	12.44	0.35	0.10	-0.29	19.17	35.40	1.85
2	3.13	-15.72	-1.07[b]	-0.05	-0.19	-1.29	19.23	35.40	1.84
3	-0.23	-6.17	21.24	-0.14	0.05	1.35	27.49	34.80	1.27
4	-0.14	12.81	7.14	-0.35	0.02	0.01	12.96	31.10	2.40
5	-0.13	12.91	7.18	-0.36	0.00	-0.02	13.06	30.60	2.34
6	-0.13	12.87	7.14	-0.36	0.00	0.00	13.02	29.70	2.28
7	-0.14	12.92	7.13	-0.36	0.00	0.00	13.07	29.10	2.23
8	-0.17	12.75	6.94	-0.35	-0.01	0.00	12.94	29.10	2.25
9	-0.29	9.76	4.16	-0.24	-0.16	0.06	10.06	30.10	2.99
10	-7.43	-1.04	1.17	0.59	-0.18	0.21	8.68	30.10	3.47
11	-5.58	0.24	0.80	0.66	-0.18	-1.51	7.22	24.08[c]	3.34
12	26.41	25.35	3.25	0.80	1.18	-1.51	23.79	34.80	1.46
13	2.95	3.19	0.05	0.00	-0.06	0.03	3.14	30.10	9.59
14	-1.38	1.63	-0.14	0.52	0.02	0.13	3.20	30.10	9.41
15	-3.47	1.19	-0.12	0.73	-0.20	-0.35	4.95	30.10	6.08

[a] See Figure 3.10.3-2 for section locations.
[b] Localized bending stresses are secondary and are excluded from evaluation.
[c] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-12 TSC1/TSC2 Normal Pressure plus 24-inch Drop, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-0.11	0.79	0.27	-0.02	0.07	0.37	1.14	47.58	large
2	1.34	-9.26	-8.42	0.24	-0.02	-0.99	10.71	47.58	4.44
3	-0.52	-8.65	-4.81	-0.17	-0.03	0.93	8.33	47.15	5.66
4	-0.03	7.81	-4.26	0.00	0.00	0.00	12.07	44.80	3.71
5	-0.04	7.80	-3.77	-0.20	0.00	0.00	11.58	44.10	3.81
6	-0.04	7.81	-3.33	0.21	0.00	0.00	11.14	42.84	3.85
7	-0.05	7.80	-3.02	0.21	0.00	0.00	10.83	42.00	3.88
8	-0.05	7.80	-2.40	0.21	0.00	0.00	10.21	42.00	4.11
9	-0.05	7.92	-1.81	0.21	0.00	0.05	9.74	43.40	4.46
10	-0.68	-1.09	-2.03	0.00	0.00	1.31	2.95	43.40	large
11	-0.22	0.63	3.05	0.00	0.00	0.63	3.51	34.72[b]	9.89
12	0.46	0.38	-1.22	-0.01	0.98	-0.95	3.19	47.15	large
13	0.04	0.04	-0.05	0.00	0.02	-0.02	0.10	43.40	large
14	-0.61	-0.65	-0.26	0.00	0.00	0.12	0.44	43.40	large
15	-0.67	-0.56	0.15	0.01	-0.02	0.14	0.87	43.40	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-13 TSC1/TSC2 Normal Pressure plus 24-inch Drop, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	1.99	7.87	-4.91	0.00	0.00	1.28	13.01	69.80	5.37
2	3.02	-14.27	-8.42[b]	0.00	0.00	-1.49	17.49	69.80	3.99
3	-0.84	-12.49	-17.20	0.00	-0.01	0.71	16.42	68.60	4.18
4	-0.06	7.90	-4.22	0.21	0.00	0.01	12.13	64.00	5.28
5	-0.06	7.91	-3.75	0.21	0.00	-0.02	11.67	63.75	5.46
6	-0.07	7.91	-3.30	0.21	0.00	0.00	11.22	63.30	5.64
7	-0.07	7.91	-2.99	0.21	0.00	0.00	10.91	63.00	5.77
8	-0.08	7.90	-2.37	-0.21	0.00	0.00	10.28	63.00	6.13
9	-0.08	7.36	-3.87	0.19	0.00	0.06	11.24	63.50	5.65
10	-0.62	-2.86	-7.82	0.00	0.00	1.68	7.95	63.50	7.99
11	-1.59	-0.02	2.52	0.00	0.00	0.86	4.46	50.80[c]	large
12	17.98	18.23	1.64	0.67	0.76	-0.94	17.24	68.60	3.98
13	0.92	0.92	-0.09	0.00	0.02	-0.02	1.01	63.50	large
14	-0.83	-0.80	-0.46	0.00	0.00	0.17	0.51	63.50	large
15	-1.65	-0.97	-0.29	0.01	-0.02	0.33	1.52	63.50	large

[a] See Figure 3.10.3-2 for section locations.
[b] Localized bending stresses are secondary and are excluded from evaluation.
[c] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-14 TSC1/TSC2 Accident Pressure plus Dead Weight, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-0.23	3.01	8.15	-0.08	0.09	-0.37	8.42	47.58	5.65
2	1.81	-16.45	-2.76	0.40	-0.01	-1.26	18.61	47.58	2.56
3	-1.13	-15.79	8.74	0.29	0.06	1.93	24.90	47.15	1.89
4	-0.06	17.74	8.63	-0.47	0.00	0.00	17.83	44.80	2.51
5	-0.09	17.74	8.63	-0.47	0.00	0.00	17.85	44.10	2.47
6	-0.10	17.74	8.63	-0.47	0.00	0.00	17.86	42.84	2.40
7	-0.11	17.74	8.64	-0.47	0.00	0.00	17.87	42.00	2.35
8	-0.11	17.73	8.64	-0.47	0.00	0.00	17.87	42.00	2.35
9	-0.15	17.58	8.66	-0.46	0.00	0.08	17.75	43.40	2.45
10	-0.91	1.73	1.29	-0.07	0.02	0.63	2.81	43.40	large
11	-0.26	2.16	1.92	-0.07	-0.02	-1.35	3.47	34.72[b]	large
12	0.43	0.52	-1.44	-0.01	2.23	-2.57	7.07	47.15	6.67
13	0.08	0.08	-0.13	0.00	-0.10	0.10	0.35	43.40	large
14	0.69	2.39	-0.20	-0.05	0.01	-0.17	2.62	43.40	large
15	0.19	2.35	0.36	-0.06	-0.02	-0.09	2.19	43.40	large

[a] See Figure 3.10.3-2 for section locations.
[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-15 TSC1/TSC2 Accident Pressure plus Dead Weight, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	-1.74	-10.29	21.53	0.15	0.04	-0.50	31.84	69.80	2.19
2	5.41	-26.12	-2.76[b]	0.00	0.00	-2.26	32.12	69.80	2.17
3	-0.46	-7.35	35.72	0.09	0.07	2.43	43.24	68.60	1.59
4	-0.13	17.95	8.70	-0.47	0.00	0.02	18.10	64.00	3.54
5	-0.15	17.96	8.68	-0.47	0.00	-0.04	18.13	63.75	3.52
6	-0.16	17.95	8.68	-0.47	0.00	0.00	18.14	63.30	3.49
7	-0.17	17.95	8.68	-0.47	0.00	0.00	18.15	63.00	3.47
8	-0.18	17.94	8.69	-0.47	0.00	0.00	18.14	63.00	3.47
9	-0.10	18.62	12.48	0.00	0.00	0.03	18.73	63.50	3.39
11	0.17	3.19	5.25	-0.08	-0.03	-2.02	6.49	50.80[c]	7.83
10	-1.70	0.77	-0.93	0.00	0.00	2.33	4.73	63.50	large
12	44.60	42.52	4.88	1.35	1.80	-2.58	40.70	68.60	1.69
13	5.04	5.00	0.07	0.01	-0.10	0.10	4.98	63.50	large
14	0.95	2.55	-0.19	-0.05	0.03	-0.12	2.75	63.50	large
15	-1.03	1.90	-0.12	-0.07	-0.02	0.05	2.93	63.50	large

[a] See Figure 3.10.3-2 for section locations.
[b] Localized bending stresses are secondary and are excluded from evaluation.
[c] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-16 TSC1/TSC2 Tip-Over plus Normal Pressure, P_m, ksi

Section[a]	Angle	Component Stresses						S_{int}	S_{allow}	FS
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	69	-0.16	1.58	3.91	0.13	0.29	-0.35	4.17	47.58	large
2	69	1.12	-8.58	-2.50	0.16	0.79	-0.72	9.95	47.58	4.78
3	69	-0.55	-8.76	3.00	-0.04	1.22	0.94	12.23	47.15	3.86
4	27	-0.03	8.93	0.26	0.01	3.26	0.00	10.84	44.80	4.13
5	0	-4.82	-12.05	-10.93	12.58	0.33	1.15	26.27	44.10	2.57
6	0	-0.39	8.60	-5.39	-0.10	-0.24	0.06	14.01	42.84	3.06
7	0	-0.32	10.05	-1.64	-0.02	-0.15	0.00	11.69	42.00	3.59
8	0	-0.52	8.21	1.81	0.27	-0.06	0.00	8.75	42.00	4.80
9	33	-1.29	16.48	2.21	1.33	-1.22	0.16	18.09	43.40	2.40
10[b]	6	-5.49	6.78	-0.91	-2.40	-2.01	-1.82	14.33	43.40	3.03
11[c]	0 - 6	-23.89	-17.09	-19.05	10.77	-1.77	-8.92	29.05	34.72[c]	1.20
12	0	0.18	0.23	-0.56	0.00	0.87	-1.04	2.82	47.15	large
13	0	-1.36	-0.23	-0.57	0.12	-0.01	-3.40	6.86	43.40	6.33
14[b]	6	1.90	-8.88	0.00	5.20	4.00	-2.09	16.65	43.40	2.61
15[b]	6	0.13	-6.01	-2.29	-0.42	-0.78	0.09	6.36	43.40	6.83

[a] See Figure 3.10.3-2 for section locations.
[b] Bearing stress evaluation is not required for accident conditions.
[c] Stresses are determined by averaging the stresses over the impact region. Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-17 TSC1/TSC2 Tip-Over plus Normal Pressure, P_m+P_b, ksi

Section[a]	Angle	Component Stresses						S_{int}	S_{allow}	FS
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	69	-0.54	-5.28	10.47	0.15	0.51	-0.44	15.81	69.80	4.41
2	66	2.77	-13.66	-2.50[b]	0.07	0.78	-1.17	16.74	69.80	4.17
3	66	-0.17	-4.90	16.94	-0.06	1.33	1.18	22.09	68.60	3.11
4	27	-0.07	19.54	3.84	0.01	4.15	0.01	20.64	64.00	3.10
5	60	0.68	59.72	41.78	0.02	0.81	0.28	59.06	63.75	1.08
6	60	-0.08	20.79	11.91	-0.01	-0.75	-0.02	20.94	63.30	3.02
7	0	-0.55	18.40	0.89	-0.23	-0.11	0.00	18.96	63.00	3.32
8	0	-0.87	18.35	4.84	0.01	-0.02	0.00	19.22	63.00	3.28
9	30	5.14	55.19	39.08	0.00	-1.26	-1.52	50.22	63.50	1.26
10[c]	6	-13.17	17.49	7.56	-2.41	2.07	-2.76	31.85	63.50	1.99
11[d]	0 - 6	-23.93	-16.43	-16.49	11.98	1.54	-13.41	36.44	50.80[d]	1.39
12	0	18.01	16.62	1.95	0.55	0.71	-1.04	16.40	68.60	4.18
13	0	-4.19	-2.86	-1.41	0.12	0.55	-3.61	7.82	63.50	8.12
14[c]	6	2.57	-10.04	0.16	5.22	5.18	-2.61	18.87	63.50	3.36
15[c]	6	8.66	-1.44	0.34	-1.10	0.55	-1.76	10.79	63.50	5.88

[a] See Figure 3.10.3-2 for section locations.
[b] Localized bending stresses are secondary and are excluded from evaluation.
[c] Bearing stress evaluation is not required for accident conditions.
[d] Stresses are determined by averaging the stresses over the impact region. Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

3.10.3.2 TSC3/TSC4 Finite Element Model Description

The stresses in the TSC3 and TSC4 configurations (i.e., TSCs with composite closure lid assembly designs) resulting from the design basis normal, off-normal, and accident loads for storage conditions are determined using the three-dimensional ½-symmetry finite element models shown in Figure 3.10.3-3 and Figure 3.10.3-4. These finite element models are similar to the finite element model used for the evaluation of the TSC1/TSC2 configuration (i.e., single-piece closure lid assembly design) that is described in Section 3.10.3.1, differing only in the geometry of the TSC closure lid assembly and closure ring. The finite element model shown in Figure 3.10.3-3 represents the TSC3 with the ¾-inch wide closure ring, whereas, the finite element model shown in Figure 3.10.3-4 represents the TSC3 with the 1½-inch wide closure ring.

The 4-inch thick closure lid and a 5-inch thick shield plate are both modeled using 3-D structural solid elements (SOLID45). The shield plate and closure lid are modeled using the temperature-dependent material properties of SA-36 carbon steel and Type 304 stainless steel, respectively. The nonlinear interaction between the shield plate and closure lid is modeled using 3-D point-to-point contact elements (CONTAC52). The gap elements are modeled initially closed with a contact stiffness of 1×10^8 lb/inch. The ten 1 ½-6 UNC-2A bolts (five bolts for ½-symmetry model) that connect the shield plate to the closure lid are modeled using 3-D spar elements (LINK10) that transfer only tensile loads. The bolt element tensile area (A_t) and an initial strain (ε_o) are defined by real constants. The initial strain corresponding to a maximum bolt torque is:

$$\varepsilon_o = \sigma_o/E_b = 0.000303 \text{ in/in}$$

where:

σ_o = 8,098 psi, Bolt tensile stress due to preload
= F_B/A_t
E_b = 26.7×10^6 psi, Elastic modulus of SA-193, Grade B6 material at 500°F.
F_B = $Q/(KD_b)$, Bolt tensile force due to torque [30].
= 11,200 lbs.
Q = 1,680 in-lbs., Maximum bolt torque
K = 0.1, Lower-bound nut factor for a lubricated bolt [30]
D_b = 1.5 in., Nominal bolt diameter
A_t = 1.383 in^2, Tensile area of 1 ½-6 UNC-2A bolt

This model represents a "bounding" combination of geometry and loading that envelops all the MAGNASTOR PWR and BWR TSC configurations with composite closure lid assembly design (i.e., TSC3 and TSC4 configurations). Specifically, the longest TSC is modeled in conjunction with a conservative fuel and basket combination. By using the longest TSC with the conservative content weight, bending stresses are maximized at the junction of the shell and lid. Thus, the analysis yields conservative results relative to the expected performance of the actual TSC configurations.

Boundary Conditions and Loading

The boundary conditions and loading applied to the TSC3/TSC4 finite element model are identical to those described in Section 3.10.3.1. Internal pressure loads are applied to the inside surface of the closure lid rather than the shield plate for the TSC3/TSC4 configuration because the closure lid forms the confinement boundary.

Post-Processing and Analysis Results

The post-processing of the finite element solution for the TSC3/TSC4 configuration is performed in the same manner as that described for the TSC1/TSC2 configuration in Section 3.10.3.1. Linearized stresses in the TSC3/TSC4 configuration at each of the stress sections shown in Figure 3.10.3-5 are calculated and compared to the corresponding allowable stress design criteria. In addition, the maximum tensile stress in the inner lid attachment bolts is evaluated for each load combination and compared to the corresponding bolt stress limits of ASME Code, Section III, Subsection NF.

The bounding linearized stress results at each section in the top end region of the TSC3/TSC4 configurations (i.e., the highest stress intensity of the TSC3/TSC4 configuration with either the ¾-inch or 1½-inch wide closure ring design) are summarized in Table 3.10.3-18 through Table 3.10.3-34, along with the corresponding allowable stresses and factors of safety. The stresses in the bottom plate (i.e., sections 1 and 12) and the cavity region of the cylindrical shell (i.e., sections 2 through 8) are the same for the TSC1/TSC2 and TSC3/TSC4 configurations, and are not repeated in Table 3.10.3-18 through Table 3.10.3-34. The maximum tensile stress in the shield plate bolts is summarized in Table 3.10.3-35, along with the corresponding allowable tensile stresses and factors of safety. Finally, the maximum tensile stresses in the shield plate are summarized in Table 3.10.3-36.

Figure 3.10.3-3 MAGNASTOR TSC3/TSC4 Finite Element Model, ¾-Inch Wide Closure Ring

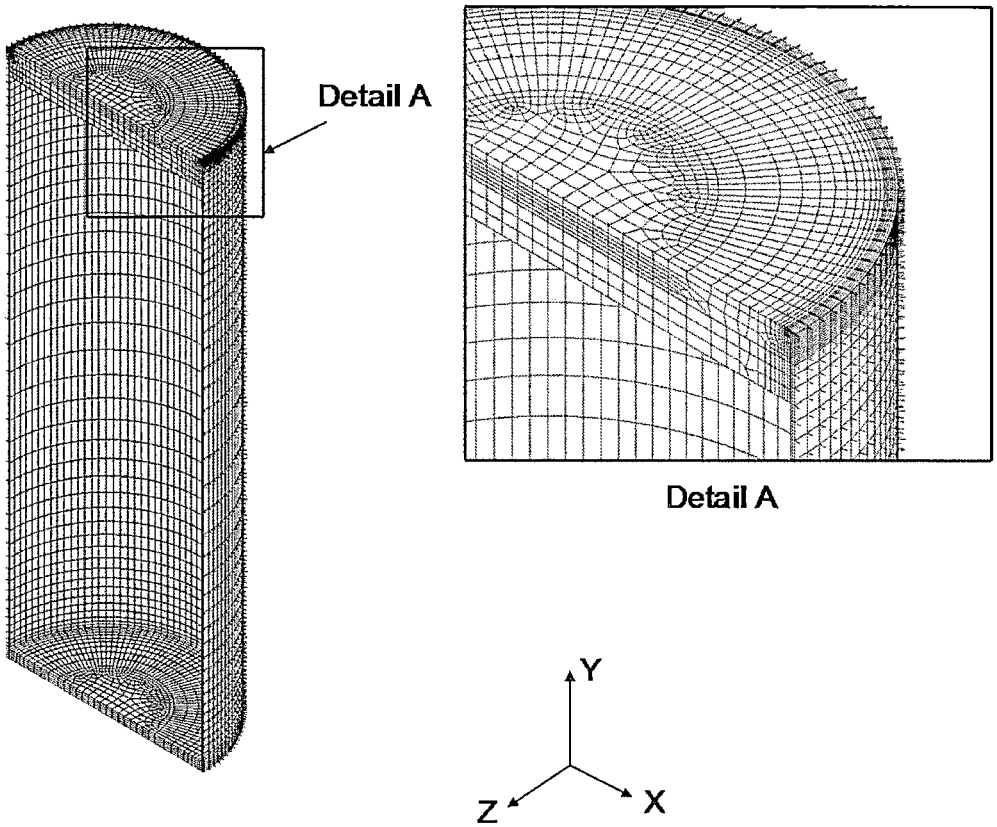


Figure 3.10.3-4 MAGNASTOR TSC3/TSC4 Finite Element Model, 1½-Inch Wide Closure Ring

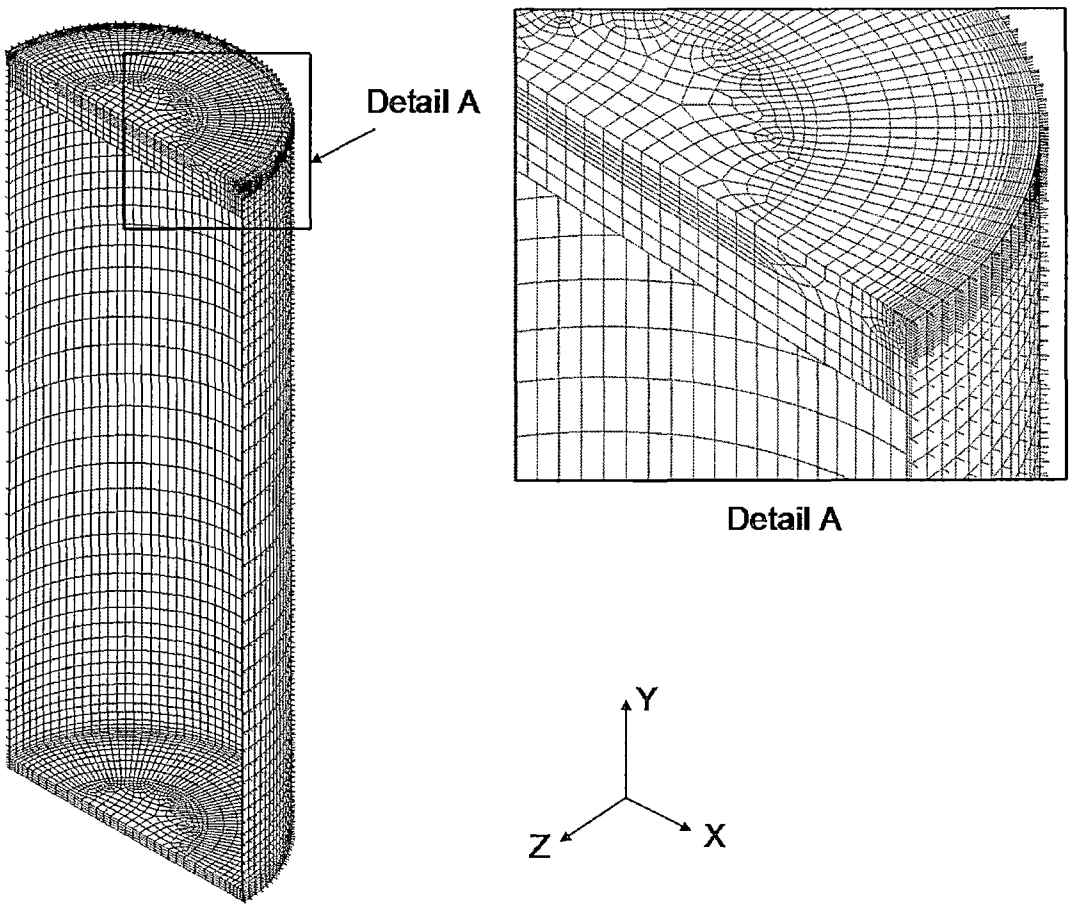
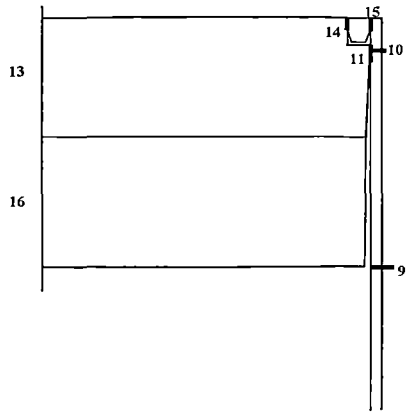


Figure 3.10.3-5 Identification of Sections for Evaluating Linearized Stresses in TSC3/TSC4



Section Cut	Temperature Allowable (F)	Section Coordinates			
		Node 1		Node 2	
		X	Z	X	Z
9	450	35.50	182.75	36.00	182.75
10	450	35.50	190.50	36.00	190.50
11	450	35.50	190.25	35.50	190.25
13	525	0.00	187.75	0.00	191.75
14	450	See Note	191.50	See Note	191.50
15	450	35.50	191.75	35.50	191.75
16	525	0.00	182.74	0.00	187.74

Note: Dimension is 34.55" for 0.75" closure ring and 33.9" for 1.5" closure ring

Table 3.10.3-18 TSC3/TSC4 Normal Pressure plus Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.05	7.47	5.04	0.18	-0.01	0.02	7.53	18.10	2.40
10	-0.65	1.80	1.13	0.01	-0.03	0.36	2.52	18.10	7.18
11	1.78	3.50	5.01	-0.02	0.00	-2.49	5.95	14.48[b]	2.43
13	0.09	0.08	-0.06	0.00	-0.04	-0.01	0.17	17.28	large
14	0.36	4.03	-0.58	0.10	0.00	-0.03	4.62	18.10	3.92
15	-0.21	3.96	0.79	0.06	-0.01	0.01	4.17	18.10	4.34
16	0.01	0.02	0.00	0.00	-0.01	0.00	0.02	19.07	large

Table 3.10.3-19 TSC3/TSC4 Normal Pressure plus Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.08	8.16	7.20	-0.01	-0.01	0.02	8.23	27.15	3.30
10	1.40	-1.13	-7.38	0.06	0.02	1.70	9.42	27.15	2.88
11	3.01	4.33	7.17	0.00	-0.01	-3.27	7.75	21.72[b]	2.80
13	9.72	9.72	-0.01	-0.05	-0.04	-0.02	9.78	25.93	2.65
14	1.89	4.87	-0.34	0.10	0.00	0.05	5.21	27.15	5.21
15	-2.42	3.44	0.51	0.05	0.00	-0.01	5.86	27.15	4.63
16	2.90	2.91	0.00	0.00	-0.01	0.00	2.91	28.61	9.83

Table 3.10.3-20 TSC3/TSC4 Normal Pressure plus Handling, P + Q, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.19	9.48	10.94	-0.02	0.14	0.05	11.14	54.30	4.87
10	1.32	4.43	-7.47	0.00	-0.03	1.83	12.26	54.30	4.43
11	-2.27	7.24	-1.24	-0.02	-0.03	-0.76	9.91	43.44[b]	4.38
13	-19.81	-19.79	0.51	0.05	-0.14	0.00	20.37	51.85	2.55
14	-0.64	12.37	0.14	0.08	0.00	-0.15	13.03	54.30	4.17
15	-2.59	10.56	0.55	0.06	0.00	0.01	13.15	54.30	4.13
16	-7.32	-7.31	-0.52	0.02	0.12	0.00	6.81	57.23	8.40

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-21 TSC3/TSC4 Normal Pressure, P_m, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
9	-0.05	7.53	3.83	-0.19	0.01	0.03	7.59
10	-0.61	1.12	0.64	0.00	0.00	0.46	1.89
11	1.76	3.00	4.81	0.00	0.00	-1.93	4.91
13	0.09	0.09	-0.06	0.00	-0.04	-0.01	0.16
14	0.17	2.68	-0.43	0.00	0.00	-0.02	3.11
15	-0.23	2.64	0.55	0.00	0.00	0.02	2.88
16	0.01	0.01	0.00	0.00	0.00	0.00	0.01

Table 3.10.3-22 TSC3/TSC4 Normal Pressure, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
9	-0.07	8.19	6.07	0.00	0.01	0.02	8.25
10	1.20	-1.08	-6.56	0.00	0.00	1.43	8.27
11	3.22	3.90	6.76	0.00	0.00	-2.54	6.19
13	7.54	7.54	-0.01	0.00	-0.04	-0.01	7.55
14	1.28	3.27	-0.25	0.00	0.00	0.04	3.52
15	-1.71	2.29	0.34	0.00	0.00	0.00	4.00
16	2.24	2.24	0.00	0.00	0.00	0.00	2.24

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

Table 3.10.3-23 TSC3/TSC4 Thermal Stresses, Q, ksi

Section[a]	Component Stresses						S_{int}
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	
9	-0.13	1.58	4.10	-0.02	0.01	0.03	4.23
10	-0.18	5.88	-0.59	-0.07	0.02	-0.05	6.48
11	-0.18	5.83	-0.69	-0.04	-0.02	-0.11	6.55
13	-10.33	-10.29	0.61	0.00	-0.09	0.00	10.94
14	-2.32	7.50	0.19	0.04	0.00	0.00	9.82
15	-0.17	7.27	-0.17	-0.01	0.00	0.18	7.62
16	-8.58	-8.56	-0.13	0.01	-0.05	0.00	8.45

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

Table 3.10.3-24 TSC3/TSC4 Off-Normal Pressure plus Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.06	8.81	5.73	0.21	-0.01	0.03	8.89	19.91	2.24
10	-0.77	2.01	1.25	0.01	-0.03	0.45	2.87	19.91	6.94
11	2.07	4.05	5.82	0.01	-0.01	-2.87	6.85	15.93[b]	2.33
13	0.11	0.10	-0.07	0.00	-0.05	-0.01	0.20	19.01	large
14	0.39	4.54	-0.66	0.10	0.00	-0.04	5.21	19.91	3.82
15	-0.26	4.46	0.89	0.06	-0.01	0.01	4.72	19.91	4.22
16	0.01	0.02	0.00	0.00	-0.01	0.00	0.02	20.98	large

Table 3.10.3-25 TSC3/TSC4 Off-Normal Pressure plus Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.09	9.61	8.34	0.00	0.11	0.02	9.71	29.87	3.08
10	1.62	-1.33	-8.59	0.07	0.03	1.97	10.94	29.87	2.73
11	3.61	5.06	8.42	0.00	-0.01	-3.73	8.88	23.89[b]	2.69
13	11.13	11.13	-0.01	-0.05	-0.05	-0.02	11.19	28.52	2.55
14	2.12	5.48	-0.38	0.10	0.00	0.06	5.87	29.87	5.09
15	-2.73	3.87	0.58	0.06	0.00	-0.01	6.61	29.87	4.52
16	3.28	3.29	0.00	0.00	-0.01	0.00	3.29	31.47	9.57

Table 3.10.3-26 TSC3/TSC4 Off-Normal Pressure plus Handling, P + Q, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.17	10.98	12.15	0.00	0.15	0.02	12.34	54.30	4.40
10	1.54	4.25	-8.68	0.00	-0.04	2.10	13.34	54.30	4.07
11	-2.63	7.41	-1.20	-0.03	-0.03	-0.83	10.42	43.44[b]	4.17
13	-21.19	-21.17	0.49	0.05	-0.14	-0.01	21.73	51.85	2.39
14	-1.33	12.23	-0.54	0.10	0.00	0.05	13.57	54.30	4.00
15	-3.48	10.41	0.71	0.06	0.00	0.05	13.90	54.30	3.91
16	-7.70	-7.69	-0.52	0.02	0.12	0.00	7.19	57.23	7.96

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-27 TSC3/TSC4 Normal Pressure plus Off-Normal Handling, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.82	7.74	4.84	0.05	0.04	0.06	8.56	21.75	2.54
10	-8.88	-1.06	0.52	0.94	-0.29	-0.15	9.58	21.75	2.27
11	-8.34	0.43	1.16	1.18	-0.39	-2.61	11.24	17.40[b]	1.55
13	0.05	0.10	-0.06	0.00	-0.05	-0.01	0.18	20.73	large
14	0.53	4.37	-0.64	0.10	0.00	-0.04	5.02	21.75	4.33
15	-5.94	1.94	-0.83	1.08	-0.40	0.07	8.22	21.75	2.65
16	0.00	0.02	0.00	0.00	-0.01	0.00	0.02	28.88	large

Table 3.10.3-28 TSC3/TSC4 Normal Pressure plus Off-Normal Handling, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.94	10.99	4.05	-0.05	-0.09	0.06	11.93	30.10	2.52
10	-8.92	1.66	6.56	1.07	-0.44	-3.08	16.82	30.10	1.79
11	-8.91	0.66	3.58	1.18	-0.47	-3.61	14.66	24.08[b]	1.64
13	10.38	10.51	-0.01	-0.06	-0.05	-0.02	10.55	28.75	2.73
14	2.25	5.29	-0.37	0.11	0.00	0.06	5.66	30.10	5.32
15	-7.26	1.10	-1.25	1.03	-0.51	0.08	8.71	30.10	3.46
16	3.02	3.13	0.00	0.00	-0.01	0.00	3.14	34.30	large

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-29 TSC3/TSC4 Normal Pressure plus 24-inch Drop, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.05	8.37	-1.82	0.21	-0.04	0.07	10.20	43.40	4.25
10	3.03	-0.40	-2.43	-0.07	-0.02	0.47	5.54	43.40	7.83
11	0.81	1.06	5.33	-0.01	-0.03	0.89	4.86	34.72[b]	7.14
13	0.05	0.07	-0.15	0.00	-0.05	0.00	0.24	41.48	large
14	-1.17	-2.50	0.57	0.00	0.00	0.04	3.07	43.40	large
15	-0.54	-2.49	-0.85	0.01	0.00	0.21	2.05	43.40	large
16	0.00	0.01	-0.09	0.00	0.05	0.00	0.13	40.60	large

Table 3.10.3-30 TSC3/TSC4 Normal Pressure plus 24-inch Drop, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.08	7.73	-3.78	0.00	-0.02	0.06	11.51	63.50	5.52
10	0.93	-3.86	-11.51	-0.12	-0.02	0.27	12.46	63.50	5.10
11	-2.25	-0.39	4.69	-0.08	-0.04	1.10	7.28	50.80[b]	6.98
13	2.58	2.57	-0.01	0.00	-0.04	-0.01	2.58	62.22	large
14	-2.61	-3.14	0.33	0.30	-0.04	-0.07	3.60	63.50	large
15	2.62	-1.46	-0.72	0.00	0.00	0.07	4.08	63.50	large
16	4.52	4.52	-0.01	0.00	0.04	0.00	4.53	58.00	large

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-31 TSC3/TSC4 Accident Pressure plus Dead Weight, P_m, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.12	17.17	8.56	0.00	0.03	0.06	17.29	43.40	2.51
10	-1.41	2.56	1.39	0.00	-0.01	1.08	4.34	43.40	large
11	4.04	6.90	11.01	0.00	0.00	-4.34	11.14	34.72[b]	3.12
13	0.20	0.20	-0.13	0.00	-0.08	-0.01	0.37	41.48	large
14	0.36	6.19	-0.97	0.00	0.00	-0.05	7.16	43.40	6.06
15	-0.55	6.10	1.23	0.00	0.00	0.05	6.64	43.40	6.54
16	0.03	0.02	0.00	0.00	-0.01	0.00	0.03	40.60	large

Table 3.10.3-32 TSC3/TSC4 Accident Pressure plus Dead Weight, $P_m + P_b$, ksi

Section[a]	Component Stresses						S_{int}	S_{allow}	FS
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	-0.19	19.19	14.02	-0.03	0.14	0.05	19.38	63.50	3.28
10	2.75	-2.50	-15.20	0.00	0.00	3.26	19.10	63.50	3.32
11	7.40	8.95	15.46	0.00	0.00	-5.73	14.00	50.80[b]	3.63
13	17.32	17.34	-0.02	0.00	-0.09	-0.01	17.36	62.22	3.58
14	2.83	7.52	-0.56	0.00	0.00	0.08	8.09	63.50	7.85
15	-3.85	5.32	0.76	0.00	0.00	0.01	9.17	63.50	6.92
16	4.81	4.81	0.00	0.00	-0.01	0.00	4.81	58.00	large

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-33 TSC3/TSC4 Tip-Over plus Normal Pressure, P_m, ksi

Section[a]	Angle	Component Stresses						S_{int}	S_{allow}	FS
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	0	-12.07	7.13	3.86	3.01	-0.06	-0.11	20.12	43.40	2.16
10[b]	6	-1.85	3.54	-5.45	-1.98	-1.51	2.52	11.47	43.40	3.79
11[c]	0 - 6	-27.36	-16.48	-14.72	10.02	-3.80	-3.33	26.15	34.72	1.33
13	0	-0.87	0.39	-0.06	0.03	-0.04	-0.03	1.27	41.48	large
14[b]	6	6.20	-6.75	0.58	4.83	-0.11	-0.46	16.19	43.40	2.68
15[b]	6	0.84	-3.65	0.51	0.39	0.69	0.46	5.06	43.40	8.58
16	0	-0.45	0.15	0.00	0.01	-0.01	-0.03	0.61	40.60	large

Table 3.10.3-34 TSC3/TSC4 Tip-Over plus Normal Pressure, P_m+P_b, ksi

Section[a]	Angle	Component Stresses						S_{int}	S_{allow}	FS
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
9	0	-13.41	26.83	2.90	2.42	0.59	-0.06	40.54	63.50	1.57
10[b]	6	-10.53	8.63	-19.42	-2.43	-0.04	4.20	30.06	63.50	2.11
11[c]	0 - 6	-40.24	-21.42	-16.86	11.92	-6.62	0.52	36.07	50.80	1.41
13	0	-9.32	-8.06	-0.11	0.04	-0.04	-0.02	9.21	62.22	6.76
14[b]	6	7.08	-7.17	0.21	4.70	0.11	-0.02	17.07	63.50	3.72
15[b]	6	10.23	-0.08	0.76	-0.41	1.25	0.82	11.34	63.50	5.60
16	0	-3.74	-3.15	0.00	0.02	-0.01	-0.03	3.74	58.00	large

[a] See Figure 3.10.3-5 for TSC3/TSC4 section locations. The stresses at the sections in the bottom plate (Sections 1 and 13) and cylindrical shell cavity region (Sections 2 through 8) are the same as those reported for TSC1/TSC2 in Section 3.10.3.1.

[b] Bearing stress evaluation is not required for accident conditions.

[c] Stresses are determined by averaging the stresses over the impact region. Allowable stress includes a reduction factor of 0.8 for the closure lid weld.

Table 3.10.3-35 TSC3/TSC4 Shield Plate Attachment Bolt Stress Summary, ksi

Load Case	Maximum Bolt Tensile Stress, f_{tb}	Allowable Tensile Stress, f_{tb}	FS
Dead Weight + Normal Pressure	24.18	47.49	1.96
Normal Handling + Normal Pressure	34.31	47.49	1.38
Normal Handling + Off-Normal Pressure	38.37	54.61	1.42
Off-Normal Handling + Normal Pressure	38.21	59.36	1.55
24-inch Drop + Normal Pressure	58.08	66.48	1.14
Dead Weight + Accident Pressure	52.69	66.48	1.26
Tip-Over + Normal Pressure	29.21	66.48	2.28

Table 3.10.3-36 TSC3/TSC4 Shield Plate Maximum Tensile Stresses, ksi

Load Case	Maximum Tensile Strength
Dead Weight + Normal Pressure	2.51
Normal Handling + Normal Pressure	3.25
Normal Handling + Off-Normal Pressure	3.68
Off-Normal Handling + Normal Pressure	3.60
24-inch Drop + Normal Pressure	3.72
Dead Weight + Accident Pressure	5.55
Tip-Over + Normal Pressure	4.26

3.10.4 Concrete Cask Finite Element Models

3.10.4.1 Pedestal Finite Element Model for Lift Evalution

An ANSYS finite element model of the concrete cask pedestal (Figure 3.10.4-1) is used to perform the structural evaluation for the lift condition. The model is constructed using SHELL63, LINK8, and CONTAC52 elements. LINK8 elements are used to model the Nelson studs. The model is a quarter-symmetry model. Symmetry boundary conditions are used on the XZ and YZ planes. The pedestal is a welded structure. CONTAC52 gap elements are used to model regions where components are not welded together (stand to pedestal plate, and support rails to stand). The gap elements do not close during the analysis, which maximizes the bending stresses in the support rails and inlet tops; therefore, the analysis is bounding. During a concrete cask top-end lift, the TSC loads the pedestal plate. A pressure load (P_{can}) is used to apply the TSC weight to the pedestal plate.

$$P_{can} = \frac{1.1 \times W_{can}}{A_{ped}} = \frac{1.1 \times 120{,}000}{4{,}071} = 32.4 \text{ psi}$$

The load in the pedestal is reacted out by the Nelson studs, which carry the load into the concrete. The tops of the Nelson studs are restrained in all degrees of freedom. An inertia load of 1.1g (Z-direction) is applied to the finite element model for dynamic load factor (DLF). The 1.1g DLF is applied per ANSI/ASME N45.2.15 [29].

3.10.4.2 Concrete Cask Finite Element Model for Thermal Stress Evaluation

Thermal stress evaluations of the bounding concrete cask configuration, both with and without the optional inner rebar cage, were performed for normal conditions and off-normal or accident events. A three-dimensional finite element model was created using the ANSYS program. The concrete cask contains 56 periodic radial sections with the 56 vertical rebars. Therefore, the model represents 6.4° ($^{1}/_{56}{}^{th}$) of the concrete cask. The model contains only the portion of the concrete cask shell and liner between the top of the lower vents and the lid assembly because the circumferential and vertical rebar are located in this region.

The thermal conduction model is constructed using ANSYS SOLID70 elements for the concrete shell and steel liner. The nodes at the liner/shell interface are coincident and are connected using temperature couples. The model is divided into four sections vertically with 0.1-inch gaps. LINK33 elements are used to connect the four sections to allow for thermal conduction across the gaps. The temperatures vary in the vertical and radial directions. Conservatively, the

temperature profile corresponding to the 106°F (off-normal) ambient condition is used for the normal conditions. The temperature profile for the 133°F ambient condition is used for the accident event. Temperatures are applied to nodes on the inner and outer surfaces of the concrete cask.

The thermal conduction model is modified for the structural evaluation. The SOLID70 elements are replaced with SOLID45 elements. COMBIN14 elements are used between the four vertical sections of the model for the steel liner. CONTAC52 gap elements are used between the liner and concrete shell to permit only compressive loads to be transmitted across the gap. Rebar was modeled into the model using LINK8 elements. LINK8 elements where also modeled across the vertical gaps to represent the vertical rebar; therefore, tensile loads are taken by the rebar. There are 24 vertical rebar on the inner radius and 56 on the outer radius. The properties of the inner vertical rebar are determined by a ratio to represent the $^{1}/_{56}{}^{th}$ model (24/56 ratio). For the analysis of the concrete cask without the optional inner rebar cage, the corresponding elements are removed. The finite element model is shown in Figure 3.10.4-2 and Figure 3.10.4-3. Boundary conditions are shown in Figure 3.10.4-4.

3.10.4.3 Pedestal Finite Element Model for 24-inch Drop Evaluation

Subjecting the concrete cask to a bottom end impact, the TSC produces a force on the base weldment located at the bottom of the cask. The ring above the air inlets is expected to yield. To determine the resulting acceleration of the TSC and deformation of the pedestal, a LS-DYNA analysis is used.

A quarter-symmetry model of the base weldment is shown in Figure 3.10.4-5. The model is constructed using 4-node shell elements. Symmetry boundary conditions are applied along the planes of symmetry (X-Z and Y-Z plane). Rigid mass 8-node solid elements located in the TSC bottom plate represent the loaded TSC. Rigid mass 8-node solid elements located above the air inlet duct top represent the weight of the inner liner shell. The impact plane is represented as a rigid plane. To determine the maximum acceleration and deformations, impact analyses are solved using LS-DYNA program.

The weldment support rails, weldment pedestal plate, air inlet ducts, and the cylindrical stand materials are modeled using the piece-wise linear plasticity model in LS-DYNA. The stress-strain curve used for this analysis was obtained from the Atlas of Stress-Strain Curves and is presented in Figure 3.10.4-6. To ensure that maximum deformations and accelerations are determined, two analyses are performed. One analysis, which uses the upper bound weight of 105 kips, envelops the maximum deformation of the pedestal. The second analysis employs the

lower-bound weight of 60 kips to account for maximum acceleration. The details of the model are described as follows.

- All structural components are modeled using shell elements. A layer of solid elements represents the TSC weight.
- The ground base plate of the pedestal is not modeled since the plate is in contact with the impact plane during impact and has no effect on the deformation of the pedestal.
- The gravitational force is aligned with the Z-axis and is acting in the negative Z direction.
- All components of the pedestal are made of ASTM A36 carbon steel.
- The cylindrical shell under the pedestal plate is separated (not welded) from the support rail to allow buckling to occur at a relative lower g-level.
- The loaded TSC is modeled as a rigid body. The density of the TSC is calculated so that the total weight of the TSC model is equal to 105 kips or 60 kips, bounding values for the maximum and minimum TSC loaded weights.
- The concrete cask liner is modeled as a rigid body. The density of the liner is calculated so that the total weight is equal to 16,900 lb, which envelops the weight of the liner shell and the S-shape steel beams attached to the concrete cask liner.
- The column weight of the concrete portion of the concrete cask projected onto the top of an air inlet plate is represented by a uniformly distributed normal pressure acting on the top of the air inlet plate. The weight is only statically applied to the top of the air inlet. Upon impact, since the air inlet is more flexible than the base plate, all of the impact force of the concrete is transmitted to the base plate. The static pressure is always present during the impact.
- The rigid wall is an infinitive rigid plane. The rigid wall featured in LS-DYNA is used to simulate the rigid ground surface on which the concrete cask is supported or dropped.
- The filter frequency used in the LS-DYNA evaluation is determined by performing natural frequency calculations of the various components in the load path of the base weldment. The component with the lowest natural frequency is the cylindrical stand. This calculation results in a natural frequency of 182 Hz. Therefore, a filter frequency of 200 Hz is selected.

Material Property

The pedestal material is A-36 carbon steel. The LS-DYNA material type 24 (Piecewise_Linear_Plasticity) is used. The true stress-strain curve of A-36 is shown in Figure 3.10.4-6.

Initial Condition

The body force applied to the TSC and the pedestal assembly is the 1g acceleration representing the ever-present gravitational force. Body force is a vectored input, depending on the angle of

drop. The 1g body force is applied in the –Z direction. Since the 24-inch drop represents the dynamic force input, the initial velocity, V_o is computed as shown below.

$$V_o = \sqrt{2gH} = \sqrt{2(386.4)(24)} = 136.1 \text{ inch/sec}$$

where:

g = 386.4 inch/sec^2
H = 24.0 inches ---------- Drop height

Post-Processing

To obtain output, a node on the TSC tracks the movements of the TSC as it impacts on the top base plate of the pedestal. Since the TSC is modeled as a rigid body, any node on the TSC is sufficient to track the global movements and deceleration of the TSC. The output database contains a time-series of nodal displacement, velocity, and acceleration. The nodal output file is a text file that the post-processor of LS-DYNA can convert into time-history plots and apply to the plotted graphs signal-conditioning operations such as filtering and rescaling. The acceleration of the TSC is obtained directly from the output file and then filtered to eliminate the ripples. The filtered acceleration (in-inch/sec^2) is rescaled to units of g (386.4 inch-inch/sec^2) value.

3.10.4.4 Concrete Cask Finite Element Model for Tip-Over Evaluation

The concrete cask is designed to hold a TSC during long-term storage conditions and is constructed of a steel liner surrounded by reinforced concrete. The critical locations for measuring accelerations are at the top of the fuel basket and top of the TSC closure lid.

Two half-symmetry finite element models of the concrete cask, concrete pad, and soil subgrade are constructed of solid brick elements using the LS-DYNA program for the cask tip-over evaluation. One model uses a standard sized pad, and the other model uses an oversized pad. The difference between the two models reflects the segments in the concrete pad. The finite element models are shown in Figure 3.10.4-7.

Material Properties

The mechanical properties used in the analyses are described in the following sections. The densities of each part are calculated to account for the total weight of nonstructural components that are not modeled as part of the finite element model.

Concrete:

The concrete is represented as a homogeneous isotropic material. The effect of the reinforcing steel is ignored. The concrete for the cask and the pad are modeled as LS-DYNA material 16 (Mat_Pseudo_Tensor), which represents a concrete constitutive model in LS-DYNA. This material model requires an equation-of-state represented in LS-DYNA as EOS_Tabulated_Compaction. The LS-DYNA input for the cask concrete is shown below.

$f_c' = 4{,}000$ psi ---------- Compressive Strength

$\rho_c = 148$ pcf $= 0.0002217$ lb-sec^2/in^4 ------- Density

$\nu_c = 0.22$ ---------- Poisson's Ratio

$E_c = 33\rho_c^{1.5}\sqrt{f_c'} = 3.758 \times 10^6$ psi ---------- Modulus of Elasticity

$G_c = \dfrac{E_c}{2(1+\nu_c)} = 1.540 \times 10^6$ psi ---------- Shear Modulus

$K_c = \dfrac{E_c}{3(1-2\nu_c)} = 2.237 \times 10^6$ psi ---------- Bulk Modulus

$\varepsilon_v = \dfrac{f_c'}{K_c} = 0.001788$ ---------- Volumetric Strain

Using the same formulae presented above, the required input data for the pad concrete is shown below.

f_c' (psi)	ρ_c (lb/ft^3)	E_c (psi)	G_c (psi)	K_c (psi)	ε_v
5,000	160	4.723×10^6	1.936×10^6	2.811×10^6	0.001779

Soil:

An elastic model with the following properties is used to represent the subgrade soil material of the site.

$\rho = 100$ pcf ---------- Density

$\nu_s = 0.45$ ---------- Poisson's Ratio

$E = 30{,}000$ psi ---------- Modulus of Elasticity

Steel Inner Liner:

The steel liner is represented by a rigid material model with the following properties.

$\nu = 0.31$ ---------- Poisson's Ratio

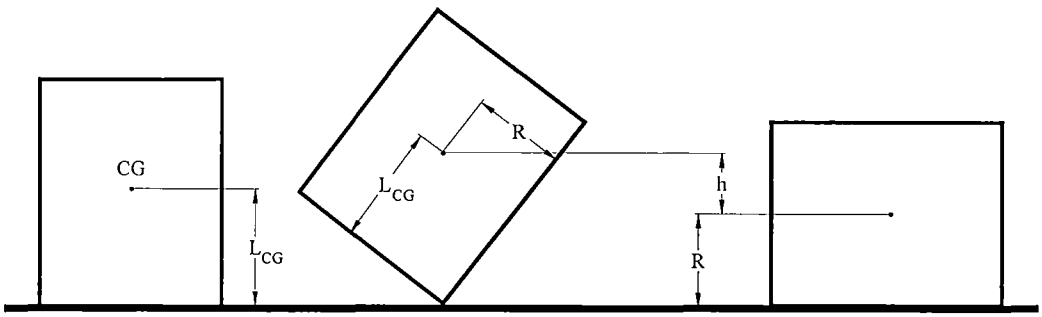
$E = 29 \times 10^6$ psi ---------- Modulus of Elasticity

Boundary Conditions

Automatic_Surface_To_Surface contact conditions are employed between the concrete cask and the pad, between the pad and soil, and between the cask steel liner and concrete. Symmetry

boundary conditions are applied to all parts at the plane of symmetry (see Figure 3.10.4-7). The vertical displacements at the bottom of the soil subgrade and horizontal displacements for the three vertical boundaries of the soil are restrained.

Tip-over is simulated by applying an initial angular velocity, ω, to the entire concrete cask. The angular velocity value is determined by the conservation of energy about the center of gravity, as the concrete cask rotates from end to corner to side orientations as shown in the figure below.



To ensure accuracy, the LS-DYNA output kinetic energies are compared to actual calculated potential energy. Equating the potential to the kinetic energy during tip-over is as follows.

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

where:

ω	= 1.527 rad/sec	Angular velocity for concrete cask
m	= 785.6 lb_m	Total mass of the concrete cask
g	= 386.4 inch/sec^2	Acceleration due to gravity
h	= $\sqrt{R^2 + L_{CG}^2} - R$	Height change of the concrete cask mass center
I		Total mass moment of inertia (lb-inch^2) of the concrete cask about the pivot point (automatically calculated by LS-DYNA)
R	= 68 inches	Outside radius of concrete cask

The potential energy due to the height change of the concrete cask's mass center during tip-over is bounded by the kinetic energy of 2.0×10^7 inch-lb.

Load Cases

Bounding load cases are used to evaluate the loaded concrete cask during tip-over conditions. Two concrete pad and subsoil combinations are considered to bound all possible storage configurations: the standard pad configuration and oversized pad configuration. The standard pad represents typical storage pad properties and boundary conditions. The oversized pad is used as a sensitivity study to determine the effect of increased foundation size on accelerations. The dimensions of the standard concrete pad are 30 ft (length) × 30 ft (width) with subsoil measuring 35 ft (length) × 35 ft (width). The dimensions of the oversized concrete pad are 60 ft (length) × 30 ft (width) with subsoil measuring 70 ft (length) × 35 ft (width).

With the exception of pad size, the standard and oversized pads use identical parameters and boundary conditions. The mesh density and element aspect ratio of the oversized pad is maintained from the standard model.

Figure 3.10.4-1 Concrete Cask Pedestal Finite Element Model for Lift Evaluation

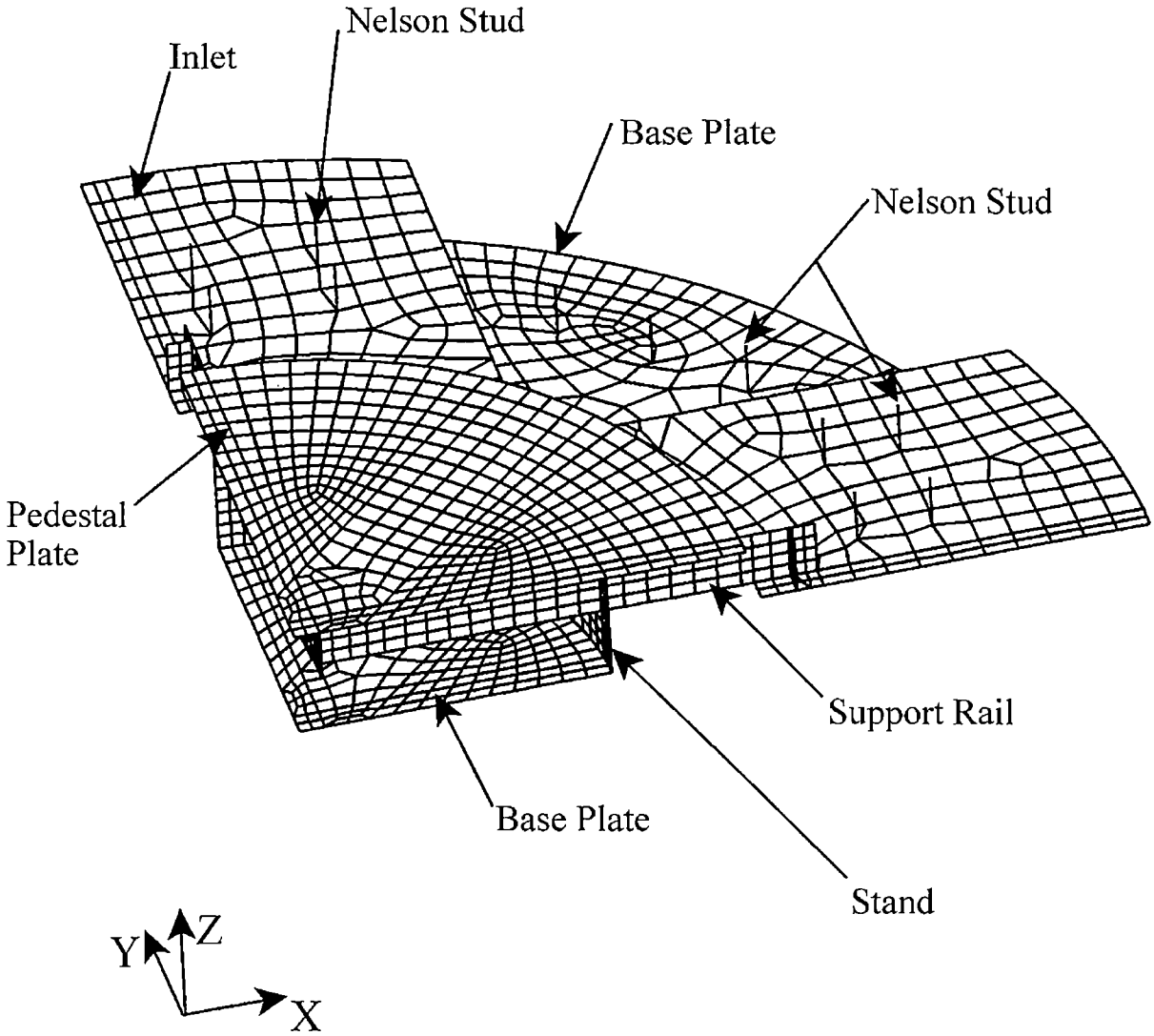


Figure 3.10.4-2 Concrete Cask Finite Element Model for Thermal Stress Evaluation

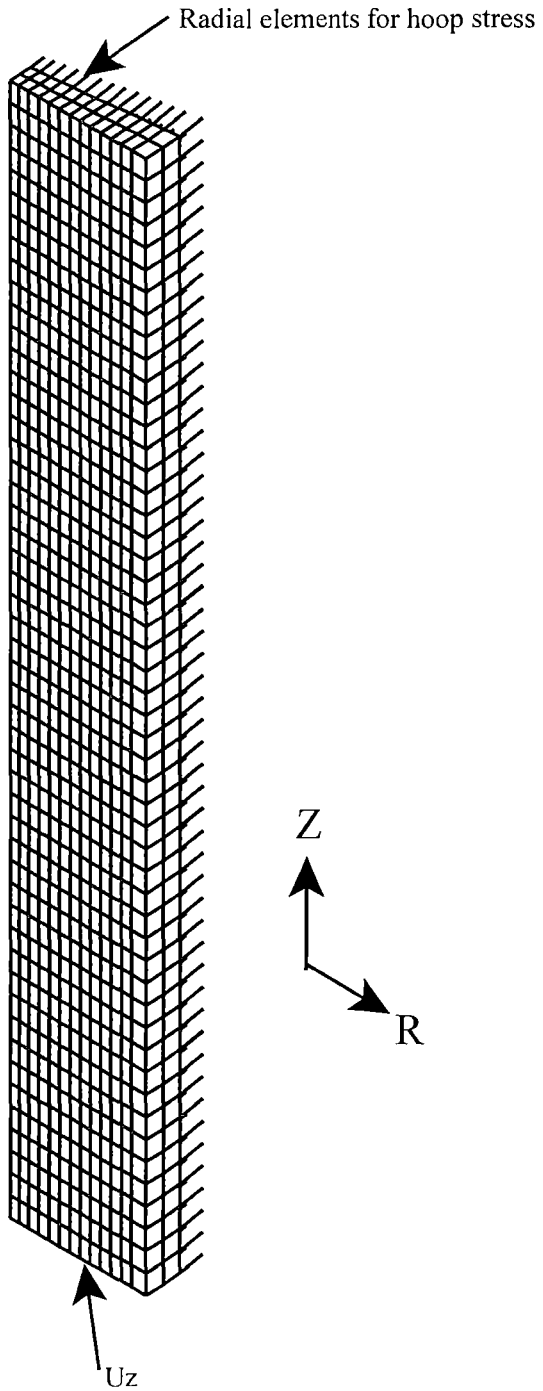


Figure 3.10.4-3 Concrete Cask Model – Elements for Rebar

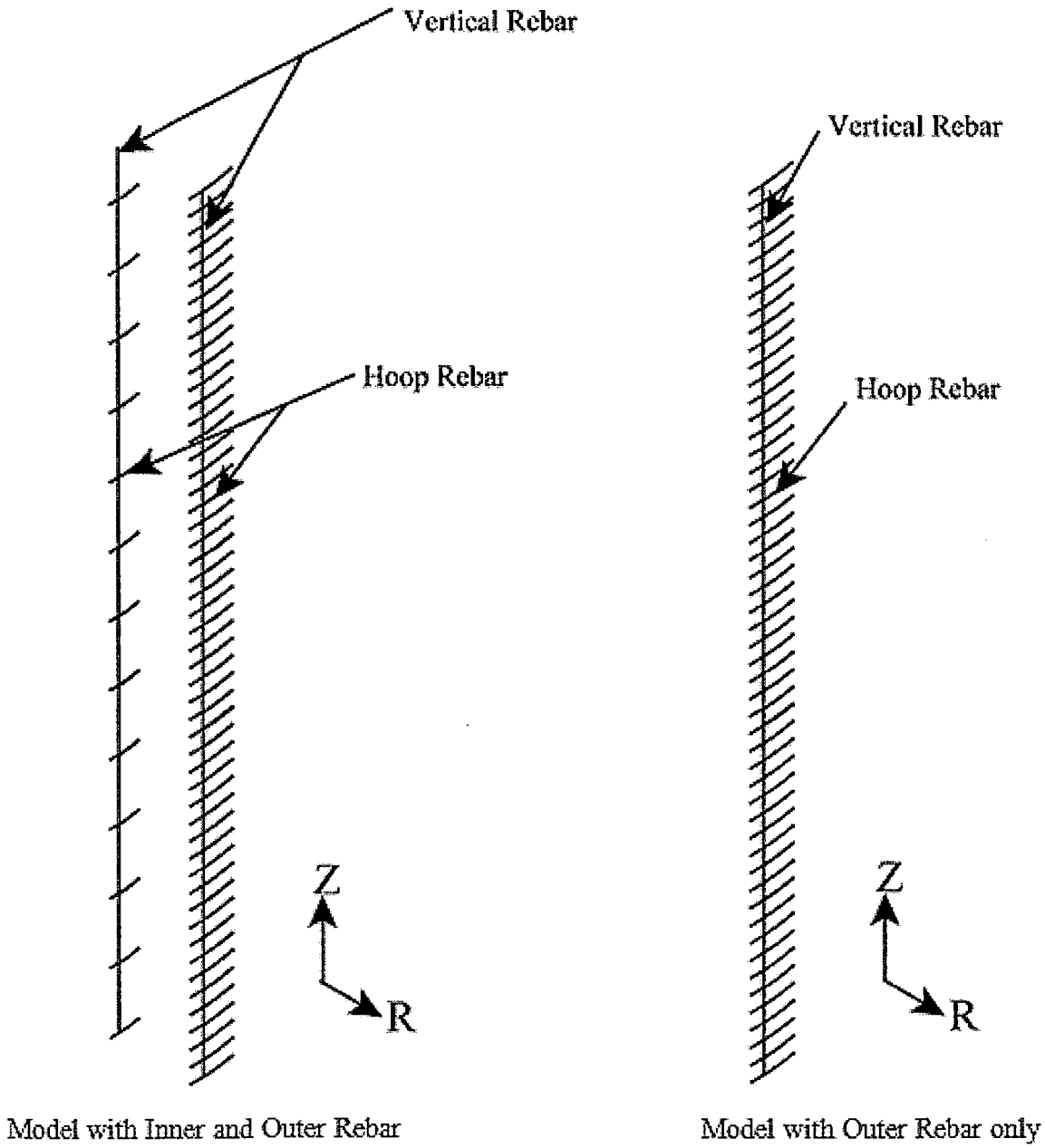


Figure 3.10.4-4 Concrete Cask Model Boundary Conditions

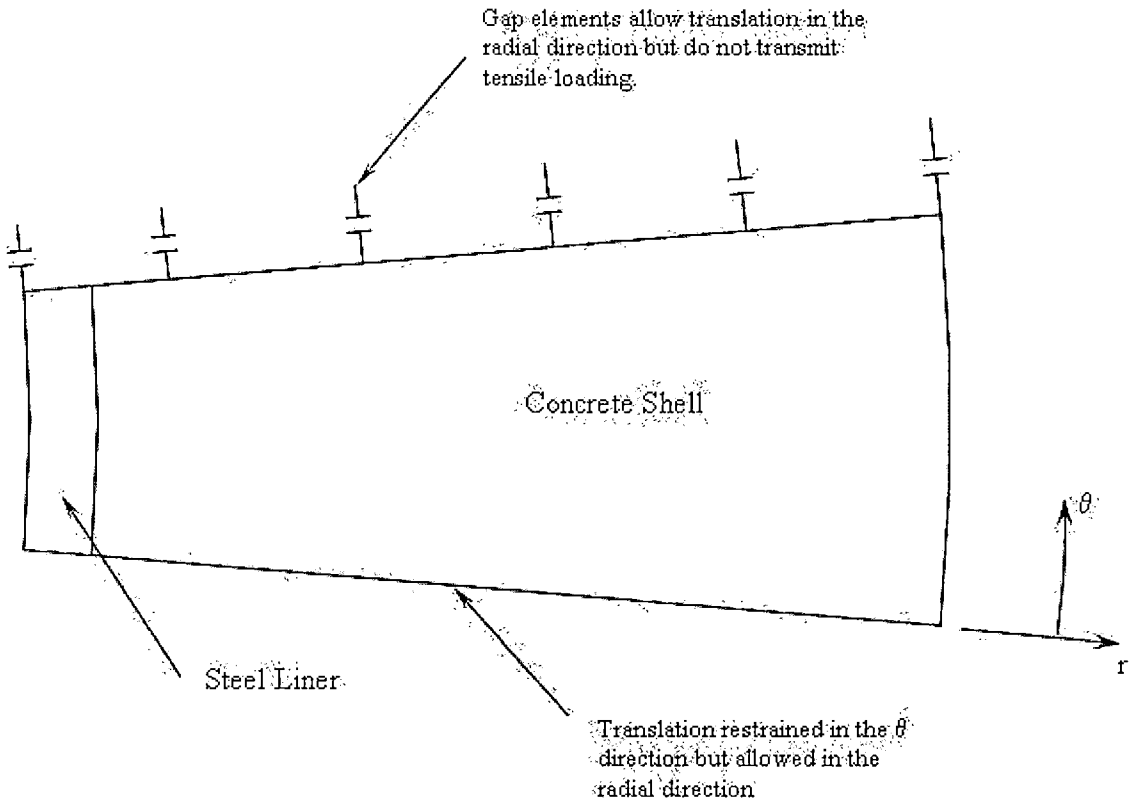


Figure 3.10.4-5 Concrete Cask Pedestal Finite Element Model for 24-inch Drop Evaluation

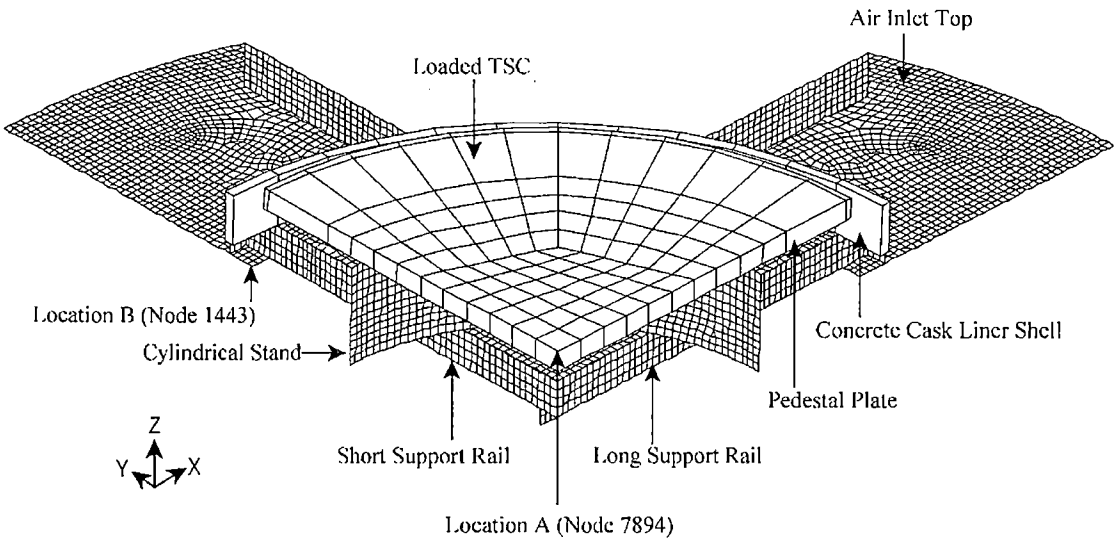


Figure 3.10.4-6 Stress-Strain Curve for A36 Carbon Steel

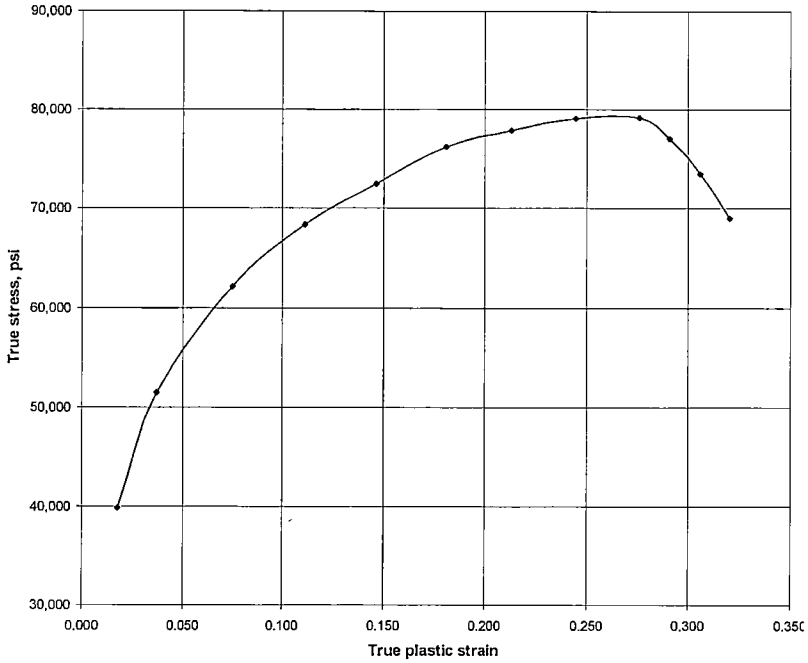
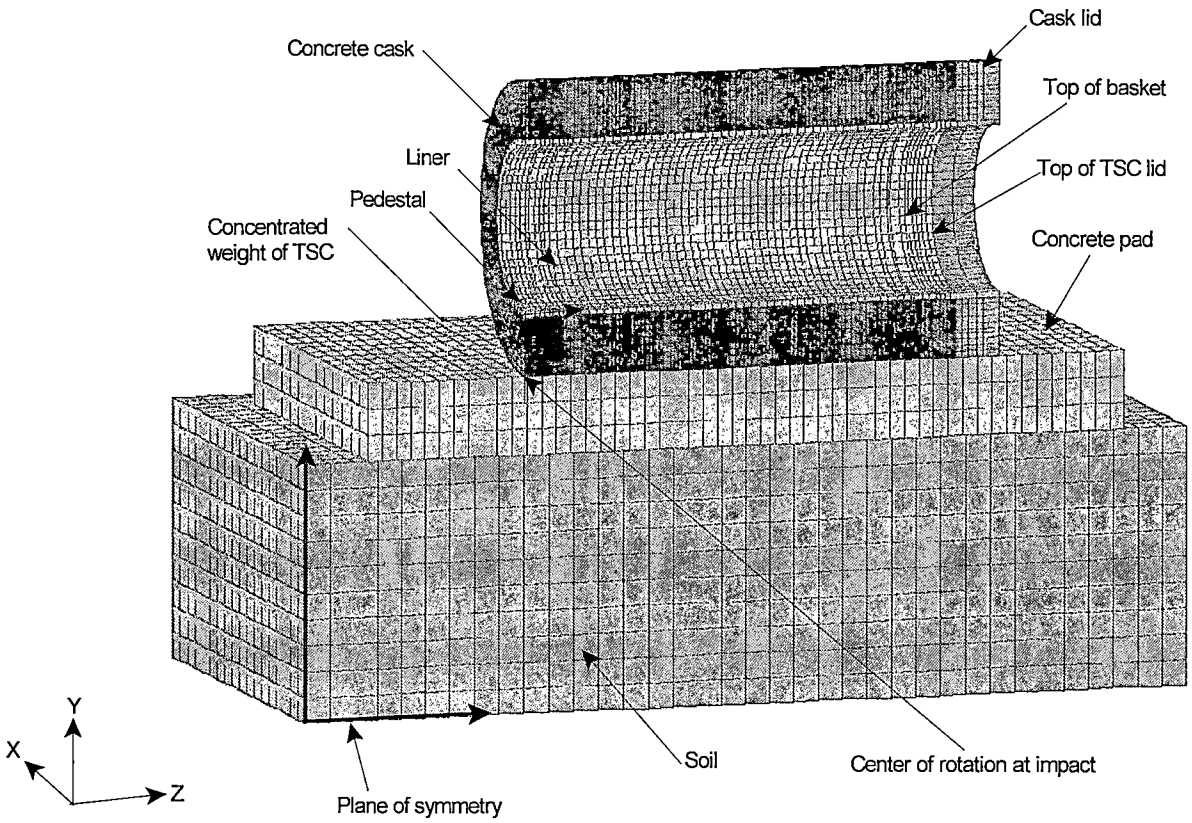
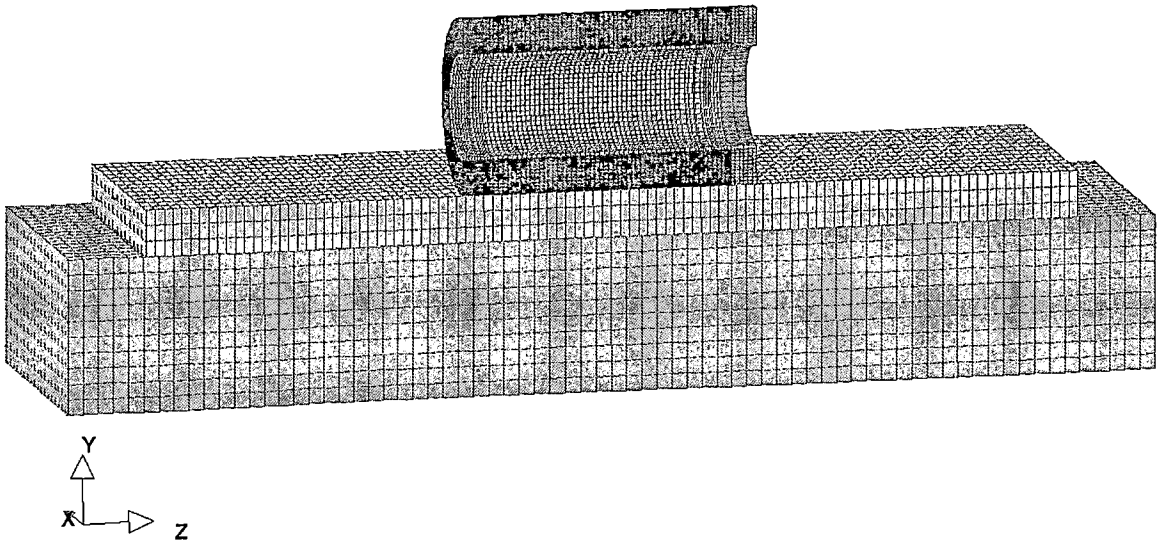


Figure 3.10.4-7 Finite Element Models for Tip-Over Evaluation

Standard Pad Model



Oversized Pad Model



3.10.5 Transfer Cask Finite Element Models

Finite element models used for the analysis of the MTC1 and MTC2 transfer casks are presented in the following sections.

3.10.5.1 MTC1 Transfer Cask Vertical Lift

The top section of the transfer cask is a solid ring made of carbon steel. A pair of trunnions, 9 inches in diameter, are mounted 180° apart on this ring. The middle section of the transfer cask is comprised of a steel inner shell, a lead layer, a neutron shield layer, and a steel outer shell. The bottom section is a solid ring made of carbon steel. A pair of rails is welded to the bottom of the solid forging. A pair of steel doors is inserted in the rails. The overall height of the transfer cask is 198.0 inches. The overall diameter of the cask is 88.0 inches. The maximum loaded weight of the transfer cask is 230,000 pounds.

A three-dimensional finite element model is used to evaluate the lifting of a fully loaded MAGNASTOR transfer cask. Because of symmetry, only one-quarter of the transfer cask is modeled, as shown in Figure 3.10.5-1. The model includes the trunnions, the top ring at the trunnion region, the inner and outer shells, the bottom, and the lead and the neutron shield between the inner and outer shells. ANSYS SOLID45 elements (8-node brick element) are used to model the transfer cask. The trunnions are partial penetration welded to the top ring. CONTAC52 elements are used to model the interface between the trunnion and the top ring. The groove welds attaching the trunnion to the top ring are represented by coupled nodes between the two components.

The total weight of the heaviest loaded transfer cask is less than 115 tons. A conservative load of 120 tons, plus a 10% dynamic load factor, is used in the model. The load used in the quarter-symmetry model is $(240{,}000 \times 1.1)/4 = 66{,}000$ pounds. The load is applied upward at the trunnion as a "surface pressure load" whose location is determined by the lifting yoke dimensions. The magnitude of the surface pressure load is calculated so that the total upward force is equal to the load of 66,000 pounds. The model is restrained along two planes of symmetry with symmetry boundary conditions. Vertical restraints are applied to the bottom of the model to resist the force applied to the trunnion.

3.10.5.2 MTC2 Transfer Cask Vertical Lift

The finite element model for the vertical lift of the MTC2 transfer cask is similar to the MTC1 transfer cask model presented in Section 3.10.5.1. The differences between the two models include the cask base material (i.e., carbon steel for MTC1 and stainless steel for MTC2), the height (i.e., MTC1 is taller than MTC2), and the trunnion placement (i.e., for MTC2, the

trunnion is shifted down so that there is more top ring material above the trunnion, as compared to MTC1). Additionally, the total weight of the heaviest loaded transfer cask is less than 113 tons for the MTC2 transfer cask. A conservative load of 114 tons, plus a 10% dynamic load factor, is used for the MTC2. Therefore, the load used in the quarter-symmetry model is (228,000 x 1.1)/4 = 62,700 pounds for MTC2.

3.10.5.3 MTC2 Transfer Cask Inadvertent Lift

A finite element model is used to analyze the stresses in the components of the retaining ring assembly for the inadvertent lift of the MTC2 transfer cask. The retaining ring has an outer diameter of 42 inches and an inner diameter of 34.3 inches. Sixteen 1"-8 UNC bolts are used to bolt attach the retaining ring to the top ring of the transfer cask. A periodic section of the retaining ring is modeled using SOLID45 brick elements for the retaining ring and bolt, as shown in Figure 3.10.5-2. Gap elements (CONTAC52), beneath the bolt head, are used to model the interface between the bolt and retaining ring. Gap elements are also used to represent the top ring's constraint of the retaining ring's vertical motion. The vertical gap elements are positioned beyond the bolt radius, with one node connected to the bottom side of the retaining ring and the other constrained in all degrees of freedom (DOF). Additionally, the base of the bolt is constrained in all DOF and the ends of the retaining ring are constrained in the angular direction.

The weight of the MTC2 transfer cask is less than 106,000 pounds. A conservative load of 108,500 pounds, plus a 10% dynamic load factor, is used in the model for the inadvertent lift. The load is applied upward at the bottom surface of the retaining ring as a "surface pressure load" over an area limited by the inner diameter of the retaining ring and the outer diameter of the canister, i.e., 36 inches. The magnitude of the surface pressure load is calculated so that the applied upward force (3,730 pounds) is equal to the total force (108,500 pounds × 1.1) scaled by the percent of the retaining ring modeled, measured by the arc length at the canister outer radius (7.07 inch / 226.195 inch), i.e.,

$$\text{Applied force} = \left(W_{TFR} \times DLF\right)\frac{L_{Model}}{C_{TSC}} = 3{,}730 \text{ lbs}$$

where:

W_{TFR} = 108,500 lbs----------Conservative weight of the transfer cask
DLF = 1.1----------Dynamic load factor
C_{TSC} = 226.2 in----------Circumference of the canister
L_{Model} = 7.07 in ----------Arc length of the model at the radius of the canister

Figure 3.10.5-1 Finite Element Model for the Transfer Cask

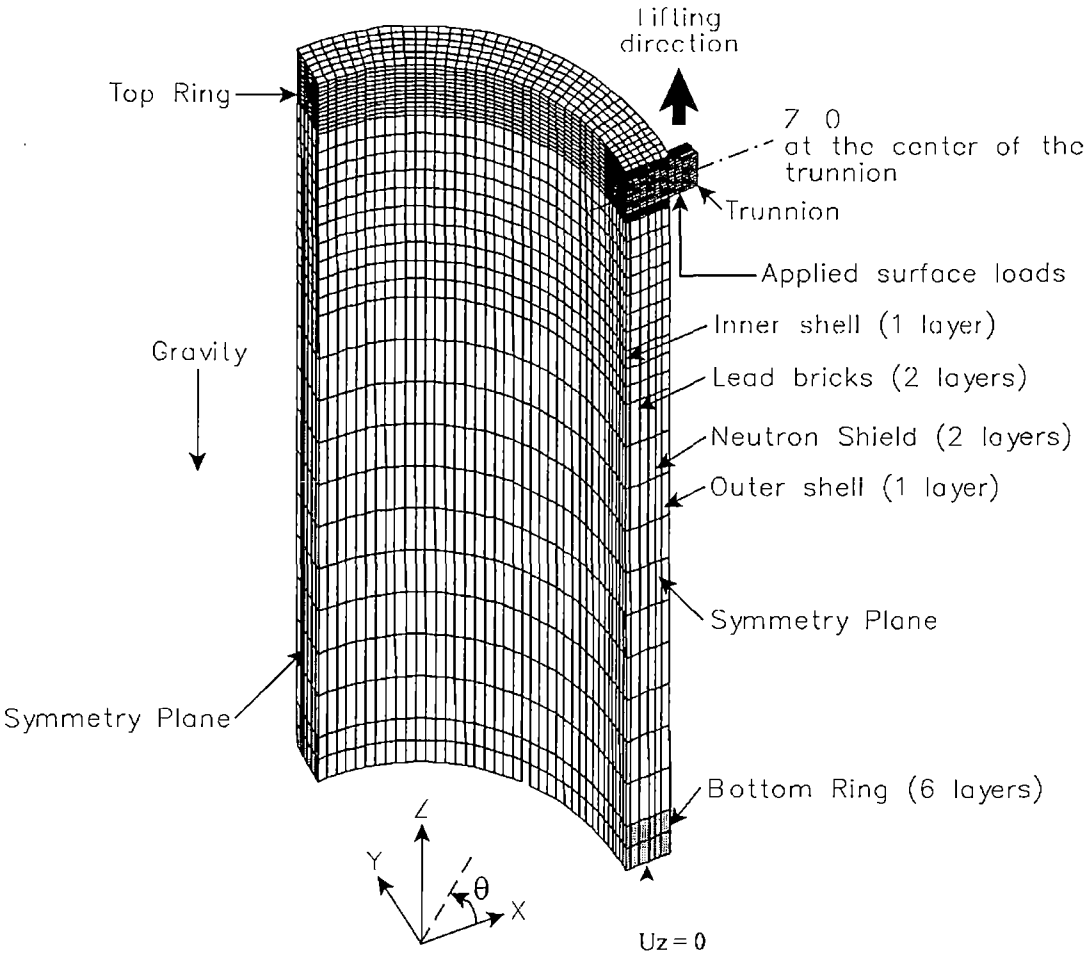
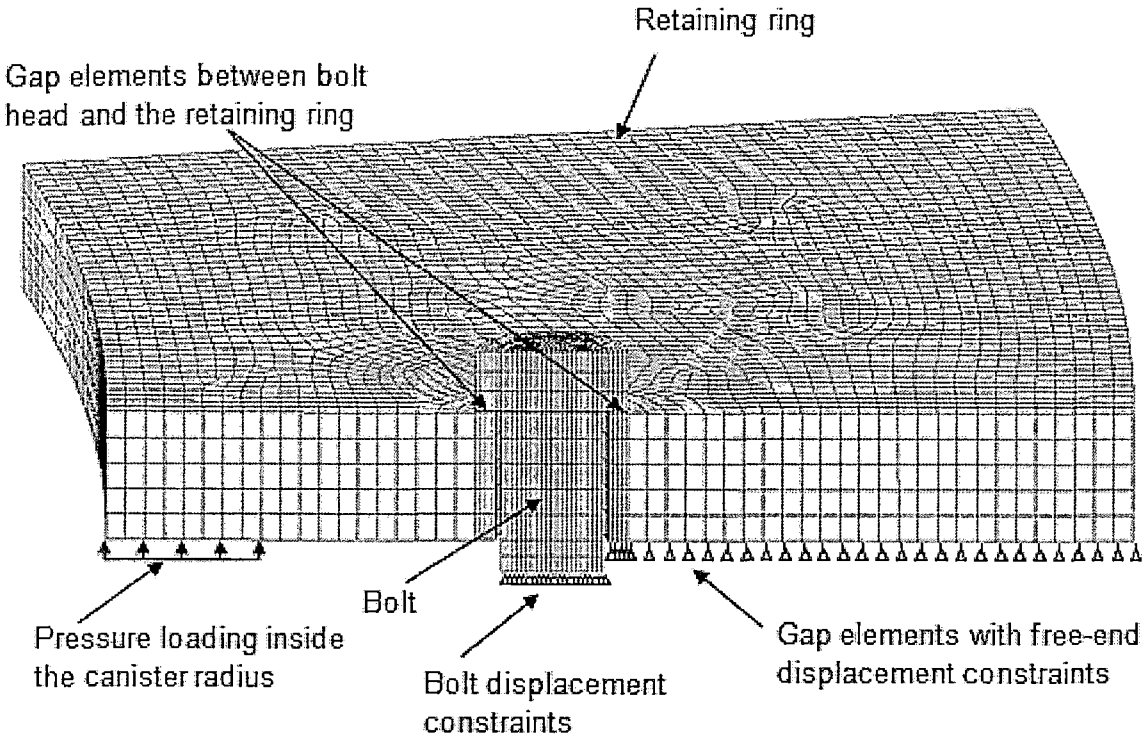


Figure 3.10.5-2 Finite Element Model for the MTC2 Transfer Cask Retaining Ring



3.10.6 Basket Stability Evaluation for Concrete Cask Tip-Over Accident Condition

This section describes the LS-DYNA models and the analyses confirming the stability of the MAGNASTOR PWR and BWR fuel baskets for the hypothetical concrete cask tip-over accident. The PWR basket stability evaluation represents the standard PWR basket configuration and bounds the PWR DF basket configuration relative to structural stability performance.

Confirmation that the basket does not buckle during the tip-over accident is addressed in Sections 3.7.2.2.1 and 3.7.2.2.2. Sections 3.5 through 3.7 also demonstrate that there are no other loads or stress-based failures that can contribute to instability in the MAGNASTOR basket design.

As described in Section 3.10.1.1 (PWR) and Section 3.10.2.1 (BWR), the basket geometric configuration is maintained by the side and corner support weldments bolted to the fuel tubes at the basket periphery and the pin-slot connections between adjacent fuel tubes.

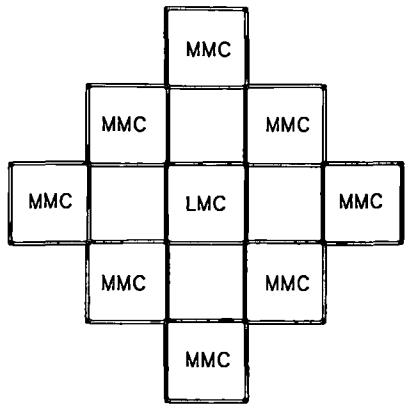
The geometric stability of the basket, addressed in this section, ensures that the fuel tubes retain their initial geometric configuration and all the pin-slot connections remain engaged after the tip-over accident. Pin-slot shear connections are placed between adjacent fuel tubes for both PWR and BWR configurations, as shown in Figure 3.10.6-1. The standard PWR basket modeled in this section is the bounding configuration for structural stability performance. The PWR DF basket through the corner weldments provide greater basket stiffness to further limit the motion of the tubes. Using the standard PWR basket is bounding for the PWR DF basket structural stability performance because the PWR-DF basket configuration replaces the standard corner weldment and independent corner fuel tube with a much stiffer integrated welded corner weldment and oversized fuel tube assembly. To observe the dynamic responses of the fuel tube assemblies and the pin-slot interface, a transient analysis is performed using a LS-DYNA model corresponding to a 10-inch periodic section (see Figure 3.10.6-1). The periodic model conservatively ignores the effect of tube and support weldment stiffness, multiple pins at the tube interface surface along the length of the tubes, and the end stiffness of the TSC shell weldment due to the bottom plate and lid. Basket geometric stability is validated using the conservative periodic model and canister shell boundary conditions representative of two axial locations along the canister shell. One location represents the maximum canister shell displacement resulting from the interaction of the basket near the middle section of the canister shell. The other axial location, corresponding to an increased acceleration and decreased canister shell displacements (since it is closer to the canister lid), is used for a sensitivity study to demonstrate that the boundary condition of the canister displacements has the governing effect on the dynamic

response of the basket for stability evaluation. With the conservative periodic model, the analysis shows that all pin-slot connections (i.e., all fuel tubes) remain engaged after the tip-over event.

The safety factor for stability is based on the loading associated with the tip-over event. During the tip-over accident, lateral loading is applied to the fuel basket. The accelerations experienced by the fuel basket are computed in Section 3.7.3.7, and the accelerations at the top of the basket are shown in Figure 3.7.3-3. Since the cask is rotating about its base, the acceleration of the basket monotonically decreases towards the base of the cask. The safety factor is defined as the factor applied to the acceleration for the basket loading in which the basket tubes maintain their geometric stability in the designed and fabricated configuration. In this evaluation, a factor of 1.5 is applied to the acceleration time history, based on the acceleration shown in Figure 3.7.3-3, for the transient evaluation of the basket using LS-DYNA. Using a factor of 1.5 confirms that the minimum safety factor for basket stability is greater than 1.5.

Since the lateral loading can be applied in an arbitrary angular direction of the basket, three basket orientations (0°, 22.5°, and 45°) are considered in the evaluations for the PWR and BWR baskets. Three-dimensional periodic finite element models are used for the evaluation, as shown in Figure 3.10.6-2 through Figure 3.10.6-4 for the PWR basket and Figure 3.10.6-5 though Figure 3.10.6-7 for the BWR basket. Full (360°) models are used for all basket orientations of the PWR and BWR baskets.

The most significant condition affecting the stability of the fuel basket is gaps between adjacent fuel tubes. Specifically, those fuel tubes that are not physically attached to the side weldment or corner weldment are identified as most susceptible to instability issues. The gaps between the fuel tubes may be developed due to a lack of straightness of the tubes and/or dimensional tolerance due to fabrication. Based on the basket assembly process and tolerance, the maximum gap between adjacent tubes occurs when a single 'Least Material Condition' (LMC) tube is surrounded by eight 'Maximum Material Condition' (MMC) tubes, as shown in the following sketch. To represent this arrangement, a bounding gap of 0.025 inch (incorporated by reduction of tube width, while maintaining the tube wall thickness) is considered for three tubes for the PWR 0° model (see tube locations 3, 6 and 11 in Figure 3.10.1-11) and six tubes for the BWR 0° model (see tube locations 2, 7, 12, 14, 19 and 23 in Figure 3.10.2-13). Note tube width reduction is also considered for the corresponding tube locations in the models analyzing other basket orientations. Use of the gap size of 0.025 inch is conservative since the maximum gap size permitted during the basket assembly is limited to 0.02 inch.



Use of this approach results in the initial position of the fuel tube, in the transient evaluation, being suspended without contact between the individual tubes. While this is analytically possible, the occurrence of such gaps during fabrication is not physically possible. The assembly process, horizontal stacking, will result in minimal gaps that would generally occur along the length of the fuel tubes between points of contact.

Model Description

The models shown in Figure 3.10.6-2 through Figure 3.10.6-7 are mainly comprised of brick elements representing the fuel tubes, the fuel assembly, the pins, the support weldments, the bolts/bosses, the canister shell and the concrete cask liner.

The length of the model in the axial direction is 10 inches, which corresponds to one-half the distance between adjacent pins along the length of the basket for the PWR basket, and the full distance between adjacent pins for the BWR basket. The corner support weldment is represented by shell elements and the shell elements are modeled along the centerline of the weldment. Since LS-DYNA takes into account the thickness of the shell element during the transient evaluation, the model must have a gap incorporated between the shell and the solid elements corresponding to a minimum value of the half-thickness of the shell element. Gaps between brick elements do not require this consideration. The bolted boss connections for attaching the support weldment to the fuel tube arrays are also modeled using brick elements. The modeling details of the bosses for the corner support weldment and side support weldment are shown in Figure 3.10.6-8 for the PWR and Figure 3.10.6-9 and Figure 3.10.6-10 for the BWR. The model allows a relative planar displacement of 1/16 inch between the support weldment and the fuel tubes by incorporating a gap of 1/16 inch on both sides of the bosses.

The pins are welded to one side of the adjacent fuel tube slots prior to the assembly of the fuel tubes to form the basket. These welds are not modeled in the finite element model.

The finite element model also contains the concrete cask steel liner, which is represented by elastic brick elements with a thickness of 4.0 inches. The purpose of these elements is to impose the accelerations on the canister and basket based on the analysis results for the concrete cask tip-over accident (Section 3.7.3.7).

The fuel assembly weight used in the PWR models is 1,680 pounds for a total contents weight of 37 × 1,680 or 62,160 pounds. Since the basket response is controlled by the total contents weight, the maximum contents weight in each storage location is 1,765 pounds (5% increase from 1,680 pounds) while constraining the maximum total basket contents weight to 62,160 pounds. The small variation in the weight in each storage location of the model has a negligible effect on the basket stability.

Material Properties

The mechanical properties used in the analyses are described as follows.

Carbon Steel Fuel Tubes and Weldments:

The fuel tubes and the corner and side weldments are represented by a piecewise linear plasticity model with the following elastic properties. Note that the maximum tube temperature is less than 700°F for the BWR basket and less than 720 °F for the PWR basket. The difference in material properties (yield and ultimate strength of SA537 carbon steel) at 700°F and 720°F is less than 1% and has an insignificant effect on the analysis results.

Fuel tubes at 700°F (SA537, Class 1, carbon steel)

Yield strength = 32.3 ksi

Ultimate strength = 68.4 ksi

Ultimate strain = 21%

ν = 0.31 ---------- Poisson's Ratio
E = 25.5×10^6 psi ---------- Modulus of Elasticity

The density corresponding to the fuel tubes was adjusted to account for the neutron absorber material.

Side and corner weldments at 500°F (SA537, Class 1, carbon steel)

Yield strength = 35.4 ksi

Ultimate strength =68.4 ksi

Ultimate strain = 21%

ν = 0.31 ---------- Poisson's Ratio
E = 27.3×10^6 psi ---------- Modulus of Elasticity

Canister Shell (SA240, Type 304/304L stainless steel)

The canister shell is represented by inelastic material with the following properties at 500°F.

Yield strength = 19.4 ksi

Ultimate strength = 63.4 ksi

ν = 0.31 ---------- Poisson's Ratio

E = 25.8×10^6 psi ---------- Modulus of Elasticity

Steel Inner Liner (A36 carbon steel)

The steel liner is represented by elastic material with the following properties at 500°F.

Yield strength = 29.3 ksi

Ultimate strength = 58.0 ksi

ν = 0.31 ---------- Poisson's Ratio

E = 27.3×10^6 psi ---------- Modulus of Elasticity

Fuel Assembly

The element representing the fuel assembly were modeled with the following inelastic properties

Yield strength =1 ksi

ν = 0.49 ---------- Poisson's Ratio

E = 1×10^5 psi ---------- Modulus of Elasticity

The density for the fuel assembly corresponds to the design weight of the fuel assembly.

Boundary Conditions

The LS DYNA contact algorithms are employed between the pins and the fuel tubes, between the support weldments and the fuel tubes, between the basket and the canister, and between the canister and the concrete cask. Symmetry boundary conditions are applied to all parts at the plane of symmetry (see Figure 3.10.6-5, typical). The axial displacements are restrained on both axial faces of the model.

The canister portion of the periodic model does not account for the end effects of the canister. With the rigid plates at each end of the canister, the canister shell physically restricts the motion of the tubes. To permit the canister shell elements in the periodic model to restrict the motion of the tube elements in the periodic model, the inner surface of the cask liner in the periodic model is defined based on a canister shell displacement profile corresponding to the maximum canister shell displacement during the cask tip-over accident. The nodal position of the inner surface of the liner is altered so that the displacements of the canister shell nodes in the periodic model are

restricted to the same physical displacements as if the ends of the canister shell were present in the model.

The canister shell displacements are determined by the quasi-static ANSYS analysis for the canister and the basket for the cask tip-over condition. See Section 3.10.9 for a detailed description of the canister-basket models. A DLF of 1.36, in conjunction with a load factor of 1.5, is conservatively used in the canister-basket models.

To represent the accelerations applied to the periodic basket model during the tip-over, an acceleration time history is applied to the nodes of the concrete cask liner elements in the model. The acceleration data corresponds to the acceleration time history at the axial location where the maximum canister displacement occurs, with a factor of 1.5. As presented in Section 3.10.9, the maximum canister shell displacements occur at approximately 90 inches from the canister bottom. Figure 3.10.6-11(a) shows the acceleration time history corresponding to the location 86 inches from the canister bottom (with a factor of 1.5), based on the filtered acceleration time history at the top of the basket as shown in Figure 3.7.3-3. Note that the acceleration time history shown in Figure 3.10.6-11(b) corresponds to the canister shell location at 135 inches from the bottom and is used for a sensitivity study.

A velocity is applied to all the nodes of the model as an initial condition. The velocity is determined based on the location of the maximum canister shell displacements and 1.5 times the angular velocity due to the cask tip-over event (Section 3.10.4.4).

A uniform body force of 1g was applied to simulate gravity.

Load Cases

The PWR and BWR basket stability evaluations are performed using the models and load conditions described in this section. As shown in Table 3.10.6-1, three base cases (P1 through P3) are considered for the PWR basket orientations of 0°, 22.5°, and 45°.

Three base cases (B1 through B3) are evaluated for the BWR for basket orientations of 0°, 22.5° and 45°, as shown in Table 3.10.6-2. Additionally, Case B4 is evaluated as a sensitivity study using the canister shell displacement from the ANSYS canister-basket model in Section 3.10.9 at a section 135 inches from the bottom of the canister. The acceleration time history used in Case B4 also corresponds to the axial section 135 inches from the bottom of the canister. Case B4 uses the basket orientation of 22.5° to allow its results to be compared with Case B2 (22.5° base case).

Model Conservatism in the Periodic LS-DYNA Models

- The models neglect any restraint developed by neighboring pin-slot connections (axially) in the tubes.
- The models incorporate beyond design basis maximum-minimum material conditions for the pins. A conservative tube size reduction of 0.025 inch is used for the base cases for the PWR and BWR basket models. The actual maximum fabricated assembly gap is 0.02 inch, and the prototype fabrication has shown the as-built gap is significantly less than 0.016 inch.
- The models consider boundary conditions corresponding to the maximum canister shell displacement, which occurs at a small section near the middle of the canister shell (see Figure 3.10.9-6 and Figure 3.10.9-7). Most parts of the basket are actually supported by the canister shell with less displacement (the periodic models neglect the stiffness of the basket support weldments and the fuel tube).
- The models consider the maximum displaced canister shell to be constant over the impact time history. This is also conservative because the canister shell displacement will be reduced significantly (providing more constraint to limit basket deflection) after the peak of the impact.
- The boundary condition of the canister shell displacement is determined based on conservative loading (a DLF of 1.36) as discussed in Section 3.10.9.

Post-Processing

The primary output of these analyses is the resulting responses of the basket components during and after the impact. Typical responses of the basket fuel tubes are shown in Figure 3.10.6-12 and Figure 3.10.6-13 for the PWR basket and the BWR basket, respectively. These plots correspond to Case P1 and Case B1 in Table 3.10.6-1 and Table 3.10.6-2, respectively.

To further observe the response of the pin-slot connections, the change of the gap at the fuel tube corners is measured as the change in the pin-slot width. The time history of the maximum change in pin-slot width is obtained from the LS-DYNA analysis results for the base cases (Cases P1 though P3 and Cases B1 through B4) for the PWR basket and the BWR basket, respectively.

Figure 3.10.6-14 through Figure 3.10.6-18 show the time history of the change in length for the location where maximum gap occurs (Point A in Figure 3.10.6-2 through Figure 3.10.6-7). The top three gap changes for each case are listed in Table 3.10.6-3 and Table 3.10.6-4 for PWR and BWR configurations, respectively. The locations of these maximum gap changes are shown in

Figure 3.10.6-2 through Figure 3.10.6-7. Note that the maximum gap change for Case P2 is 0.158 inch (Point A of Figure 3.10.6-3). The maximum gap change for Case B4 (sensitivity study for BWR), 0.124 inch (Point A of Figure 3.10.6-6), is also significantly less than the maximum gap change of the base case for 22.5 degrees (Case B2), 0.201 inch. This comparison shows that the canister shell profile, as opposed to the impact load, is the governing boundary condition for the basket stability evaluation. Each stability analysis orientation is performed using the maximum canister shell displacement with the corresponding acceleration time history for the axial location of the maximum displacement from the point of rotation. All the pin-slot connections remain engaged for all the cases for both the BWR basket and PWR basket.

In order to be responsive to the requirements of 10 CFR 72.236 to provide assurance that the MAGNASTOR basket maintains stability when subject to transport accident load configurations, a specific dynamic analysis is performed. The basket and the orientation producing the worst case pin-slot displacement identified for the tip-over accident are evaluated for transport loading, with the transport cask inner shell as the boundary condition. The results summary presented in Table 3.10.6-3 and Table 3.10.6-4 identify that the BWR basket with a 22.5-degree orientation has the largest relative pin-slot displacement. Results from the governing analysis of a 30-foot side drop for the BWR basket with a 22.5-degree orientation validate basket stability for transport conditions.

A sensitivity study is performed to evaluate the effect of the gap size between the flats at tube corners. A gap of 0.016 inch is used as compared to the 0.025 inch for the base cases. The analysis is performed for the BWR configuration with a 22.5° basket orientation, and the results are compared with the results of Case B2 (base case) in Table 3.10.6-4. The maximum gap change for this sensitivity study case is 0.227 inch, which is approximately 30% less than the maximum gap change for Case B2 (0.305 inch). This indicates that the models used in the base cases for both the PWR and BWR configurations are conservative.

A typical time history of the gap at the bosses connecting the fuel tubes and the support weldment is shown in Figure 3.10.6-20 and Figure 3.10.6-21. The gap time history curves correspond to the BWR basket with a 45° orientation and the locations of the bosses are shown in Figure 3.10.6-7 (Points G1 and G2). At location Point G2, See Figure 3.10.6-20, the distance in the time history plot is measured by two nodes with 0.02-inch difference in the axial direction (Z) of the basket, which is perpendicular to the gap. The initial gap size is 0.0656 (Curve A) inch in the model. The gap starts to close at approximately 0.0225 second and then maintains at that position during the remainder of the time as indicated by Curve A. The final gap size is 0.05 inch.

At location Point G1, See Figure 3.10.6-21, the distance in the time history plot is measured by two nodes with 0.02-inch difference in the axial direction (Z) of the basket, which is perpendicular to the gap. The initial gap size is 0.0656 (Curve A) inch in the model. At approximately 0.011 second, the block moves to close the gap in the X and Y directions and maintains at that position during the remainder of the time as indicated by Curve A. The final gap size is 0.04 inches.

Summary

The evaluations provided in this section confirm that the PWR and BWR baskets maintain their configuration during a cask tip-over accident event. As previously discussed, a 1.5 factor is applied to the loading used for the periodic LS-DYNA for stability evaluation. The same factor was also used (in addition to a DLF of 1.36) for loading of the three-dimensional canister-basket model to determine the canister shell displacements as the boundary condition of the periodic LS-DYNA models. Considering all the conservatism in the periodic models, as previously described, it is concluded that the factor of safety for the PWR and BWR basket stability for the cask tip-over accident is considerably greater than 1.5 (and greater than acceptance criteria of 1.1, as defined in the following discussion).

The acceptance criteria for basket stability evaluation is established based on the acceptance criteria of the Collapse Load Analysis as discussed in ASME Code Subsection III, Appendix F. Section F-1341.3 states that the load should not exceed 90% of the analysis collapse load. The criterion for the minimum safety factor for the basket stability evaluation is considered to be 1.1 (1/0.9).

Figure 3.10.6-1 Basket Pin-Tube Slot Connections at Fuel Tube Corners

[redacted]

Figure 3.10.6-2 PWR Basket Finite Element Model for Storage Cask Tip-Over – 0° Basket Orientation

[redacted]

Figure 3.10.6-3 PWR Basket Finite Element Model for Storage Cask Tip-Over – 22.5° Orientation

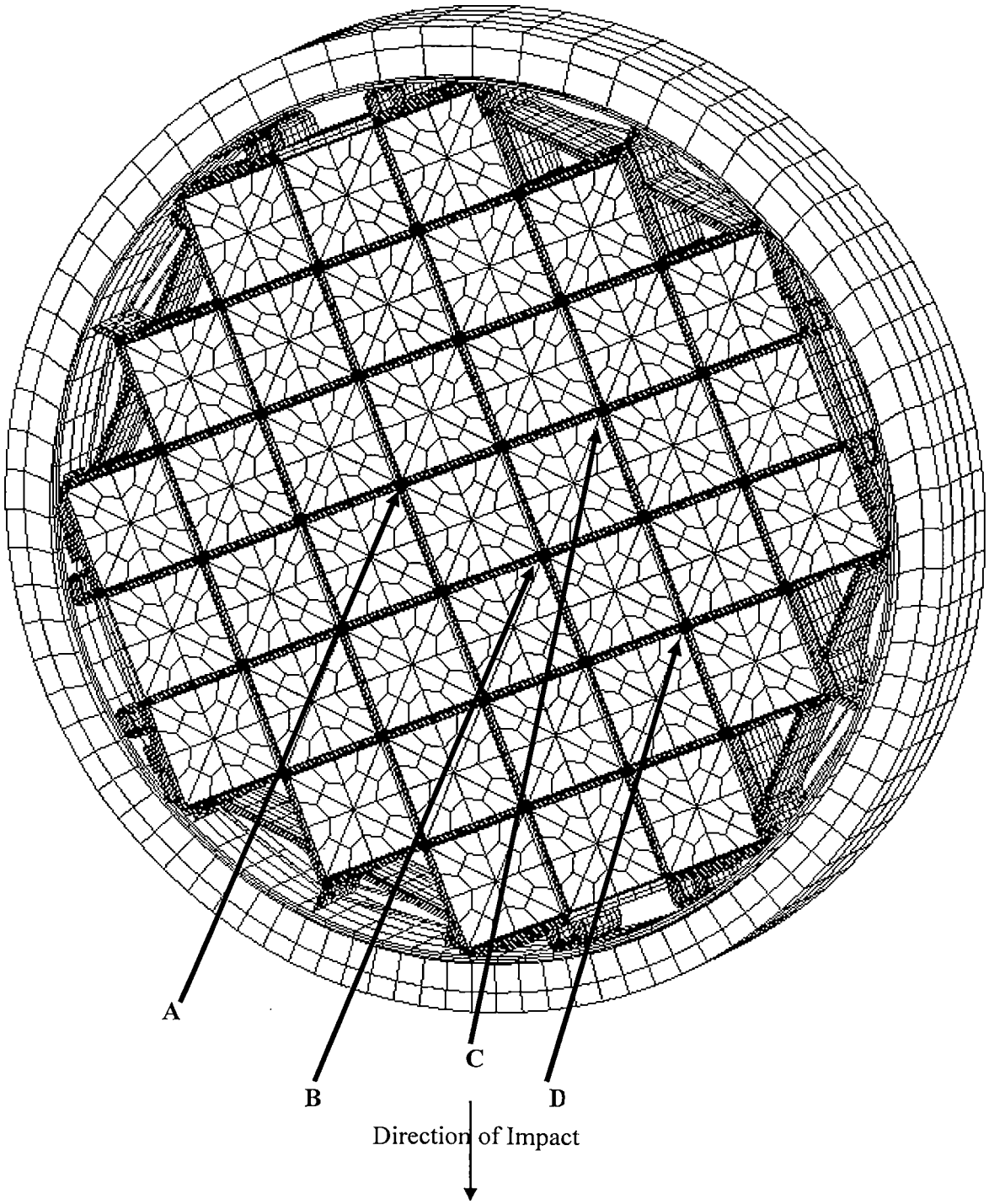


Figure 3.10.6-4 PWR Basket Finite Element Model for Storage Cask Tip-Over – 45° Orientation

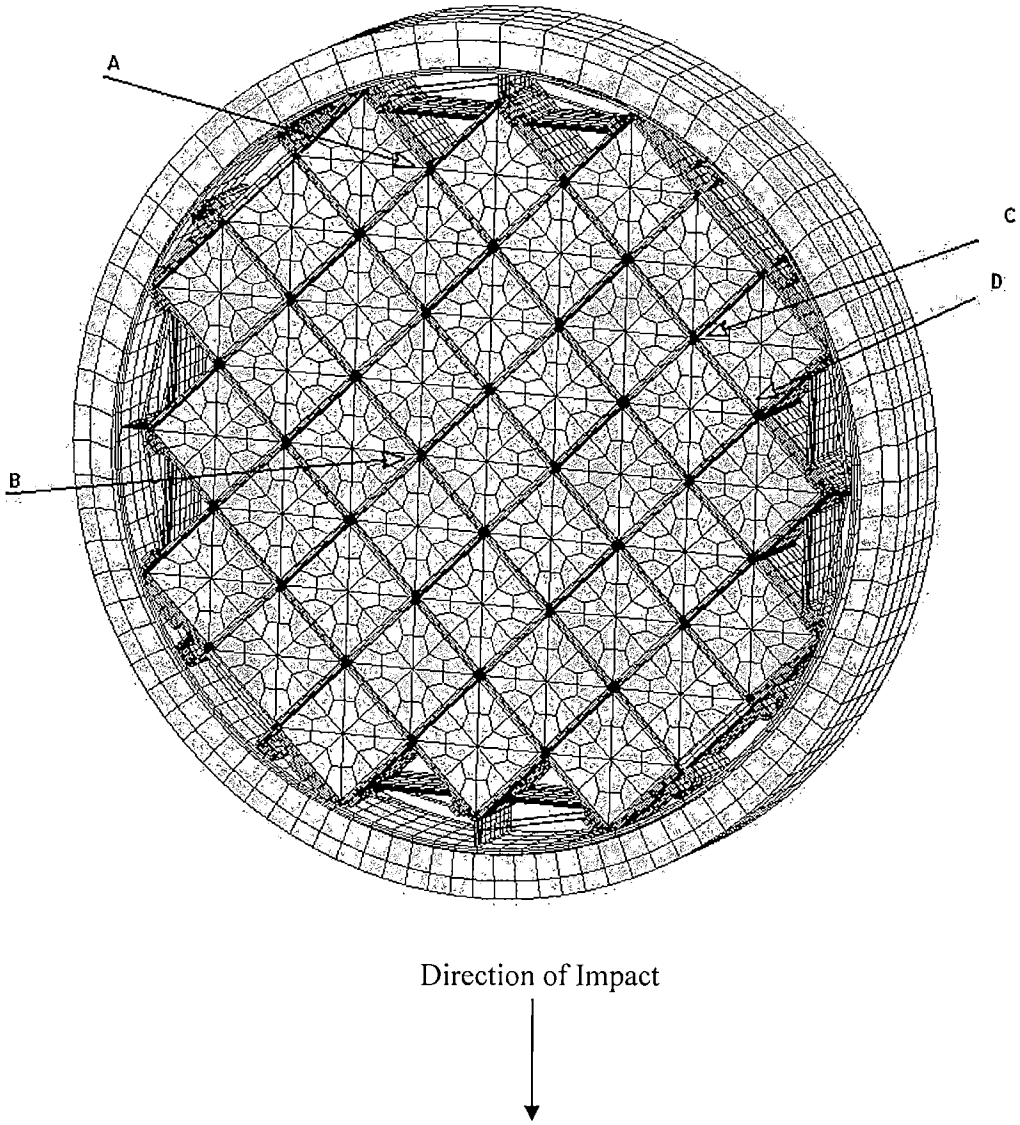


Figure 3.10.6-5 BWR Basket Finite Element Model for Concrete Cask Tip-Over Accident – 0° Basket Orientation

[redacted]

Figure 3.10.6-6 BWR Basket Finite Element Model for Concrete Cask Tip-Over Accident – 22.5° Basket Orientation

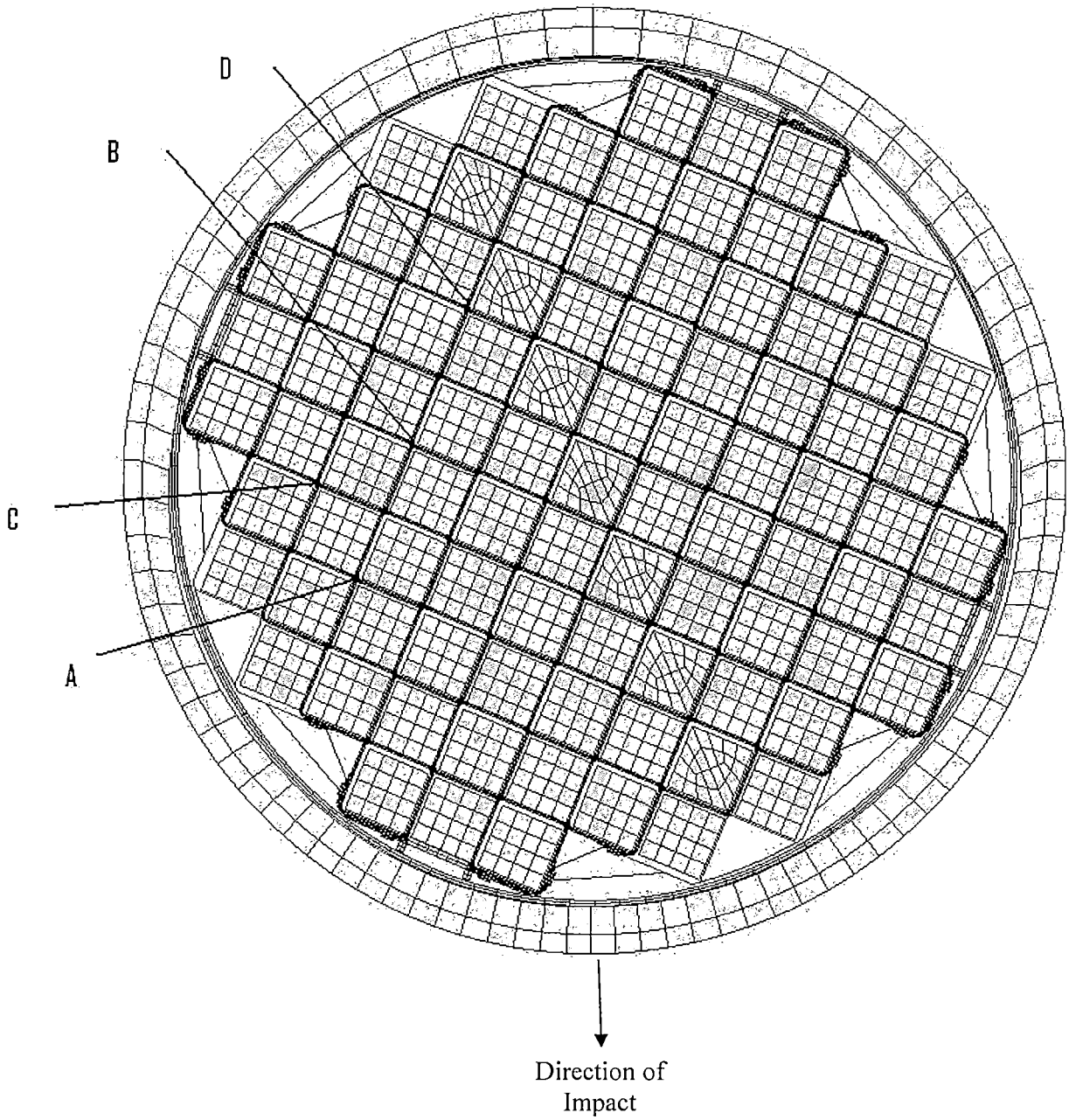


Figure 3.10.6-7 BWR Basket Finite Element Model for Concrete Cask Tip-Over Accident – 45° Basket Orientation

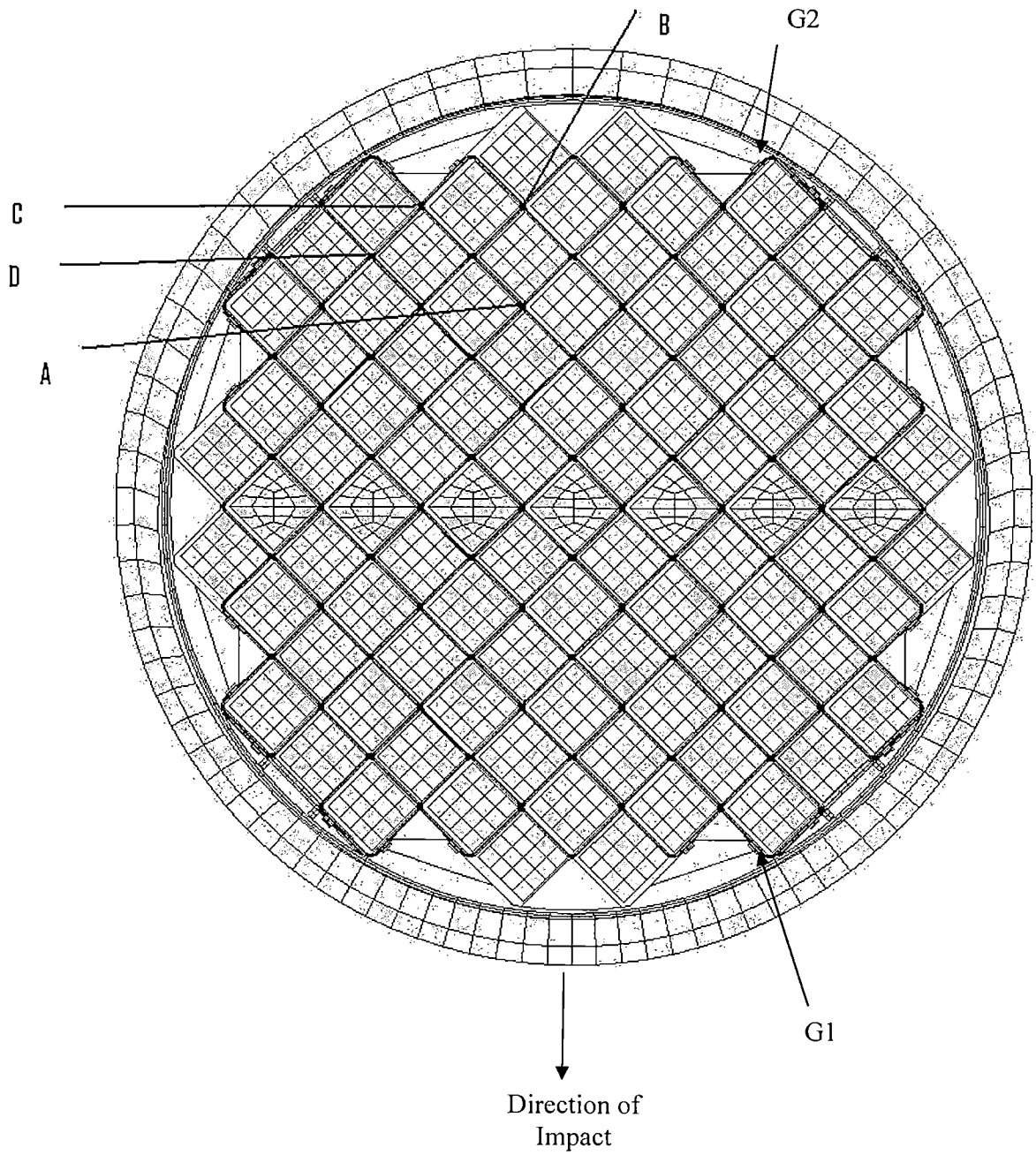


Figure 3.10.6-8 PWR Basket Finite Element Model – Boss Connection for Corner and Side Support Weldment

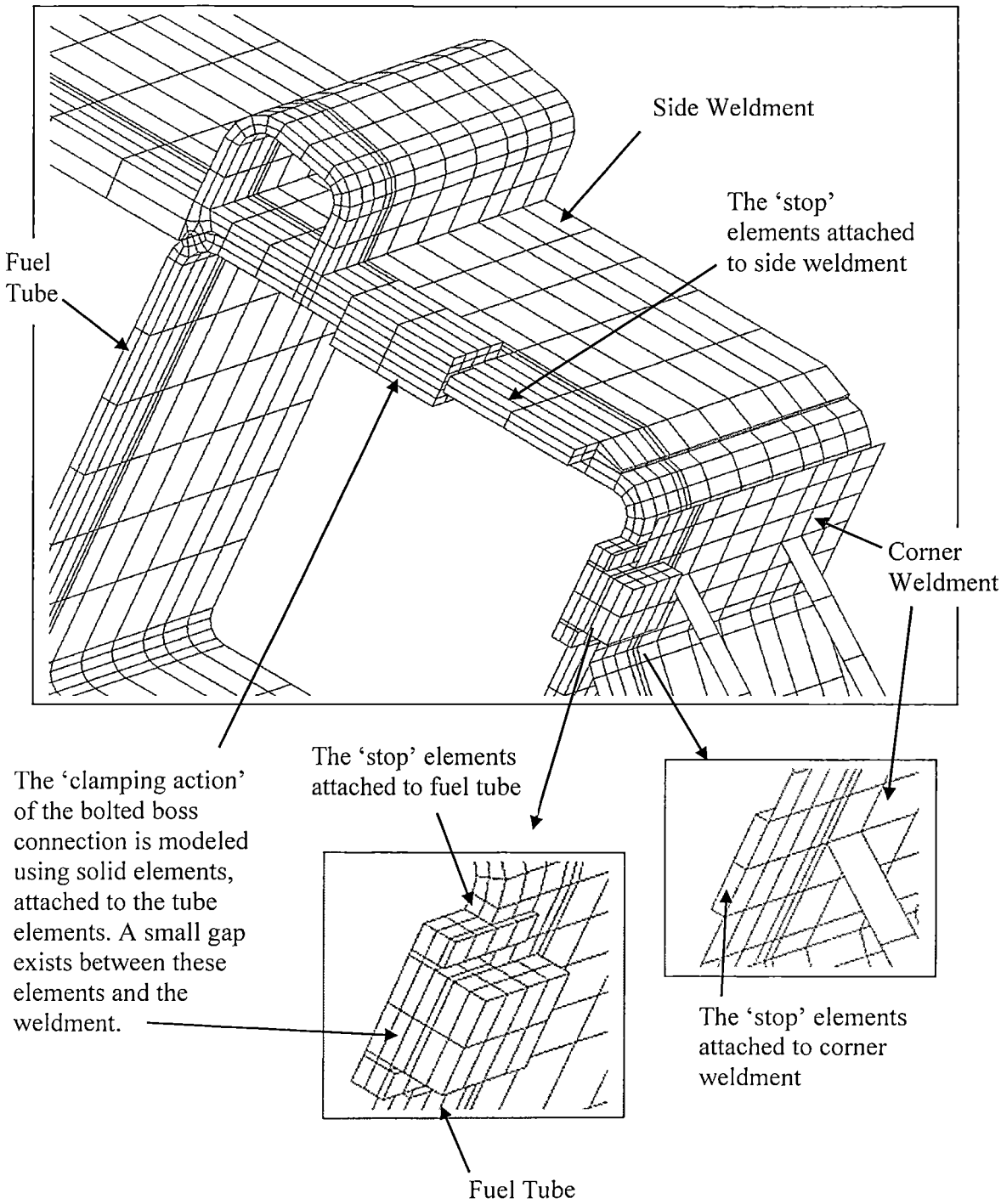


Figure 3.10.6-9 BWR Basket Finite Element Model – Boss Connection for Corner Support Weldment

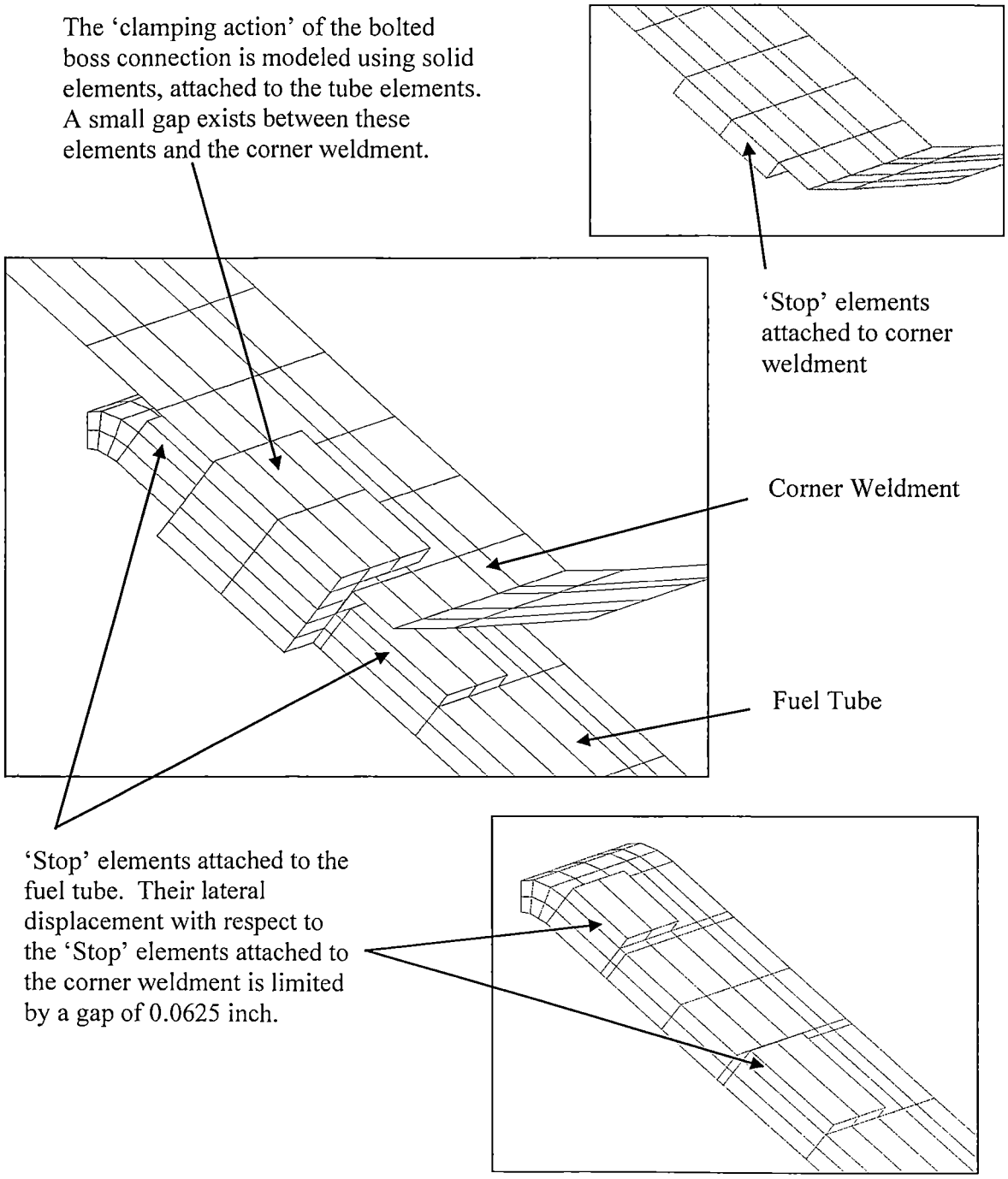


Figure 3.10.6-10 BWR Basket Finite Element Model – Boss Connection for Side Support Weldment

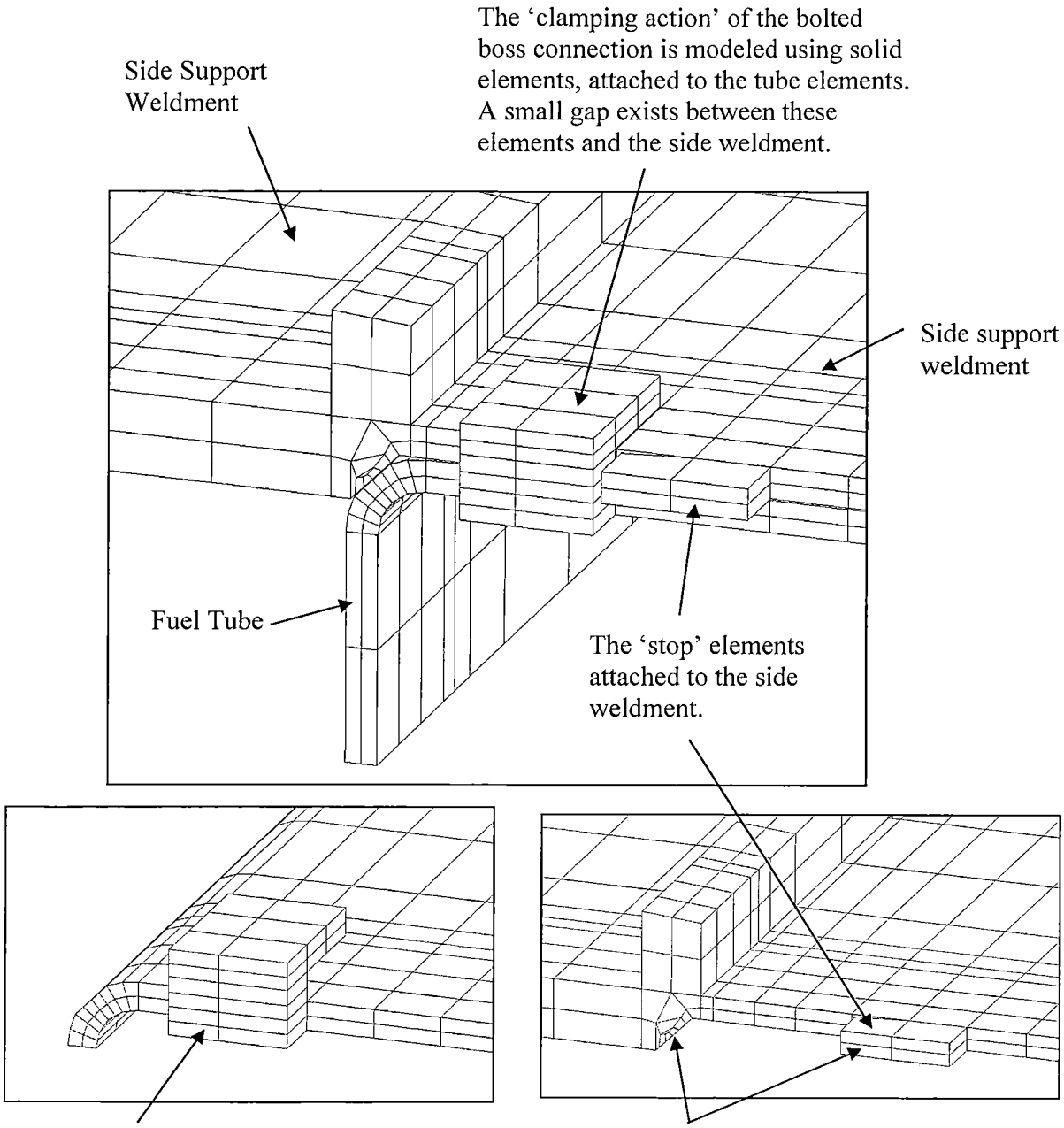
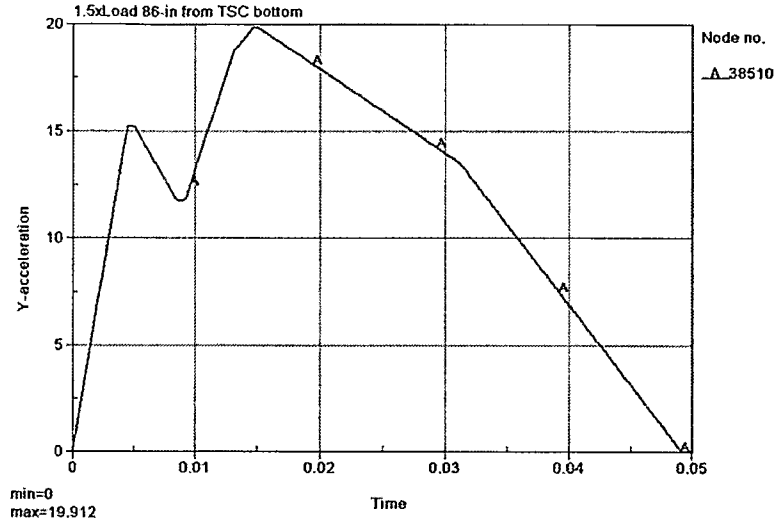


Figure 3.10.6-11 Acceleration Time History for Basket Stability Evaluation

(a) 1.5 × acceleration at 86 inches from TSC bottom



(b) 1.5 × acceleration at 135 inches from TSC bottom

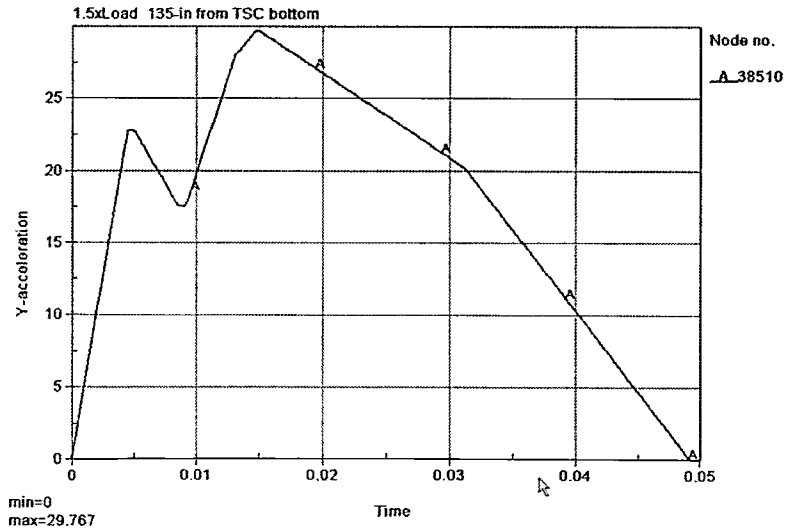


Figure 3.10.6-12 Typical Response of PWR Basket Fuel Tubes Pin-Slot Connections

[redacted]

Figure 3.10.6-13 Typical Response of BWR Basket Fuel Tubes Pin-Slot Connections

[redacted]

Figure 3.10.6-14 Time History of Maximum Gap Change at Fuel Tube Corner – PWR Basket 0° Orientation

[redacted]

Figure 3.10.6-15 Time History of Maximum Gap Change at Fuel Tube Corner – PWR Basket 22.5° Orientation

[redacted]

Figure 3.10.6-16 Time History of Maximum Gap Change at Fuel Tube Corner – PWR Basket 45° Orientation

[redacted]

Figure 3.10.6-17 Time History of Maximum Gap Change at Fuel Tube Corner – BWR Basket 0° Orientation

[redacted]

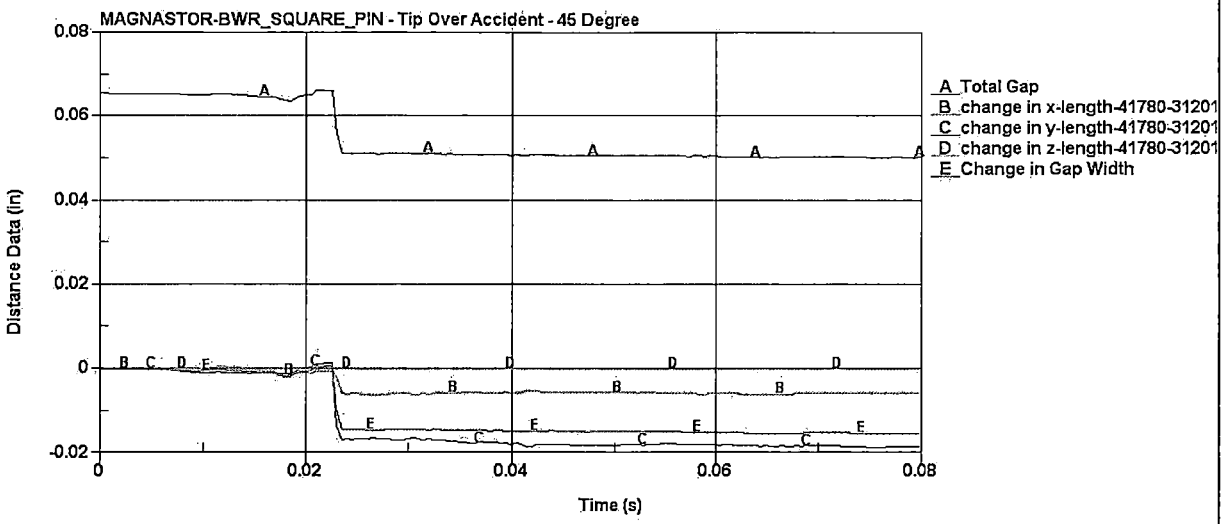
Figure 3.10.6-18 Time History of Maximum Gap Change at Fuel Tube Corner – BWR Basket 22.5° Orientation

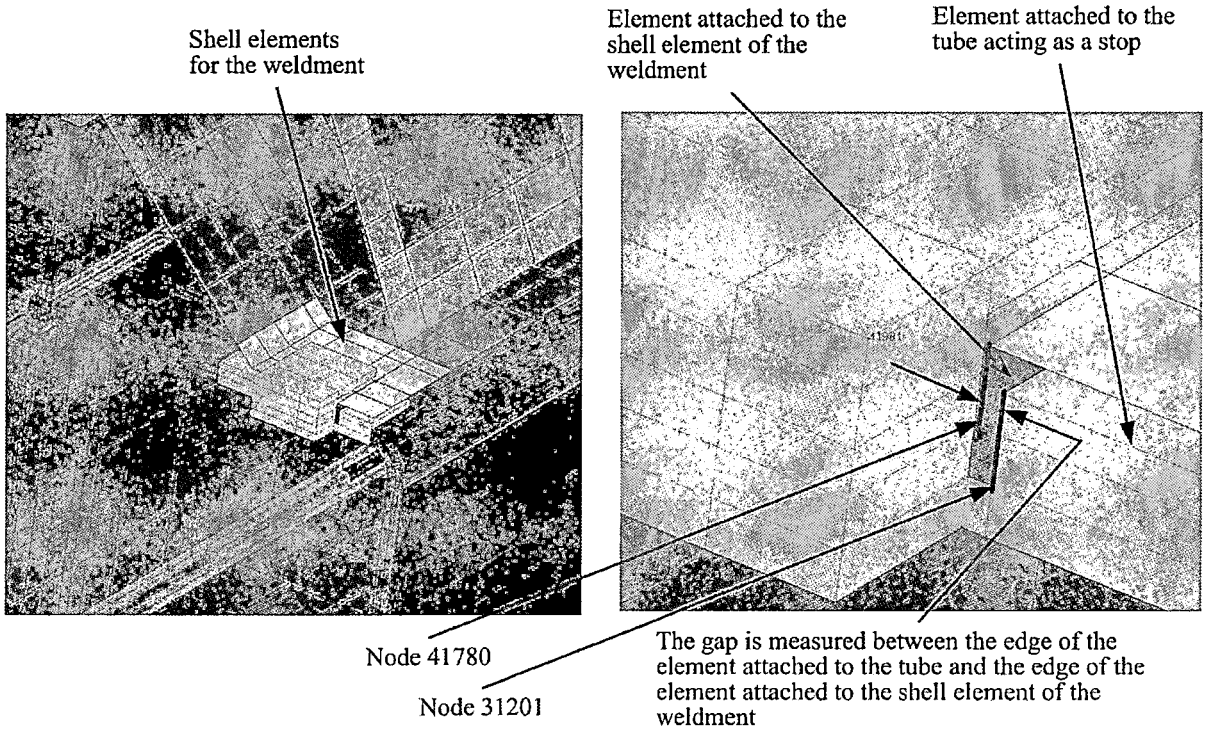
[redacted]

Figure 3.10.6-19 Time History of Maximum Gap Change at Fuel Tube Corner – BWR Basket 45° Orientation

[redacted]

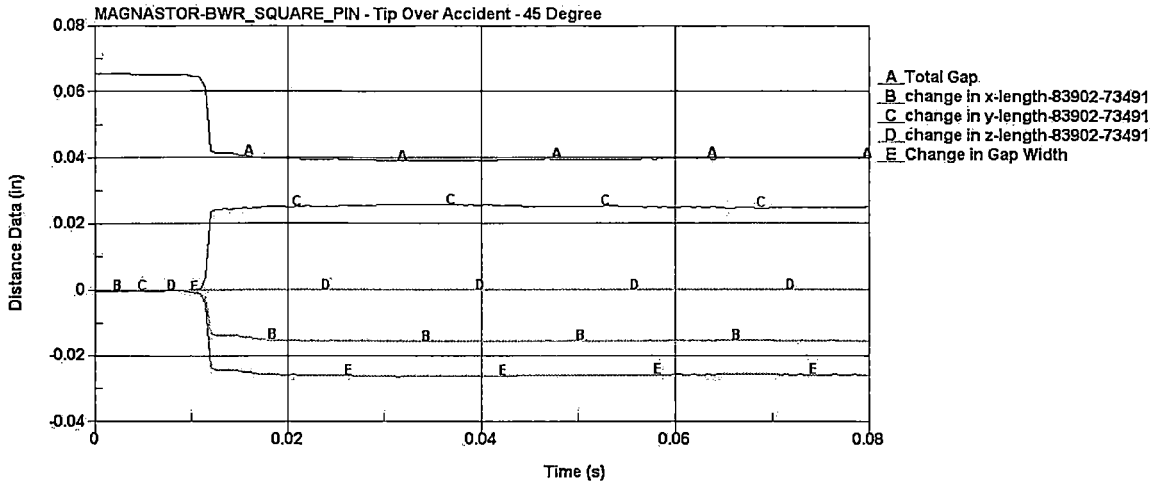
Figure 3.10.6-20 Typical Time History of Gap at Boss for BWR Support Weldments – Location G2

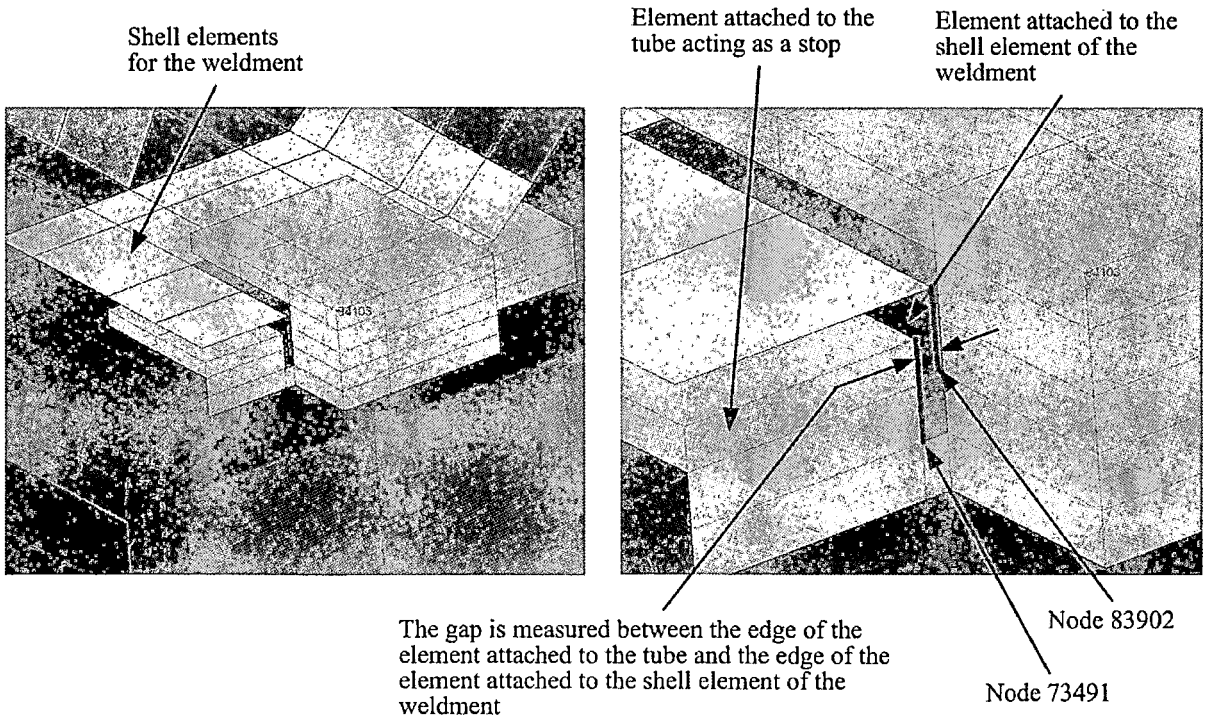




Note: See Figure 3.10.6-7 for the G2 location.

Figure 3.10.6-21 Typical Time History of Gap at Boss for BWR Support Weldments – Location G1





Note: See Figure 3.10.6-7 for the G1 location.

Table 3.10.6-1 Load Cases Evaluated for PWR Fuel Basket Stability

Case	Basket Orientation	Model Cross-Section	Remarks
P1	0	360°	Base Case
P2	22.5	360°	Base Case
P3	45	360°	Base Case

Table 3.10.6-2 Load Cases Evaluated for BWR Fuel Basket Stability

Case	Basket Orientation	Model Cross-Section	Remarks
B1	0	360°	Base Case
B2	22.5	360°	Base Case
B3	45	360°	Base Case
B4	22.5	360°	Sensitivity Study[a]

[a] Sensitivity study for boundary conditions using canister shell displacement at 135 inches from canister bottom and the associated acceleration time history.

Table 3.10.6-3 Summary of Maximum Gap Changes at Pin-Slot Connections for PWR Basket

[redacted]

Table 3.10.6-4 Summary of Maximum Gap Changes at Pin-Slot Connections for BWR Basket

Case	Basket Orientation	Max Gap Change at Pin-Slot Connection (inch)			
		Location A[a]	Location B[a]	Location C[a]	Location D[a]
B1	0	0.136	0.126	0.124	0.118
B2	22.5	0.201	0.101	0.098	0.087
B3	45	0.141	0.12	0.079	0.067
B4[b]	22.5	0.124	-	-	-

Notes:
[a] See Figure 3.10.6-5 through Figure 3.10.6-7 for locations for Cases B1 through B3, respectively.
[b] Only the maximum gap change is reported for Case B4, see Figure 3.10.6-6 for details of location A. Comparison of the maximum gap change results for cases B4 and B2 indicate that the base cases (B1, B2, and B3) are bounding.

3.10.7 Fuel Tube Plastic Analysis for Concrete Cask Tip-Over Accident Condition

This section describes the LS-DYNA models for the fuel tubes in the PWR and BWR fuel baskets and the analyses to evaluate any possible permanent deformation of the fuel tubes for the hypothetical concrete cask tip-over accident.

Model Description

As shown in Figure 3.10.7-1, a three-dimensional half-symmetry model is constructed to represent a half cross-section of a PWR fuel tube using the LS-DYNA program. The model for the BWR fuel tube is similar to that for the PWR fuel tube. The model contains a cross section of the fuel tube and a rigid block through which the displacement is applied to the top of the fuel tube.

Material Properties

Piecewise linear plastic properties corresponding to 700°F are used for the carbon steel fuel tubes.

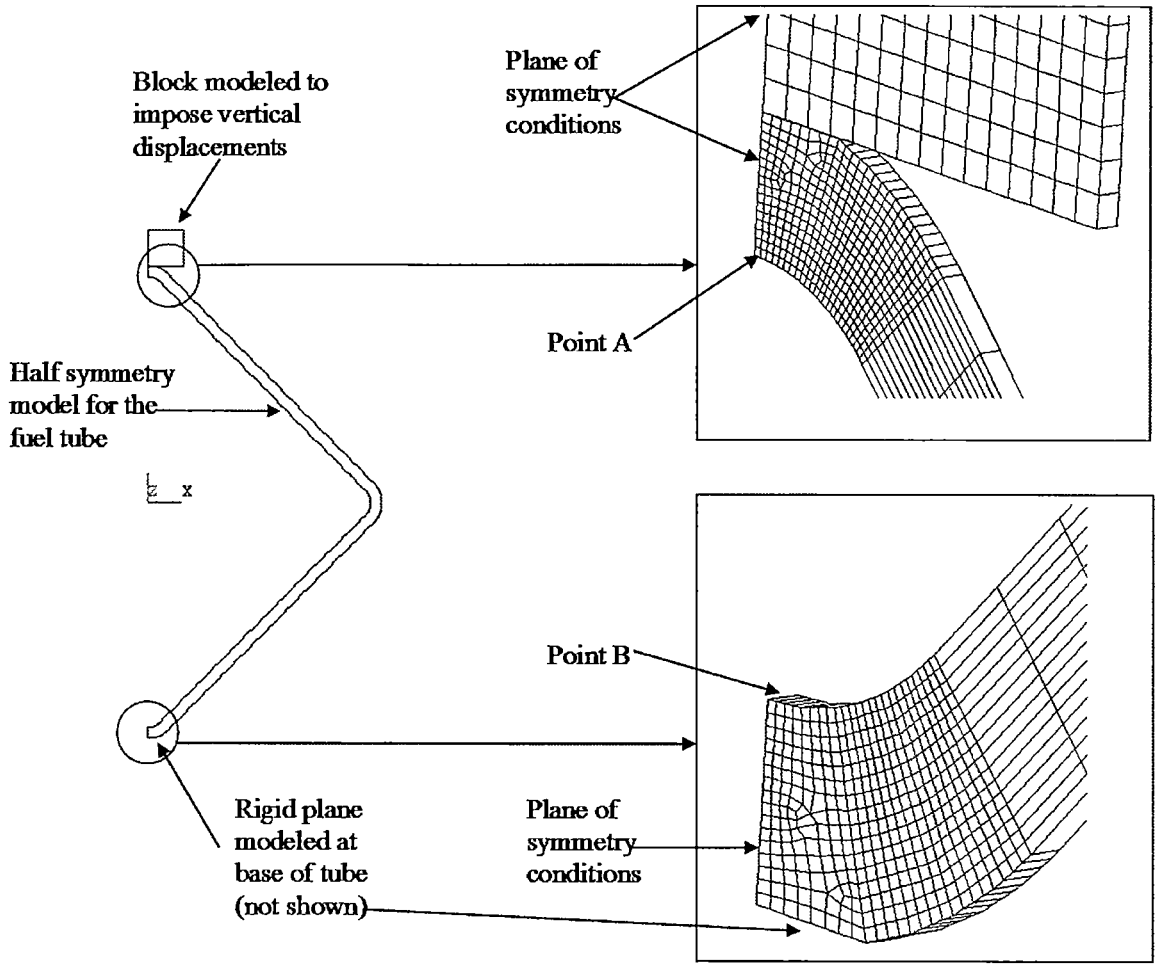
Boundary Conditions

Automatic surface-to-surface contact conditions are employed between the block imposing the displacement and the top of the fuel tube. The motion at the bottom of the fuel tube is limited by the definition of a rigid plane. Symmetry boundary conditions are applied to the plane of symmetry (see Figure 3.10.7-1, typical). The vertical displacement of the block is specified as a triangular shaped time history with the maximum displacement of 0.294 inch for the PWR fuel tube and 0.34 inch for the BWR fuel tube. The displacement for the PWR tube corresponds to the maximum diagonal displacements of the fuel tubes for the tip over condition as evaluated in Section 3.7.2.1.2. For the BWR configuration, the displacement corresponds to the BWR evaluation using LS-DYNA in Section 3.10.6. The duration of the motion is 0.045 seconds which reflects the duration of the impact in the tip-over accident. The analysis is continued until a time of 0.060 seconds to obtain the final deformed shape of the fuel tube.

Post-processing

The permanent deformation of the fuel tubes is determined by computing the difference in the vertical displacements of Point A and Point B (Figure 3.10.7-1) in the final deformed shape. The maximum permanent diagonal displacement of the fuel tubes is computed to be 0.008 inch and 0.004 inch for the PWR and BWR fuel tubes, respectively.

Figure 3.10.7-1 Typical Finite Element Model for the Basket Fuel Tube Displacement



3.10.8 Basket Pin-Slot Connection Evaluation for Concrete Cask Tip-Over Accident Condition

As part of the stability evaluation for the BWR and PWR fuel baskets for the hypothetical concrete cask tip-over accident, this section describes the structural evaluation for the basket pin-slot connections subjected to maximum shearing conditions using the finite element models presented in Section 3.10.6. [redacted]

The three-dimensional half-symmetry finite element models for the 0° basket orientation, as shown in Figure 3.10.8-1 (BWR) and Figure 3.10.8-3 (PWR), are used for the evaluation. These models are associated with the maximum shear forces at the pin-slot connections, based on the quasistatic analyses for BWR and PWR baskets for the tip-over accident as documented in Section 3.7.2. The BWR model is constructed using the same modeling methodology as used for the model presented in Section 3.10.6. To more accurately solve for the stress/strain at the pin-slot connections, the pin-slot connection associated with the largest shear load is modeled with a finer mesh, as shown in Figure 3.10.8-2 (BWR) and Figure 3.10.8-4 (PWR). The LS-DYNA program is used to perform transient (time history) analyses to simulate the side impact condition of the cask tip-over accident. The unfiltered acceleration time history at the top of the basket (Figure 3.7.3-3) is conservatively used in the BWR evaluation. The maximum filtered acceleration is 26.4g and the unfiltered acceleration at the same time is 32.3g, which results in a load factor of 1.22 (32.3/26.4). The unfiltered acceleration with a factor of 1.1 is used for the PWR analysis for additional conservatism (the resulting load factor for PWR is 1.1 × 1.22, or 1.34). The calculated maximum plastic strains at this pin-slot connection are shown in the following table. See Figure 3.10.8-5 and Figure 3.10.8-6 for locations of the maximum strains in

the pin and the tube slots, as well as the time history of the maximum plastic strain, for the BWR and the PWR basket, respectively.

	Maximum Plastic Strain	
Basket Type	Tube Slot	Pin
BWR	15.4%	8.4%
PWR	16.5%	15.4%

As shown in the table, the calculated maximum plastic strains at the pin-slot connection for all of the analyzed cases are well below the material ultimate true strain of the SA 537 carbon steel (21%). Also note that the analysis results show that the plastic strain in the tube slot or pin occurs in localized regions and the majority of the material remains elastic. The pins remain completely enclosed in the tube slots and allow transfer of shear and bearing loads between adjacent fuel tubes during the cask tip-over accident. Therefore, the pin-slot connections of the BWR and PWR fuel baskets are structurally adequate for the concrete cask tip-over accident condition.

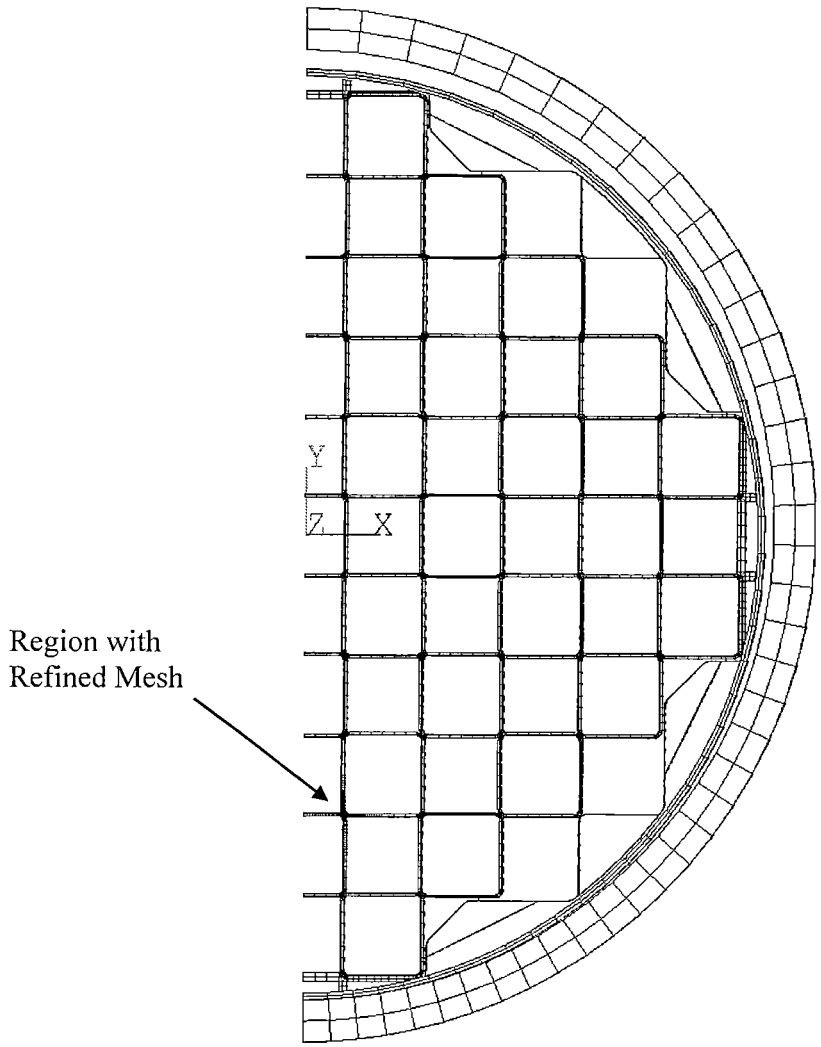
In addition, sensitivity studies are performed for the BWR basket to evaluate the effect of increased acceleration on the response of the basket in terms of stability. Three cases are considered as shown in the following table. The factor is applied to the unfiltered acceleration time history used for the base case of the BWR evaluation.

Case No.	Factor for the Acceleration Applied to the Model
1	2.0
2	3.0
3	4.0

The failure mode is defined as the pin moved out of the fuel tube slot. For Case 1 and Case 2, the analysis results indicate that all pins remain enclosed in the tube slots. At the end of the solution, the pin moved into the inner surface of the fuel tube slot for approximately 0.03 inch and 0.05 inch for Case 1 and Case 2, respectively. This displacement is insignificant compared to the size of the pin and tube slot and does not result in shear failure of the material or the disengagement of the pin and fuel tube slot. However, for Case 3, when the G-load is increased by 4 times, the pin penetrates though the tube wall at the region with minimal thickness. It is observed that bulking in the fuel tube wall is initiated with Case 3 loads. Therefore, it can be concluded that the factor of safety is greater than 3 (factor used for Case 2) for the BWR basket in terms of shear failure in the pin-slot connections. A similar factor of safety is expected for the PWR basket because the shear forces at the pin-slot connections are similar for the BWR and PWR baskets based on the quasi-static analyses presented in Section 3.7.2.

Figure 3.10.8-1 BWR Basket Finite Element Model – Location of Pin-Slot Connection with Refined Mesh

See Figure 3.10.8-2 for details for region with refined mesh.



(Fuel elements not shown for Clarity)

Figure 3.10.8-2 BWR Basket Finite Element Model – Pin-Slot Connection with Refined Mesh

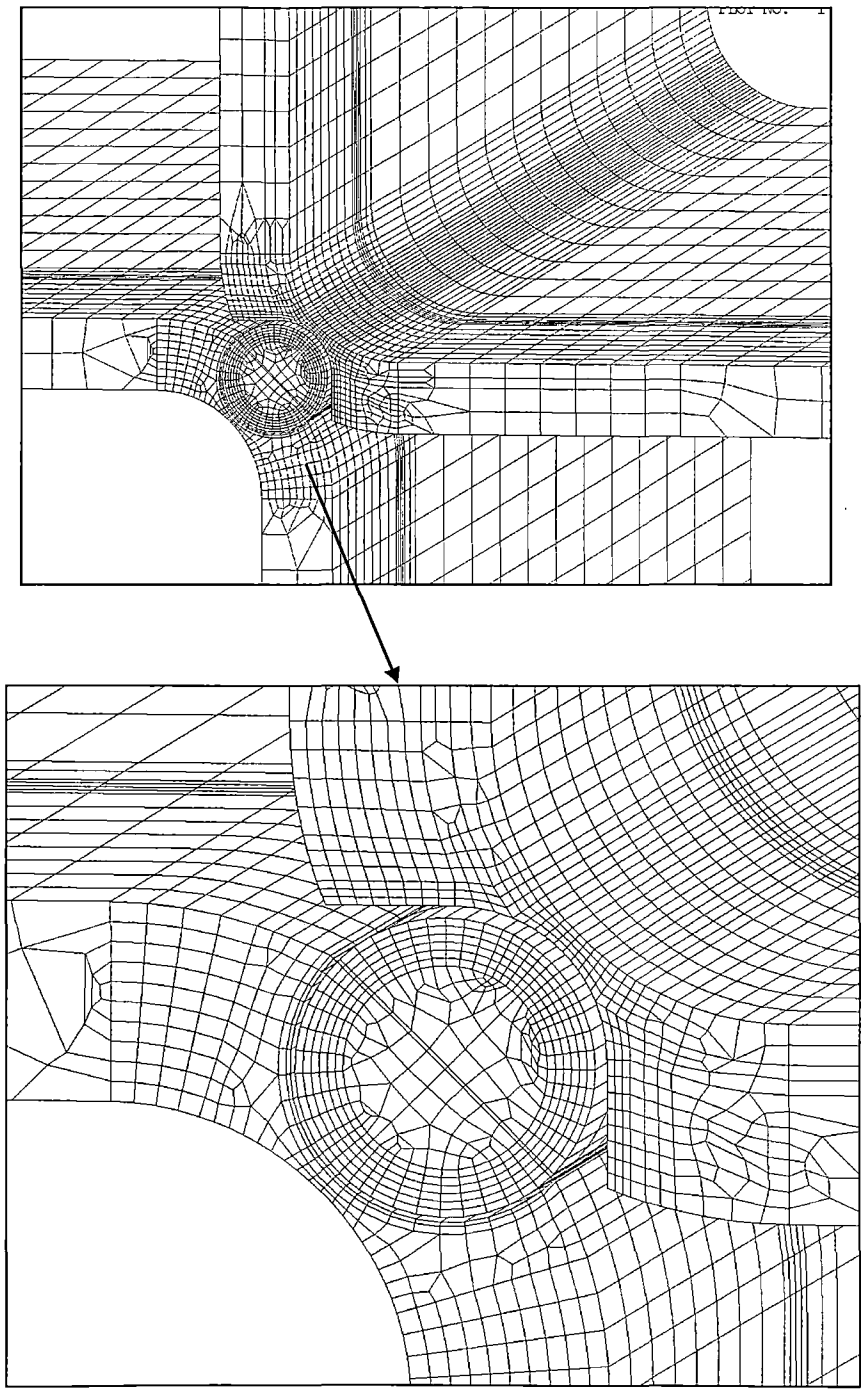
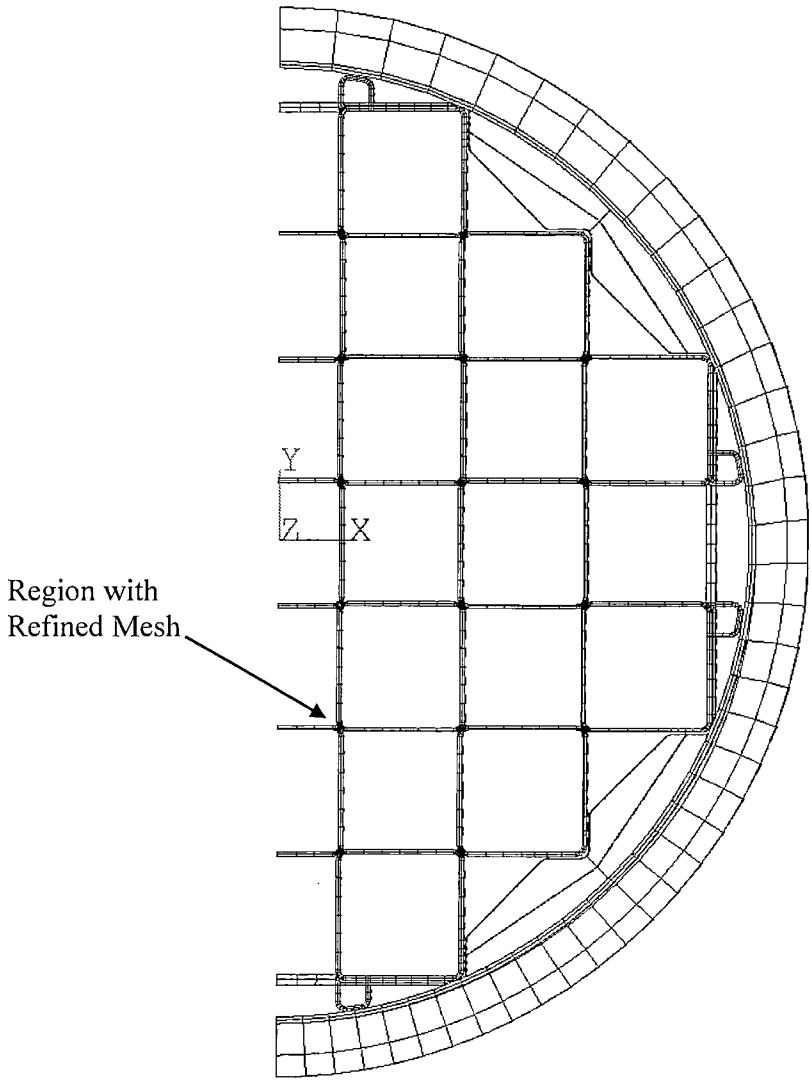


Figure 3.10.8-3 PWR Basket Finite Element Model – Location of Pin-Slot Connection with Refined Mesh

See Figure 3.10.8-4 for details for region with refined mesh.



(Fuel elements not shown for Clarity)

Figure 3.10.8-4 PWR Basket Finite Element Model – Pin-Slot Connection with Refined Mesh

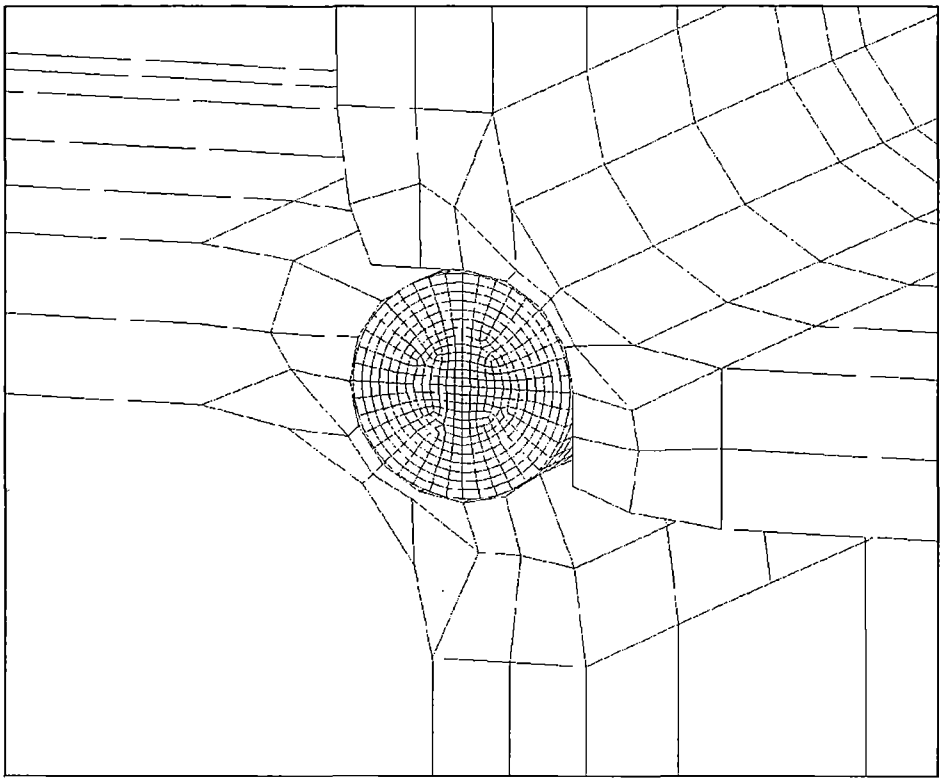
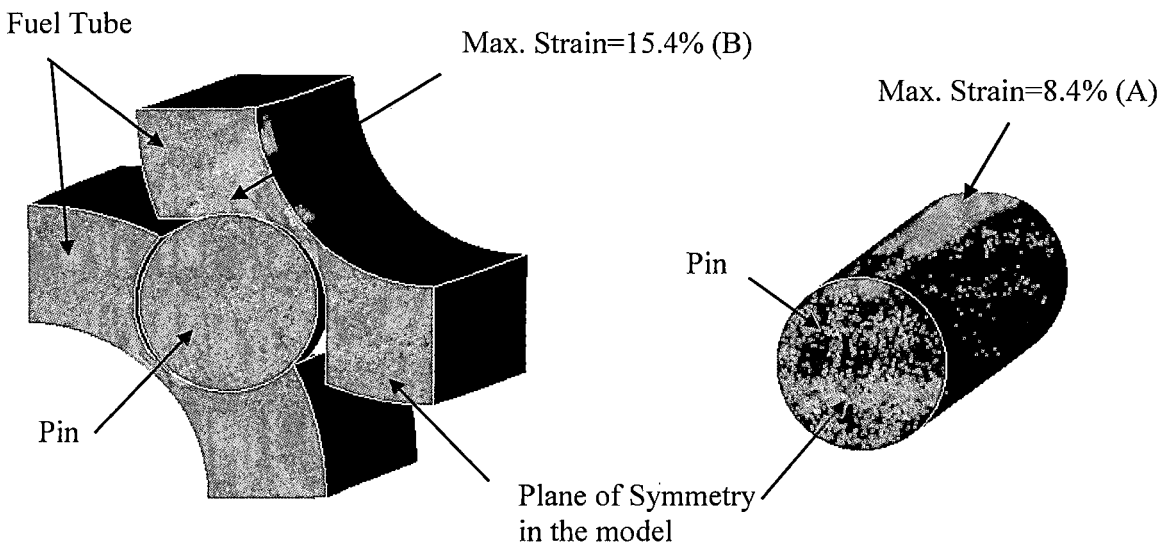
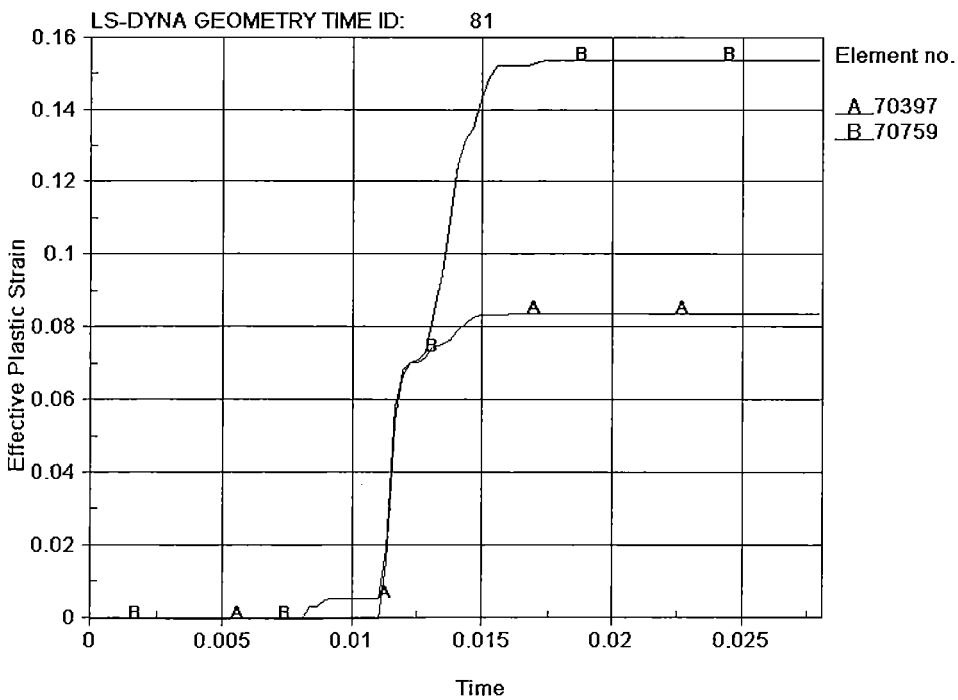


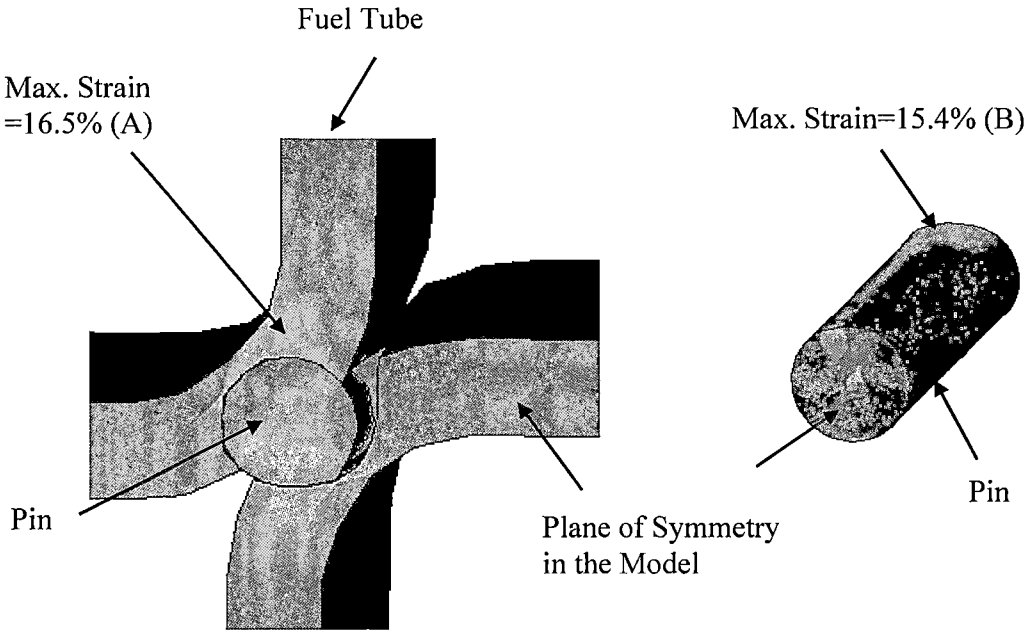
Figure 3.10.8-5 BWR Basket Pin-Slot Connection Plastic Strain – Cask Tip-over Condition

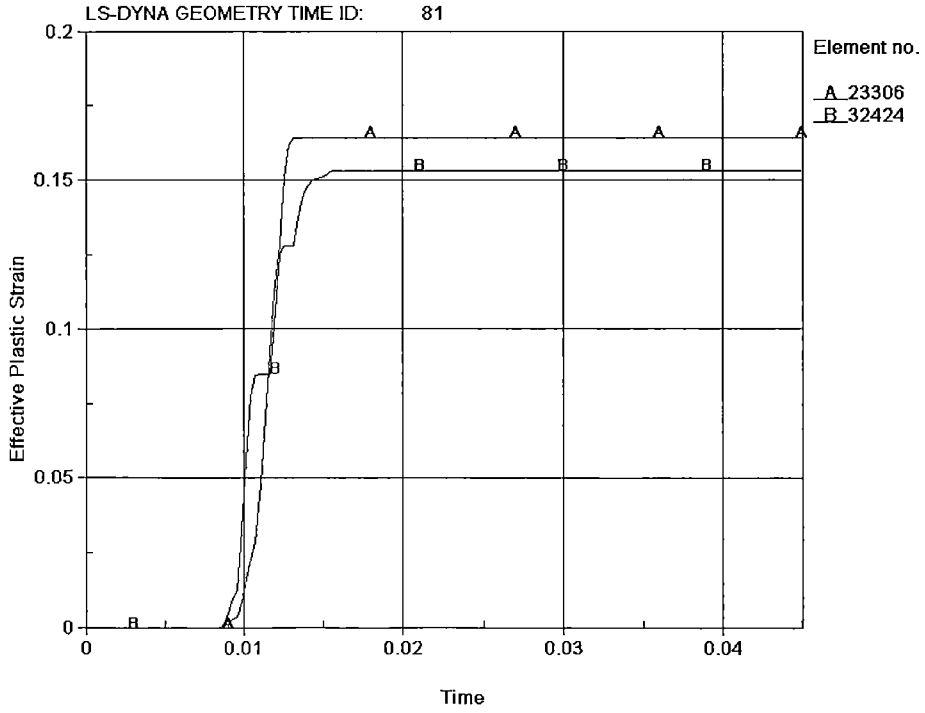




Time History of Plastic Strain at Points A and B

Figure 3.10.8-6 PWR Basket Pin-Slot Connection Plastic Strain





Time History of Plastic Strain at Points A and B
Strain=15.4% (B)

3.10.9 TSC-Basket Finite Element Models

This section describes the TSC-Basket finite element models used to calculate the TSC shell displacements used as the boundary conditions in the LS-DYNA basket stability evaluation (Section 3.10.6). The finite element model includes the details of the basket and canister to account for the interaction between the basket and the canister shell, as well as the effect of the different basket orientations during the side impact of the cask tip-over condition.

To be consistent with the basket stability evaluation presented in Section 3.10.6, the canister shell displacements due to the cask tip-over condition are determined in this Section for six basket orientations, 0°, 18°, 22.5°, 27°, 34° and 45°, for the PWR configuration and three basket orientations, 0°, 22.5° and 45°, for the BWR configuration. Four finite element models are used to determine the canister shell displacements for basket orientations of 0°, 22.5°, 34° and 45° for PWR and three models are used for basket orientations of 0°, 22.5° and 45° for BWR. The shell displacements for the PWR 18° and 27° cases are determined by linear interpolation of the finite element analysis results (e.g., the shell displacements for 18° are determined based on the shell displacements of the 0° and 22.5° cases). Half-symmetry models are used for 0° and 45° cases and full 360° three-dimensional models are used for 22.5° and 34° models. Symmetry boundary conditions are applied at the plane of symmetry for the 0° and 45° models.

The PWR 45° model is shown in Figure 3.10.9-1 and Figure 3.10.9-2. The PWR 22.5° model (canister not shown for clarity) is presented in Figure 3.10.9-3. The BWR 45° and 22.5° models are shown in Figure 3.10.9-4 and Figure 3.10.9-5, respectively. The canister shell, canister lid and bottom plate, basket fuel tubes, and basket side and corner support weldments are modeled explicitly using ANSYS SOLID45 and/or SHELL63 elements. Note that the support weldments are modeled with four pieces axially with a gap of 0.25 inch between the adjacent pieces. This is slightly conservative since it reduces the stiffness of the support weldments in the model and results in slightly larger displacements of the basket and, consequently, slightly larger displacements of the canister shell. The interface between the canister shell and the standoffs at the concrete cask liner is simulated by the CONTAC52 elements, as shown in Figure 3.10.9-1 and Figure 3.10.9-4. A stiffness of 3.0×10^6 psi is used for the gap elements representing the stiffness of the standoffs (carbon steel S-beam). A sensitivity study has been performed to assess the effect of the gap stiffness on the canister shell displacements. The sensitivity analysis uses one-half of the gap stiffness for the standoff, and the results indicate an insignificant (0.2%) change of the maximum canister shell displacement. A buckling evaluation was performed, per NUREG/CR-6322 [9], for the standoff at the concrete cask steel liner for the impact load from the canister during the cask tip-over accident. The evaluation results show that the standoff will not buckle with a safety factor of 1.4.

The interface between the canister shell and the basket is modeled using CONTA175 and TARGE170 elements. The CONTA175 elements are 3-D node-to-surface contact elements and are modeled at the basket (support weldment) nodes adjacent to the inner surface of the canister shell. The TARGE170 elements are modeled at the canister shell inner surface, representing the target surface for the CONTA175 elements. CONTAC52 elements are used for the interface between basket components (e.g., surfaces between fuel tubes, between fuel tube and support weldments). The connector pin-tube slot connection at both ends of basket is modeled using COMBIN40 elements, with a gap of 0.03 inch (to allow a maximum relative movement of 0.03 inch in all transverse directions of the basket). The intermediate pin-tube slot connections are located every 20 inches axially. The pins are not modeled explicitly. COMBIN40 elements are also used to represent the pin-tube slot interface, where a relative movement of 0.016 inch is modeled, based on the fabrication tolerance on the gap between fuel tubes. The bolts connecting the support weldments and the fuel tubes are modeled with LINK10 elements. The associated bosses are modeled using COMBIN40 elements with a gap of 0.0625 inch.

Symmetry boundary conditions are applied at the plane of symmetry for the 0° and 45° models. The material properties for the canister and the basket components are identical to those used in the PWR and BWR basket models and the canister model presented in Section 3.10.1 through Section 3.10.3 for the evaluation of the concrete cask tip-over accident.

The model considers a tapered inertia load of 60g at the top of the canister and 1g at the base of the concrete cask. As shown in Figure 3.7.3-3, the peak g-load at top of the canister is 29.5g based on the cask tip-over analysis. Therefore, the applied inertia load to the model includes a load factor of 1.5 and a conservative DLF of 1.36 ($60 = 29.5 \times 1.5 \times 1.36$).

Maximum radial displacements of the canister shell occur at approximately 90 inches from the TSC bottom. The shell displacements at the cross-section with the maximum displacement are shown in Table 3.10.9-1 and Table 3.10.9-2 for PWR and BWR configurations, respectively. The canister shell displacements at 135 inches from the canister bottom are also presented (for sensitivity studies). Figure 3.10.9-6 and Figure 3.10.9-7 show the representative contour plots of the lateral (UZ) displacement of the canister shell for the PWR and BWR configurations, respectively. These displacement contours correspond to the cases with a 45° basket orientation, where the maximum lateral displacement occurs. The canister shell displacements shown in Table 3.10.9-1 and Table 3.10.9-2 are used as the boundary condition for the basket stability evaluation in Section 3.10.6.

Figure 3.10.9-1 PWR Canister-Basket Finite Element Model for Concrete Cask Tip-Over Accident – 45° Basket Orientation

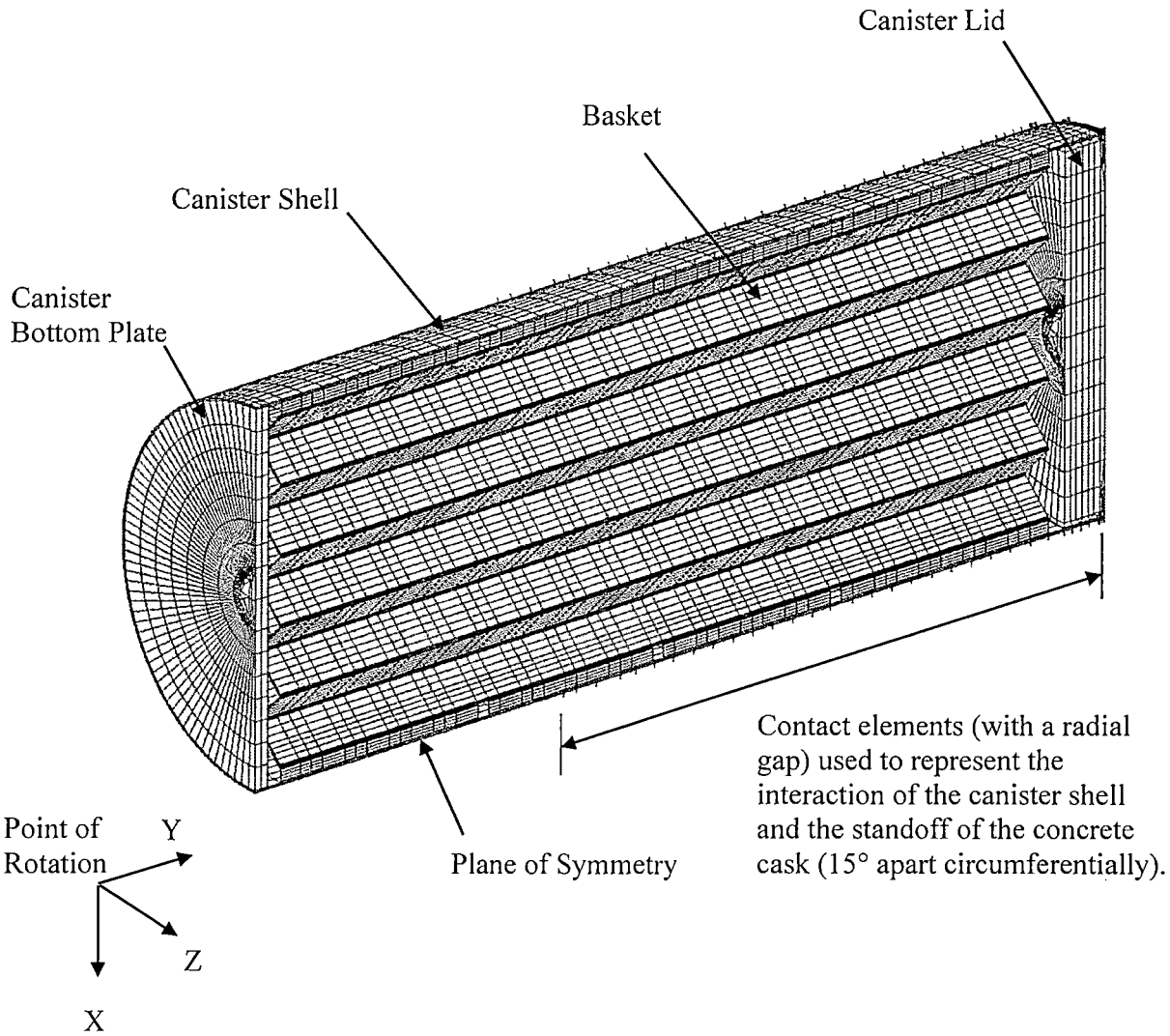
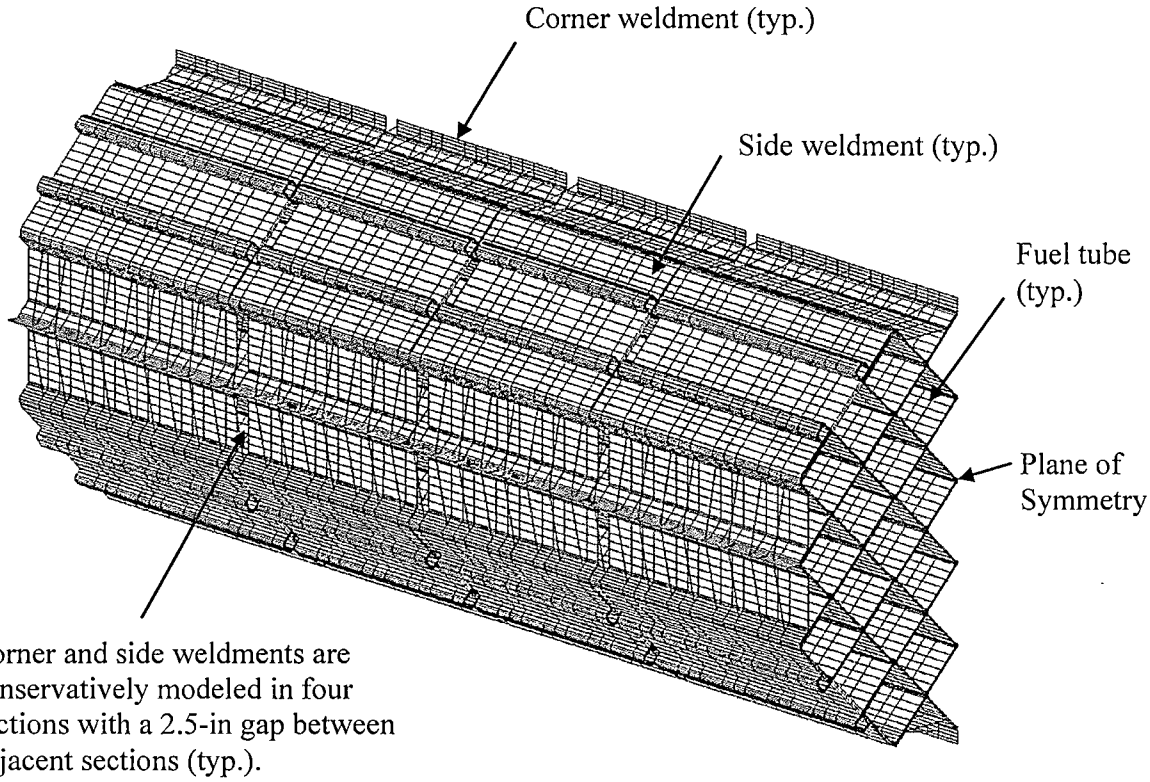
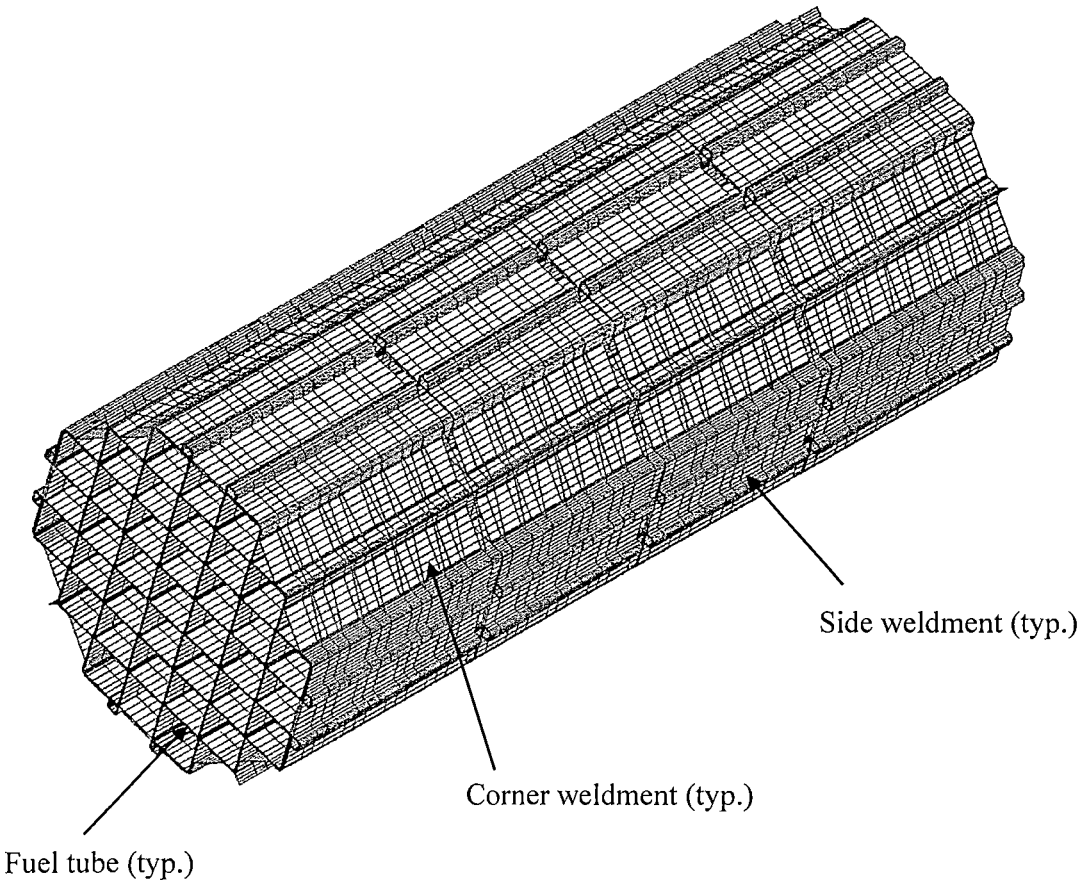


Figure 3.10.9-2 PWR Canister-Basket Finite Element Model for Concrete Cask Tip-Over Accident – Basket Elements - 45° Basket Orientation



(Canister elements not shown for clarity)

Figure 3.10.9-3 PWR Canister-Basket Finite Element Model for Concrete Cask Tip-Over Accident – Basket Elements – 22.5° Basket Orientation



(Canister elements not shown for clarity)

Figure 3.10.9-4 BWR Canister-Basket Finite Element Model for Concrete Cask Tip-Over Accident – 45° Basket Orientation

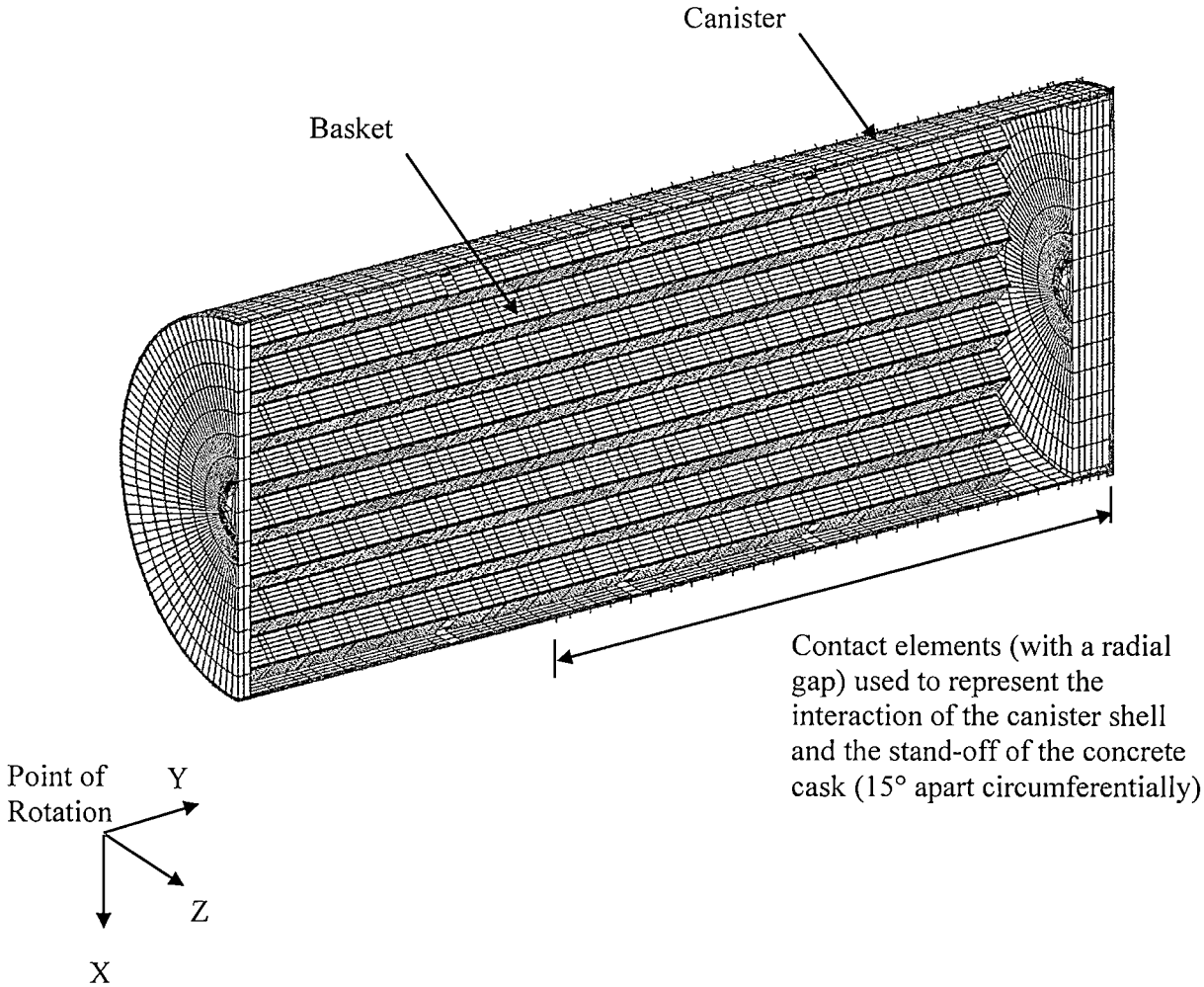
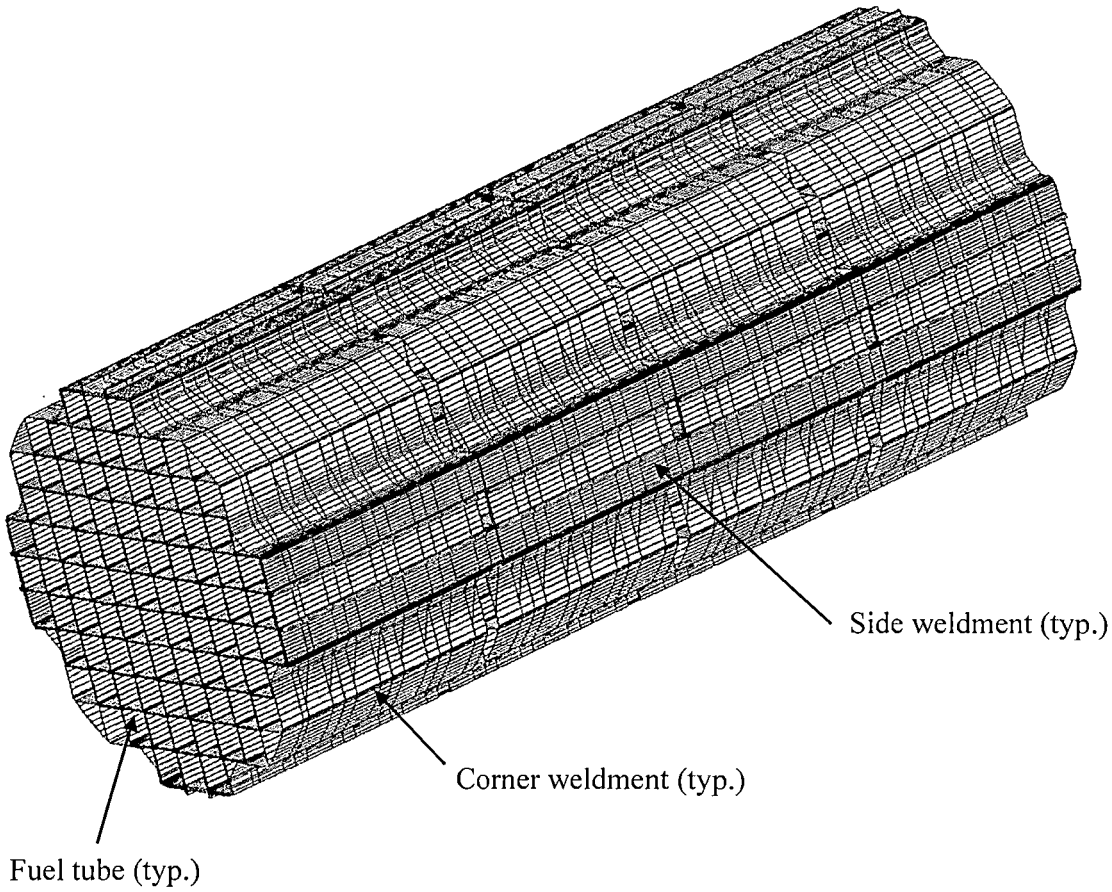


Figure 3.10.9-5 BWR Canister-Basket Finite Element Model for Concrete Cask Tip-Over Accident – Basket Elements – 22.5° Basket Orientation



(Canister elements not shown for clarity)

Figure 3.10.9-6 PWR Canister Shell Lateral Displacement Contour – 45° Basket Orientation

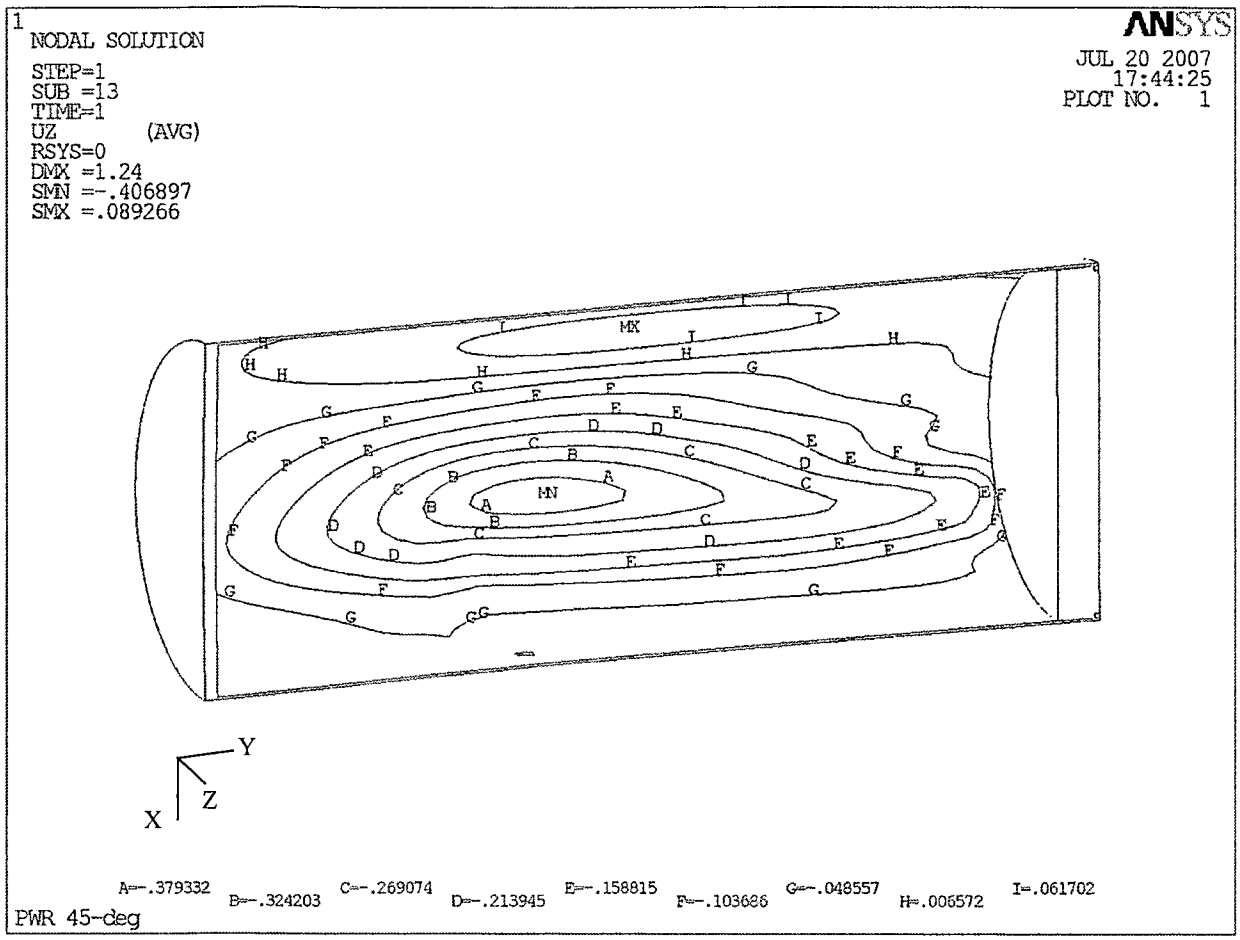


Figure 3.10.9-7 BWR Canister Shell Lateral Displacement Contour – 45° Basket Orientation

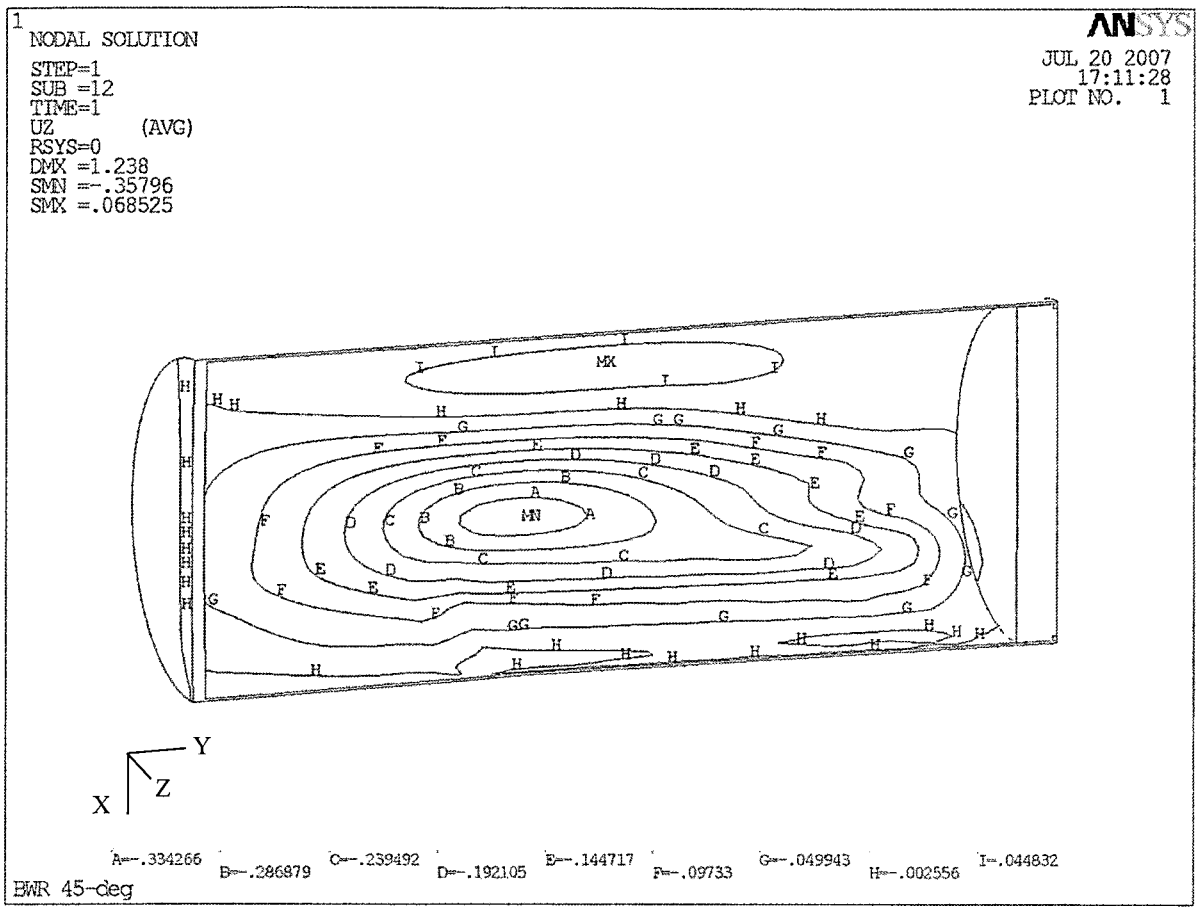


Table 3.10.9-1 Canister Shell Displacements Used as Boundary Conditions for the LS-DYNA Models for PWR Basket Stability Evaluation

Basket Orientation / Angle	Canister Shell Radial Displacement (inch)						
	0°	18°	22.5°	27°	34°	45°	22.5° (135 in)
0°	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15°	0.029	0.011	0.007	0.019	0.038	0.024	0.003
30°	0.096	0.035	0.020	0.062	0.127	0.100	0.020
45°	0.206	0.186	0.180	0.196	0.219	0.211	0.194
60°	0.368	0.318	0.300	0.328	0.371	0.362	0.258
75°	0.292	0.372	0.394	0.423	0.480	0.507	0.275
90°	0.091	0.239	0.274	0.269	0.258	0.286	0.217
105°	-0.105	-0.019	0.000	-0.009	-0.027	0.021	-0.016
120°	-0.216	-0.217	-0.218	-0.209	-0.198	-0.236	-0.186
135°	-0.242	-0.283	-0.295	-0.311	-0.339	-0.414	-0.232
180°	-0.174	-0.144	-0.137	-0.186	-0.262	-0.280	-0.156
225°	-0.242	-0.233	-0.230	-0.255	-0.293	-0.414	-0.128
240°	-0.216	-0.205	-0.200	-0.219	-0.247	-0.236	-0.130
255°	-0.105	-0.087	-0.080	-0.073	-0.058	0.021	-0.073
270°	0.091	0.114	0.121	0.148	0.193	0.286	0.034
285°	0.292	0.293	0.295	0.318	0.356	0.507	0.140
300°	0.368	0.304	0.284	0.322	0.381	0.362	0.211
315°	0.206	0.245	0.255	0.232	0.197	0.211	0.249
330°	0.096	0.099	0.100	0.084	0.058	0.100	0.084
345°	0.029	0.010	0.006	0.005	0.004	0.024	0.013

Note: Radial displacements are reported at the canister shell section where the maximum displacement occurs, except the last column, which corresponds to shell displacements at 135 inches from the canister bottom for a sensitivity study.

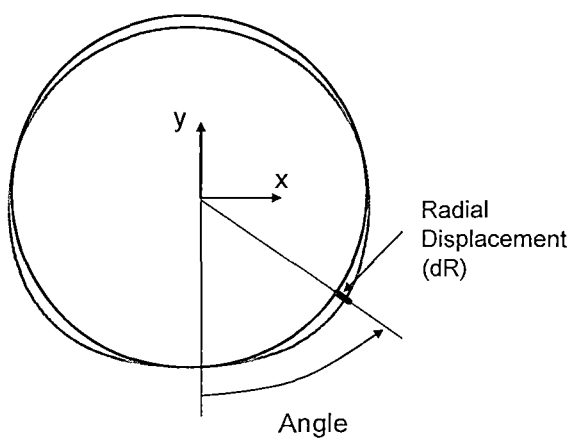
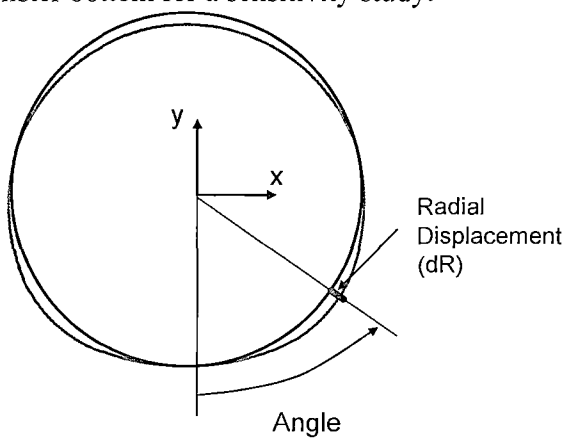


Table 3.10.9-2 Canister Shell Displacements Used as Boundary Conditions for the LS-DYNA Models for BWR Basket Stability Evaluation

Canister Shell Radial Displacement (inch)

Basket Orientation / Angle	0°	22.5°	45°	22.5° (135-in)
0°	0.000	0.000	0.000	0.000
15°	0.025	0.066	0.024	0.078
30°	0.093	0.095	0.098	0.087
45°	0.202	0.205	0.213	0.171
60°	0.342	0.366	0.361	0.349
75°	0.372	0.444	0.440	0.352
90°	0.126	0.279	0.261	0.174
105°	-0.084	0.052	-0.029	-0.032
120°	-0.217	-0.298	-0.245	-0.251
135°	-0.260	-0.372	-0.356	-0.256
180°	-0.195	-0.224	-0.276	-0.154
225°	-0.260	-0.320	-0.356	-0.201
240°	-0.217	-0.285	-0.245	-0.190
255°	-0.084	-0.130	-0.029	-0.118
270°	0.126	0.142	0.261	0.027
285°	0.372	0.396	0.440	0.228
300°	0.342	0.418	0.361	0.357
315°	0.202	0.217	0.213	0.215
330°	0.093	0.152	0.098	0.159
345°	0.029	0.076	0.024	0.084

Note: Radial displacements are reported at the canister shell section where the maximum displacement occurs, except the last column, which corresponds to shell displacements at 135-in from canister bottom for a sensitivity study.



3.10.10 Structural Evaluation of the Damaged Fuel Can

The MAGNASTOR Damaged Fuel Can (DFC) and spacer are analyzed in accordance with ASME Code, Section III, Subsection NG for normal and accident conditions of storage. Conservative bounding temperatures of 700°F and 550°F are used for the DFC and spacer, respectively, for both normal and accident conditions. Thermal stresses are considered negligible, as the can and spacer are free to expand.

3.10.10.1 Structural Evaluation of the Damaged Fuel Can

The following evaluation demonstrates that the MAGNASTOR DFC is structurally adequate for normal and accident conditions of storage.

Normal Conditions of Storage

In normal conditions of storage, the MAGNASTOR DFC is loaded by its own weight in the vertical orientation. The compressive load (P) on the tube is considered to be the entire weight of the DFC, which includes the weight of the lid, side plates, tube body and bottom assembly. The analysis uses a conservative weight of 150 pounds for the DFC and a 1.1g acceleration load, which corresponds to the dead weight with a 10% dynamic load factor.

The compressive load (P) is:

$$P = 150 \text{ lbs} \times 1.1 \text{ g} = 165 \text{ lbs}$$

The compressive stress (σ_c) in the tube body is:

$$\sigma_c = \frac{P}{A} = \frac{165}{1.68} = 98 \text{ psi}$$

where:

$A = 1.68 \text{ inch}^2$ ---------- Cross-sectional area of the tube

The factor of safety (FS) is determined based on the normal condition allowable primary membrane stress (S_m) for SA-240, Type 304 stainless steel at a bounding temperature of 700°F:

$$FS = \frac{S_m}{\sigma_c} = \frac{15{,}800}{98} = \text{Large}$$

The buckling analysis of the DFC for normal conditions is bounded by the 24-inch end drop accident condition evaluation.

Twenty-Four-Inch Drop of the Concrete Cask

The 24-inch end drop of the concrete cask onto an unyielding surface (Section 3.7.1.2) results in accelerations that are bounded by the 60g acceleration used in this structural evaluation for the MAGNASTOR DFC. The DFC is conservatively assumed to be 150 pounds, which is considered as the compressive load (P) on the tube for the end drop evaluation. The length of the longer DFC (171.8 inches) is used for the buckling analysis.

The compressive load (P) is:

$$P = 150 \times 60 = 9{,}000 \text{ lbs}$$

The compressive stress (σ_c) in the tube body is:

$$\sigma_c = \frac{P}{A} = \frac{9{,}000}{1.68} = 5{,}357 \text{ psi}$$

The factor of safety (FS) is determined based on the accident condition allowable primary membrane stress (2.4 S_m) at a bounding temperature of 700°F:

$$FS = \frac{2.4S_m}{\sigma_c} = \frac{2.4(15{,}800)}{5{,}357} = 7.1$$

The potential buckling of the tube is evaluated, using the Euler formula, to determine the critical buckling load (P_{cr}):

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2(24.8\times10^6)(21.42)}{(2\times171.8)^2} = 44{,}400 \text{ lbs}$$

where:

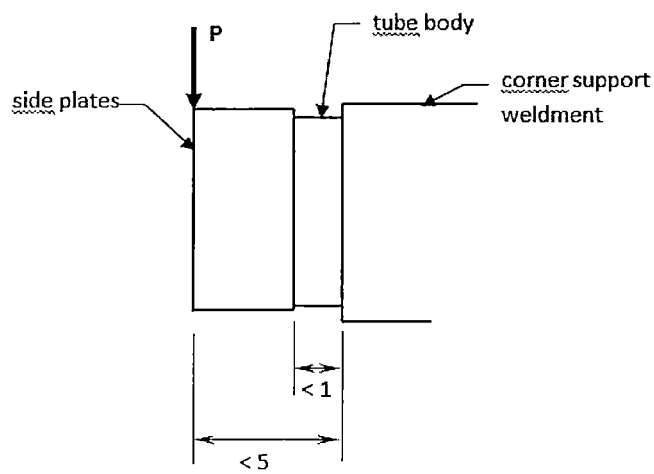
E	$= 24.8\times10^6$ psi	Elastic modulus for SA-240, Type 304 stainless steel at 700°F
I	$= 21.42$ inch^4	Moment of inertia for the DFC spacer
K	$= 2$	Conservative effective length factor
L	$= 171.8$ inches	Tube body length, conservatively assumed the full length of the DFC

Because the maximum compressive load (9,000 lbs under the accident condition) is much less than the critical buckling load (44,400 lbs), the tube has adequate resistance to buckling.

Tip-Over of the Concrete Cask

The majority of the fuel can tube body is contained within the DF corner support weldment of the basket assembly. Because both the tube body of the fuel can and the weldment have square cross-sections, they are effectively in full contact (for 167.8 inches longitudinally, for the longer DFC) during a side impact, and no significant bending stress is introduced into the tube body. For the longer DFC, the last 0.2 inch of the tube body and the 3.8-inch length of the side plates are unsupported past the end of the fuel tube in the side impact orientation.

The tube body is evaluated as a cantilevered beam with the combined weight (P) of the overhanging tube body and side plates and, conservatively, concentrated at the top end of the side plates multiplied by a deceleration factor of 60g. Note that the maximum g-load for the PWR basket is less than the specified design value of 40g for the tip-over accident (Section 3.7.1.3).



The maximum bending moment (M) is:

$$M = PgL = 35(60)(5) = 10{,}500 \text{ lbs-inch}$$

where:

P = 35 lbs ---------- Bounding weight of the overhanging tube and side plates

g = 60 ---------- Conservative g-load that bounds the tip-over condition

L = 5 inches ---------- Bounding total of overhanging length of the tube body and side plates

The maximum bending stress, f_b, is:

$$f_b = \frac{Mc}{I} = \frac{10{,}500(4.4)}{21.42} = 2{,}157 \text{ psi}$$

where:

c = 4.4 inches ---------- Half of the outer dimension of the tube

I = 21.42 inch^4 ---------- Moment of inertia of the tube

The shear stress (τ) is:

$$\tau = \frac{Pg}{A} = \frac{35(60)}{1.68} = 1{,}250 \text{ psi}$$

where:

A = 1.68 inch^2---------- Cross-sectional area of the tube

The corresponding stress intensity is:

$$\sigma_{max} = \sqrt{f_b^2 + 4\tau^2} = 3{,}302 \text{ psi}$$

The factor of safety (FS) is calculated based on the allowable primary membrane plus bending stress (3.6 S_m) at a bounding temperature of 700°F:

$$FS = \frac{3.6S_m}{\sigma_{max}} = \frac{3.6(15{,}800)}{3{,}302} = \text{Large}$$

The DFC is also analyzed for damaged fuel with a bounding 100% rod failure condition. For this evaluation, a bounding fuel load of 2,100 lbs is used (actual fuel weight is less than 1,600 lbs).

The maximum bending stress, f_b, is:

$$f_b = \frac{M_{max}c}{I} = \frac{14{,}960(4.4)}{21.42} = 3{,}073 \text{ psi}$$

where:

$$M_{max} = \left(PL + \frac{w(L-a)^2}{2}\right)g = 14{,}960 \text{ lbs}$$

P = 35 lbs ---------- Bounding weight of the overhanging tube and side plates

g = 60 ---------- Conservative g-load for the tip-over condition

$L = 5$ inches ---------- Bounding total of overhanging length of the tube body and side plates

$a = 2.3$ inches ---------- Lid assembly thickness

$w = \frac{2{,}100 \text{ lbs}}{l_c} = 20.4$ lbs/inch ---------- Fuel assembly distributed load

$l_c = 103$ inches ---------- Length occupied by 100% failed consolidated fuel (bounding for 50% compaction ratio)

$c = 4.4$ inches ---------- Half of the outer dimension of the tube

$I = 21.42$ inch^4 ---------- Moment of inertia of the tube

The shear stress (τ) is:

$$\tau = \frac{(P + w(L-a))}{A} g = \frac{(35 + 20.4(5-2.3))}{1.68} 60 = 3{,}217 \text{ psi}$$

where:

$A = 1.680$ inch^2 ---------- Cross-sectional area of the tube

The corresponding stress intensity is:

$$\sigma_{max} = \sqrt{f_b^2 + 4\tau^2} = 7{,}130 \text{ psi}$$

The factor of safety (FS) is calculated based on the allowable primary membrane plus bending stress (3.6 S_m) at a bounding temperature of 700°F:

$$FS = \frac{3.6 S_m}{\sigma_{max}} = \frac{3.6(15{,}800 \text{ psi})}{7{,}130 \text{ psi}} = 8.0$$

Therefore, the MAGNASTOR DFC maintains its integrity for the accident conditions.

3.10.10.2 Structural Evaluation of the Damaged Fuel Can Spacer

The following evaluation demonstrates that the MAGNASTOR DFC spacer remains structurally adequate for normal and accident conditions of storage.

Normal Conditions of Storage

In normal conditions of storage, the DFC spacer is loaded by its own weight and the loaded DFC. Using a fuel assembly weight of 1,600 lbs, a DFC spacer weight of 15 lbs and a 1.1g acceleration load, which corresponds to the dead weight with a 10% dynamic load factor, compressive load (P) is:

$P = (150 + 1{,}600 + 15)$ lbs × 1.1 g = 1,765 lbs x 1.1 g = 1,942 lbs

The compressive stress (σ_c) in the spacer is:

$$\sigma_c = \frac{P}{A} = \frac{1{,}942}{9.08} = 214 \text{ psi}$$

where:

A = 9.08 inch^2---------- Cross-sectional area of the DFC spacer

The factor of safety (FS) is determined based on the normal condition allowable primary membrane stress (S_m) for SA-240, Type 304 stainless steel at a bounding temperature of 550°F:

$$FS = \frac{S_m}{\sigma_c} = \frac{17{,}100}{214} = \text{Large}$$

The bearing stress on the DFC, DFC spacer and TSC bottom plate (σbrg) is:

$$\sigma_{brg} = \frac{P}{A_{brg}} = \frac{1{,}942}{5.0} = 388 \text{ psi}$$

where:

A_{brg} = 5.0 inch^2 ---------- Bearing area for the DFC spacer

The factor of safety (FS) for bearing is:

$$FS = \frac{S_y}{\sigma_{brg}} = \frac{18{,}900}{388} = \text{Large}$$

where:

S_y = 18,900 psi ---------- Yield strength, SA-240, Type 304 St. Stl., at 550°F

The DFC spacer is evaluated for buckling in accordance with NUREG/CR-6322 [9]. The buckling factor of safety for the DFC spacer is calculated based on the criteria for Service Level 'A' limits for Linear-Type Supports. The maximum allowable compressive stress is:

$$F_a = S_y\left(0.47 - \frac{Kl/r}{444}\right) = 18.9\left(0.47 - \frac{4.32}{444}\right) = 8.7 \text{ ksi}$$

where:

$Kl/r = 4.32$

$K = 2$ ---------- Conservative effective-length factor

$r = \left(\frac{I}{A}\right)^{\frac{1}{2}} = 2.53$ inch ---------- Radius of gyration

$l = 5.46$ inch ---------- Length of DFC spacer

$S_y = 18.9$ ksi ---------- Yield strength, SA-240, Type 304 St. Stl., at 550°F

$I = 58.2$ inch^4 ---------- Moment of inertia of the DFC spacer

$A = 9.08$ inch^2 ---------- Cross-sectional area of the DFC spacer

The factor of safety (FS) for buckling is:

$$FS = \frac{F_a}{\sigma_c} = \frac{8.7}{0.1944} = \text{Large}$$

Twenty-Four Inch End Drop of the Concrete Cask

The DFC spacer is evaluated for the 24-inch end drop accident condition using a conservative acceleration of 60g. The compressive stress for the DFC spacer is:

$$\sigma_c = \frac{60 \times P_b}{A} = \frac{60 \times 1.765}{9.08} = 11.7 \text{ ksi}$$

where:

$P_b = 1{,}765$ lb ---------- Weight of the fuel assembly, DFC and DFC spacer

The factor of safety (FS) for primary membrane stress is determined based on the accident condition allowable primary membrane stress (2.4 S_m) for SA-240, Type 304 stainless steel at a bounding temperature of 550°F:

$$FS = \frac{2.4S_m}{\sigma_c} = \frac{2.4(17.1)}{11.7} = 3.5$$

The DFC spacer is evaluated for buckling in accordance with NUREG/CR-6322 [9]. The buckling factor of safety for the DFC spacer is calculated based on the criteria for Service Level 'D' limits for Linear-Type Supports. Using the following parameters, the maximum allowable compressive stress (F_a) for the DFC spacer is calculated to be 12.9 ksi.

$K = 2$ ---------- Conservative, effective-length factor

$r = \left(\frac{I}{A}\right)^{\frac{1}{2}} = 2.53$ inches ---------- Radius of gyration

$I = 58.2$ inches^4 ---------- Moment of inertia for the DFC spacer

$A = 9.08$ inches^2 ---------- Cross-sectional area of the DFC spacer

$l = 5.46$ inches ---------- Length the DFC spacer

$E = 25.6 \times 10^6$ psi ---------- Elastic modulus, SA-240, Type 304 St. Stl., at 550°F

$S_y = 18.9$ ksi ---------- Yield strength, SA-240, Type 304 St. Stl., at 550°F

The factor of safety (FS) for buckling is:

$$FS = \frac{F_a}{\sigma_b} = \frac{12.9}{11.7} = 1.10$$

Therefore, the MAGNASTOR DFC spacer maintains its integrity for the accident condition.

Chapter 4
Thermal Evaluation

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4 THERMAL EVALUATION

This section presents the thermal design and analyses of MAGNASTOR® for normal conditions and off-normal and accident events of storage. Results of the analyses demonstrate that with the design basis contents, MAGNASTOR meets the thermal performance requirements of 10 CFR 72 [1], NUREG-1567 [20], and NUREG-1536 [22].

4.1 Discussion

MAGNASTOR consists of a TSC, concrete cask, and a transfer cask. In long-term storage, the fuel, including fuel contained in damaged fuel cans and PWR minimum reduced cool time fuel, is loaded in a basket structure positioned within the TSC. The TSC is placed in the concrete cask, which provides passive radiation shielding, structural protection and natural convection cooling. The transfer cask is used to handle the TSC. The thermal performance of the concrete cask containing a loaded TSC with design basis fuel, and the performance of the transfer cask containing a loaded TSC with design basis fuel are evaluated in this chapter.

The thermal evaluation considers normal conditions and off-normal and accident events of storage. Each of these conditions can be described in terms of the environmental temperature, use of solar insolation, and the condition of the air inlets as shown in Table 4.1-1. The evaluation of the different phases of the transfer operation is accomplished by altering the properties of the medium in the canister to correspond to water or helium.

In order for the heat from the stored spent fuel assemblies, including fuel contained in damaged fuel cans and PWR minimum reduced cool time fuel, to be rejected to the ambient environment via the concrete cask or the transfer cask, the decay heat from the contents is transferred to the TSC surface. The MAGNASTOR baskets for the PWR and the BWR fuel assemblies use all three heat transfer modes—radiation, conduction and convection—to transfer the heat to the TSC surface. The basket design enhances convection heat transfer. Helium is used as the backfill gas in the TSC because its thermal conductivity is better than other allowable backfill gases. The basket is comprised of full-length carbon steel tubes that provide a significant path for conduction heat transfer. Radiation is a significant mode of heat transfer in the fuel region and between the outer surface of the basket and the TSC shell.

The significant thermal design feature of the concrete cask is the passive convective airflow around the outside of the TSC. Cool (ambient) air enters at the bottom of the concrete cask through four air inlets. Heated air exits through the four air outlets in the upper concrete cask body. Radiant heat transfer occurs from the TSC shell to the concrete cask liner, which then transmits heat to the annular airflow. Conduction through the concrete cask, although not significant, is included in the analytical model. Natural circulation of air through the concrete cask annulus, in conjunction with radiation from the TSC surface, maintains the fuel cladding temperature and all component temperatures below their design limits.

The MAGNASTOR design basis heat load is 35.5 kW for PWR fuel. The fuel loading may be in the 37 PWR Basket Assembly, i.e., up to 37 undamaged PWR fuel assemblies, or up to 37 PWR

minimum reduced cool time fuel, or in the DF Basket Assembly, which has a capacity of up to 37 undamaged fuel assemblies including four DFC locations. Damaged fuel cans may be located in the DFC locations at the four outer corners of the DF basket assembly (Figure 2.2-3 and License Drawing 71160-675). Both the PWR fuel basket and the DF basket assembly can accommodate a uniform heat load of 959 W per assembly, or a preferential loading pattern as shown in Figure 4.1-1. The preferential loading pattern identified in Figure 4.1-1 defines three values of heat generation that place the fuel assemblies with the maximum heat generation rate in an intermediate region of fuel storage locations. The PWR fuel basket can also accommodate a various heat load per assembly for the PWR minimum reduced cool time fuel with a preferential loading pattern, as shown in Figure 4.1-2. Analyses are performed using the two-dimensional axisymmetric model with the same fluid resistances and material properties for both the preferential and uniform loading patterns of the standard PWR fuels, as well as for the preferential load pattern for the PWR minimum reduced cool time fuel. The calculated maximum fuel temperature is essentially the same for both loading configurations for standard PWR fuels. The maximum temperatures at the radial location of the center of a preferential loaded fuel assembly with the 1.2 kW heat load is determined to be 689°F. At this same radial location, the calculated temperature for the uniform heat load is 684°F. This small increase is a localized bounding temperature response due to the localized increased heat generation for the preferential loading configuration. As shown in Sections 4.4.1.6 and 4.4.3 and as concluded in Sections 4.5 and 4.6, the maximum fuel temperature for the DF basket assembly configuration is bounded by that for the standard PWR basket configuration. The analysis for the PWR minimum reduced cool time fuel with the preferential loading pattern (Figure 4.1-2) is also performed using the modified two-dimensional axisymmetric model. As shown in Sections 4.4.1 and 4.4.3 and as concluded in Sections 4.5 and 4.6, the maximum fuel temperature for the PWR minimum reduced cool time fuel configuration is bounded by that for the standard PWR basket configuration.

The identical maximum fuel cladding temperature calculated for both the PWR fuel basket and the DF basket assembly loading configurations, resulting from identical total heat and small differences in inner region heat (4%), demonstrates efficiencies in the alternate PWR preferential loading configuration. Placement of the highest heat load for the preferential loading configuration in an intermediate radial location balances system performance. The thermal loading basis for the PWR analyses in this chapter uses the preferential loading since it represents the system loading with maximum heat concentration. The maximum fuel temperature reduction for the PWR minimum reduced cool time fuel also states that placement of the highest heat load in an intermediate radial location, plus the low heat in the basket center nine

(9) slots, enhances system performance. The BWR fuel basket can accommodate 87 fuel assemblies with a uniform design basis total heat load of 33 kW, or 379 watts, per assembly.

The thermal evaluation applied different component temperature limits and allowable stress limits for long-term conditions versus short-term conditions. Normal storage operation is considered to be a long-term condition. Off-normal and accident events are considered to be short-term conditions. Thermal evaluations are performed for the design basis PWR and BWR fuels for all design conditions. The maximum allowable material temperatures for long-term and short-term conditions are provided in Table 4.1-2.

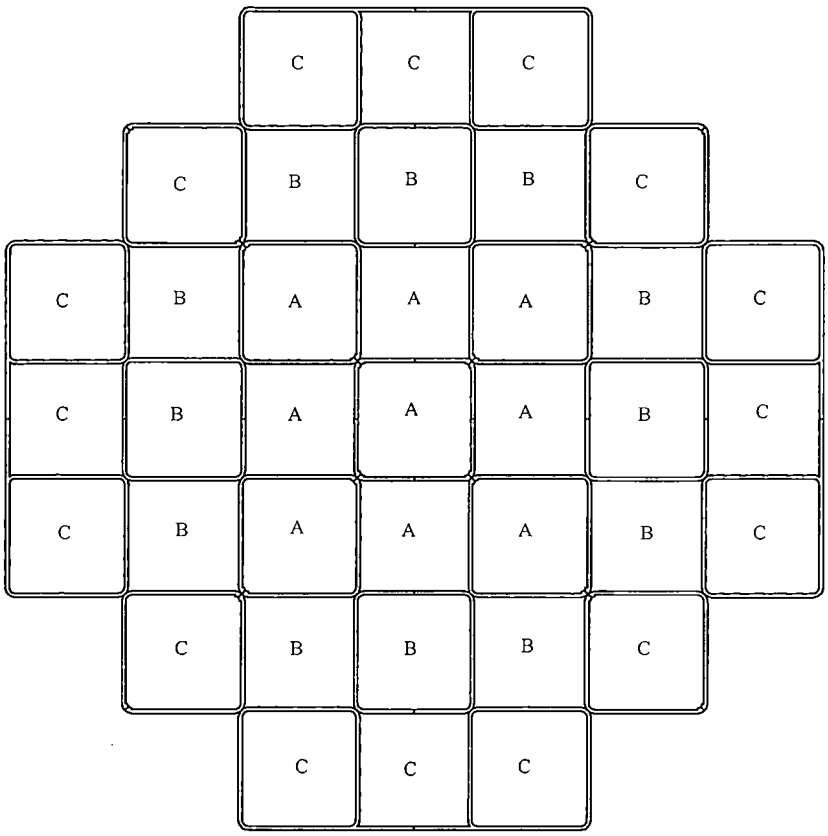
During normal conditions of storage and off-normal and accident events, the concrete cask must reject the decay heat from the TSC to the environment without exceeding the system components temperature limits. In addition, to ensure fuel rod integrity for normal conditions of storage, the spent fuel must be maintained at a sufficiently low temperature in an inert atmosphere to preclude thermally induced fuel rod cladding deterioration. To preclude fuel degradation, the maximum cladding temperature under normal conditions of storage and canister transfer operations is limited to 752°F (400°C) per ISG-11 [2]. The maximum cladding temperature for off-normal and accident events is limited to 1,058°F (570°C). For the structural components of the storage system, the thermally induced stresses, in combination with pressure and mechanical load stresses, are limited to the material allowable stress levels.

Thermal evaluations for normal conditions of storage and canister transfer operations are presented in Section 4.4. The finite element method is used to compute the effective properties for the basket, neutron absorber and fuel region. The thermal solutions for the concrete cask and transfer cask are obtained using finite element and finite volume methodologies. Thermal models used in the evaluation of normal and transfer conditions are described in Section 4.4.1.

A summary of the thermal evaluation results for normal conditions of storage is provided in Table 4.4-3 for the PWR and the BWR cases. Table 4.4-5 through Table 4.4-15 contain the maximum fuel cladding temperatures for the different phases of the transfer operations for the PWR and BWR cases. Thermal evaluation results for off-normal and accident events are presented in Sections 4.5 and 4.6, respectively. Comparison of the evaluation results shows that the standard PWR basket evaluation bounds that of the DF basket assembly and also bounds that of the PWR minimum reduced cool time fuel basket assembly. The results demonstrate that the calculated temperatures are less than the allowable fuel cladding and component temperatures for all normal (long-term) storage conditions and for short-term events. As shown in Chapter 3, the thermally induced stresses, combined with pressure and mechanical load stresses, are also within allowable limits.

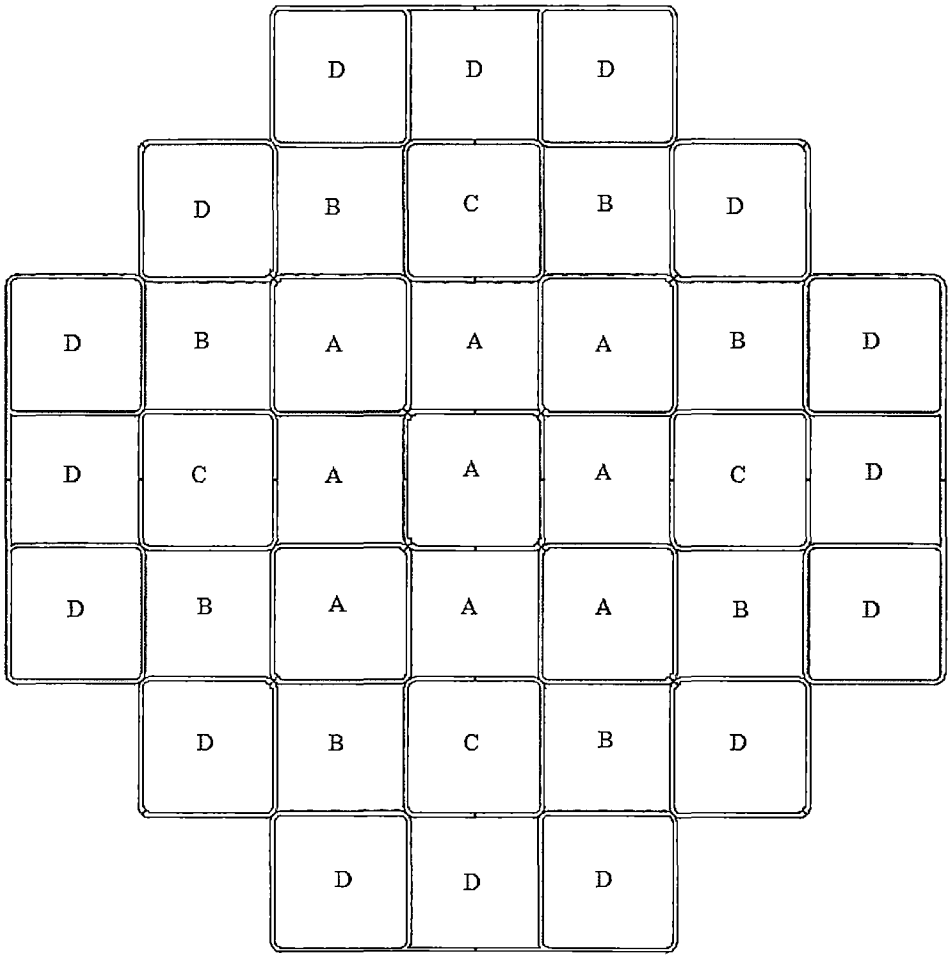
As discussed in Section 4.4.1, for TSC that is less than fully loaded, empty fuel storage locations shall begin at the center of the basket and continue outward, as required in an approximately symmetric pattern.

Figure 4.1-1 Definition of the Preferential Loading Pattern for the PWR Basket Assembly



Zone Identification	A	B	C
Maximum Heat Load per Assembly (kW)	0.922	1.20	0.80
Total Number of Fuel Assemblies	9	12	16

Figure 4.1-2 Preferential Loading Pattern for the PWR Basket with Minimum Reduced Cool Time Fuel



Zone Description	Designator	Heat Load [Watts]	No. of Assemblies
Inner Ring	A	513	9
Middle Ring	B	1300	8
Middle Ring	C	1800	4
Outer Ring	D	830	16

Table 4.1-1 Summary of Thermal Design Conditions for Storage for MAGNASTOR

Condition		Environmental Temperature (°F)	Solar Insolation [a]	Condition of Concrete Cask Inlets
Normal		76[b]	Yes	All inlets open
Off-Normal - Half Air Inlets Blocked		76	Yes	Half inlets blocked
Off-Normal - Severe Heat		106	Yes	All inlets open
Off-Normal - Severe Cold		-40	No	All inlets open
Accident - Extreme Heat		133	Yes	All inlets open
Accident - All Air Inlets Blocked		76	Yes	All inlets blocked
Accident - Fire	During Fire	1475	Yes	All inlets open
	Before and After Fire	76	Yes	All inlets open

[a] Solar Insolation per 10 CFR 71 [3]:
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.

[b] Maximum average annual temperature in the 48 contiguous United States is 75.6°F. [25]

Table 4.1-2 Maximum Allowable Material Temperatures

Material	Temperature Limits (°F)		Reference
	Long Term	Short Term	
Concrete	200(B)/300(L)[a]	350	ACI-349 [4] NUREG-1567 [20]
Fuel Clad PWR Fuel BWR Fuel	 752 752	 752/1,058[b] 752/1,058[b]	 ISG-11 [2] and PNL-4835 [5]
NS-4-FR	300	300	JAPC [6]
Chemical Copper Lead	600	600	Baumeister [7]
ASME SA693 17-4PH Type 630 Stainless Steel	650	800	ASME Code [8] ARMCO [9]
ASME SA240 Type 304 Stainless Steel	800	800	ASME Code [8]
ASME SA537 Class 1 Carbon Steel	800	850/1,000[c]	ASME Code [8] ASME Code Case N-707 [26]
ASTM A588 Carbon Steel	700	700	ASME Code Case N-71-17 [10] ASTM Standard [19]
ASTM A350 LF2 Carbon Steel	700	700	ASTM Standard [19]
ASTM A36 Carbon Steel	700	700	ASME Code Case N-71-17 [10] ASTM Standard [19]
ASME SA695 Type B Grade 40 and SA696 Type C Carbon Steel	800	800	ASME Code [8]

[a] B and L refer to bulk temperature and local temperature, respectively.
[b] 752°F TSC transfer operations; 1,058°F off-normal and accident events.
[c] 850°F TSC transfer operations; 1,000°F off-normal and accident events.

4.2 Thermal Properties of Materials

Material properties used in the analytical model are separated into two categories. One category represents materials specified in the design that are explicitly represented in the model and are tabulated in Chapter 8. The second category represents effective properties of the basket, neutron absorber and fuel region, which are calculated using the thermal models presented in Section 4.4.1.

4.3 Technical Specifications for Components

The three major components of MAGNASTOR must be maintained within their safe operating temperature ranges: the concrete cask, the transfer cask, and the TSC with fuel basket. The safe operating ranges for these components are from a minimum temperature of -40°F to the maximum temperatures defined in Table 4.1-2.

The criterion for the safe operating range of the lead in the transfer cask is maintaining the lead temperature below its melting point of 620°F [7]. The maximum operating temperature limit of the NS-4-FR neutron shield material in the transfer cask has been determined by the manufacturer and ensures the stability of the material. The temperature limits for the steel components of the fuel basket and the TSC are defined by ASME Code Section II, Part D [8] and ASME Code Case N-707 [26]. The temperature limits for the steel components of the transfer cask and the concrete cask are defined by ASTM Standards [19]. The temperature limits for concrete are defined by ACI-349 [4] and NUREG-1567 [20].

4.4 Normal Storage Conditions

The finite element and finite volume methods are used to evaluate the thermal performance of MAGNASTOR for normal conditions of storage. The general-purpose finite element analysis program ANSYS [11] is used to perform analyses requiring radiation and conduction. The Computational Fluid Dynamics (CFD) program FLUENT [12], which is based on finite volume methods, is used to perform analysis that includes conduction, radiation and convection. In FLUENT, convection of heat is simulated through motion of fluid, as well as by the specification of a film coefficient for a surface boundary condition.

4.4.1 Thermal Analysis Models

Analysis models used for the thermal evaluation of both the PWR and BWR design configurations are described in the following sections. The methodology inherent in the models conservatively reflects the heat transfer performance provided by the MAGNASTOR design.

The designs for both the PWR and the BWR fuel systems utilize the same method of passive heat rejection to transfer the decay heat from the fuel assemblies (and the damaged fuel cans, as applicable) to the ambient environment. The TSC is a closed system, whereas the concrete cask and the transfer cask are open to the environment. Internal to the TSC, the decay heat is transferred from the fuel assemblies, or the damaged fuel cans, in each of the fuel tubes to the TSC shell by three modes of heat transfer: convection, conduction and radiation. The fuel baskets designed for PWR and BWR fuel assemblies permit the helium backfill gas to flow up the fuel tubes containing the fuel assemblies and carry the heat away from the fuel assemblies. Note that no helium flow is considered in the basket slots containing damaged fuel cans. The region in the TSC just above the fuel basket allows the helium flow upward from the fuel tubes to combine and flow through the downcomer regions formed between the TSC shell and the basket side weldments. The gas exiting the downcomer regions at the bottom of the fuel basket enters a region below the basket tubes. The flow of the helium upward in the fuel basket and downward in the downcomer regions is driven by the buoyancy forces created by the effect of the heated helium rising up through the fuel tubes. To increase the buoyancy force, the density of the helium is increased by raising the helium backfill pressure. Since the fuel tubes are full-length carbon steel tubes, they provide a path for conduction of heat. While the tubes are not welded together, the effect of the gap between the tubes is mitigated by the use of the helium backfill. The side and corner weldments of the fuel basket, which support the fuel basket during a side impact, also provide a path of heat conduction. The DF basket assembly corner weldment with thicker carbon steel plates provides a more effective path of heat conduction than does the standard PWR basket assembly. While a gap is considered between the side and corner

weldments and the TSC shell for analysis purposes, the heat transfer across the gap is provided by the radiation from the weldments and conduction through the helium gap to the TSC shell. Radiation is also a mode of heat transfer, which allows heat from the interior of the fuel assembly to be transferred to the outer pins of the fuel assembly. Additionally, since the fuel assemblies are assumed to be in the center of each fuel tube, radiation also contributes to the heat transfer from each fuel assembly to the fuel tube wall. Radiation is also taken into account for all gaps, such as those between the tubes. Additionally, radiation contributes to the heat being transferred from the outer basket surface to the TSC shell.

As the heat is being transferred to the TSC shell, the airflow up the annulus region between the TSC and the concrete cask carbon steel liner is removing heat from the TSC outer surface and rejecting it to the ambient environment. This annulus airflow is also driven by the buoyancy of the heated air. The air entering the air inlets at the base of the concrete cask provides a supply of cooler air into the annulus region. The heated air rises and exits the air outlets. Since the TSC shell faces the concrete cask liner, it radiates heat to the liner, which allows heat from the liner to be transferred to the annulus airflow. The liner also serves to distribute the heat along the length of the liner. Heat not rejected into the airflow is conducted through the concrete cask wall to the outer surface. At the surface, both convection and radiation modes of heat transfer reject the heat to the ambient.

Due to the convection of the fuel decay heat into the downcomer, the temperature distribution along the length of the TSC shell inner surface is not uniform, but increases monotonically from the base of the TSC to an elevation near to the top of the basket. This indicates that the heat flux due to the heated helium along the TSC wall is not uniform, and that this heat flux actually can be considered to be a boundary condition to the airflow in the annulus region of the concrete cask. For this reason, it is more efficient to consider a model in which both the TSC fuel basket and fuel region are considered in conjunction with the airflow in the annulus region of the concrete cask. The model used to represent the TSC and the concrete cask is a two-dimensional axisymmetric model, which is described in Section 4.4.1.1.

The fuel basket and fuel regions inside the TSC are modeled as homogeneous regions incorporating all modes of heat transfer. Effective thermal conductivities are used to represent the conduction and radiation in the fuel region and fuel basket, which require a two-step modeling process. A series of two-dimensional planar models is generated to determine the effective conductivities for the fuel assembly (Section 4.4.1.3) and the neutron absorber (Section 4.4.1.4). Using the effective conductivity for the fuel region and the neutron absorber, the effective conductivity for the fuel basket is determined using the two-dimensional fuel basket model as presented in Section 4.4.1.2.

The flow of helium in the fuel region is affected by the wetted perimeter associated with the fuel pins. To represent the flow of helium in the fuel region, which is represented as a homogenized entity, porous media is used in the modeling. The porous media model allows the effect of the reduced flow area of the fuel rods and the fuel assembly grids to be considered in representing the momentum of the helium flow by including a pressure drop based on the geometry of the fuel assembly, i.e., the pitch of the fuel rods, the fuel rod diameter, and the fuel assembly grid geometry. Additional fluid flow analyses are required to determine the constants inherit in the porous media use for flow between cylindrical-shaped fuel rods and for fuel assembly grids. The determination of porous media constants is presented in Section 4.8.2. The flow of helium in the downcomer regions in the TSC does not require special consideration of effective flow conditions. To confirm that the use of a two-dimensional model for the TSC is an acceptable and conservative methodology, a benchmark is provided in Section 4.8.1.

Additional analysis results have demonstrated that a TSC that is less than fully loaded, i.e., with empty fuel storage locations in its center region, is bounded by the results of a fully loaded TSC. Therefore, empty fuel storage locations shall begin at the center of the basket and continue outward, as required, in an approximately symmetric pattern.

The thermal evaluation for the transfer conditions is performed using the two-dimensional axisymmetric models of the transfer cask and TSC, as presented in Section 4.4.1.5. Similar to the model of the concrete cask and TSC, the fuel basket and fuel assemblies inside the TSC in the transfer cask are modeled as homogeneous regions using effective thermal properties.

4.4.1.1 Two-Dimensional Axisymmetric Concrete Cask and TSC Models

This section describes the finite volume models used to evaluate the thermal performance of the concrete cask and TSC for the PWR and BWR fuel configurations. As shown in Figure 4.4-1, the two-dimensional axisymmetric concrete cask and TSC model includes the following:

- Concrete cask, including lid, liner, pedestal and stand
- Air in the air inlets, the annulus and the air outlet
- TSC shell, lid and bottom plate
- Basket with fuel (including damaged fuel cans, as applicable) and neutron absorber
- Helium internal to the TSC

The fuel basket, fuel and neutron absorber are modeled as homogeneous regions with effective properties. The effective thermal conductivities for the TSC internals in the radial and axial directions are determined using the two-dimensional models as detailed in Section 4.4.1.2.

The two-dimensional axisymmetric concrete cask and TSC model is used to perform computational fluid dynamics analyses to determine the component temperature, the mass flow

rate, velocity and temperature of the airflow in the annulus region, as well as for the helium flow internal to the TSC. Since the concrete cask and its components are contained in the model, the temperature distributions in the concrete and the concrete cask steel liner are also determined. Three separate models are generated for the evaluations of the following configurations:

1. CC1/CC2 concrete cask with a PWR TSC.
2. CC1/CC2 concrete cask with a BWR TSC.
3. CC3 concrete cask with a PWR TSC.

The first two models are identical, except for differences in dimensions of the downcomer regions and the effective properties of the TSC internals. Note that these two models are applicable to both the CC1 and CC2 cask configurations since CC2 is a segmented version of CC1. Figure 4.4-2 shows an overall view of the cells employed in the model representing both the concrete cask and the TSC containing a design basis fuel heat load. The third model is identical to the first model, with the following differences:

1) The overall height of the concrete cask is reduced to 218.3 inches (CC3).
2) The concrete cask liner thickness is increased from 1.75 inches to 3 inches (CC3).
3) The concrete thickness of the center of the concrete cask lid is increased by 6 inches (CC3).
4) Shield bars are modeled in the concrete cask air inlets (CC3).
5) TSC with composite closure lid assembly (4-inch stainless steel closure lid with a 5-inch thick carbon steel shield plate) is modeled.

The CC4 configuration is similar to the CC1/CC2 and CC3 configurations, with the same lid and steel liner thickness as CC1/CC2 and the same height and additional shielding at the air inlets as CC3. A sensitivity study was performed using the governing CC3 model with a steel liner thickness corresponding to the CC4 configuration. The analysis results showed that maximum fuel/basket temperature for CC4 is approximately 1°F less than that for the CC3 configuration, indicating that the differences between CC4 and other cask configurations do not have a significant effect on the thermal performance of the casks. Therefore, no additional thermal model is needed for the CC4 configuration. The bounding component temperatures from the thermal analysis results using the models for CC1/CC2 and CC3 are applicable to the CC4 configuration.

The models used for the thermal evaluation are explained in greater detail as follows:

Modeling of the Concrete Cask

The concrete cask body has four air inlets at the bottom and four air outlets at the top. Since the configuration is symmetrical, it can be simplified into a two-dimensional axisymmetric model by using equivalent dimensions for the air inlets and outlets, which are assumed to extend around the concrete cask periphery. In the model for the CC3 concrete cask, additional shielding in the inlet vent is considered by a lumped porous zone that is represented by viscous and inertial flow resistance coefficients. The flow resistances are determined using a geometrically correct three-dimensional computational fluid dynamics (CFD) model of the air inlet that includes shield bars. The vertical air gap is an annulus, with a radial width of 3.5 inches. This radial dimension of the air annulus between the TSC shell and the concrete cask liner is modified to a smaller effective value to account for the reduction of the airflow cross-sectional area due to the standoffs welded to the liner. The bottom ends of the standoffs are more than 63 inches from the bottom of the TSC, which means that for over 30% of the length of the annulus, the standoffs do not exist. The model conservatively represents them as being the full length of the TSC. The additional axial conductance from the standoffs is conservatively neglected. Thermal radiation across the annulus gap is considered in the model, and the emissivities of the TSC surface and the concrete cask liner are reported in Chapter 8. Heat being radiated to the concrete cask liner is transferred into the annulus by convection, as well as being conducted through the concrete cask wall.

The most significant mechanism for rejecting heat into the environment is through the movement of air up through the annulus. The airflow in the vertical annulus is modeled as transitional turbulent flow using the k-ω turbulence model in FLUENT [12]. This determination was made through the use of a thermal test of PWR canistered fuel contained in a vertical concrete cask, which is described in EPRI Report TR-100305 [21] and provides a description of the test canister, the concrete cask, the fuel assemblies, and the boundary conditions employed in a series of tests. The total heat load of the fuel used in the tests was 14.9 kW. Extensive temperature measurements were made for the basket, fuel, canister and concrete cask for each test conducted. The thermal test of interest employed the vacuum condition for the canister. This test was selected since it removed the influence of convection inside the canister and simplified the thermal model inside the canister. FLUENT was used to perform a two-dimensional steady-state axisymmetric analysis of the system described in [21] using two turbulent flow models: a low Reynold's number turbulence model (low Re k-ε) and a transitional turbulence model (k-ω). Technical details for these turbulence models are contained in the documentation for FLUENT. The thermal models and boundary conditions used in the analyses are detailed in Section 4.8.3. Results for the temperature profiles for the canister surface and the concrete liner surfaces for both turbulence models are shown in Figure 4.8-12 and Figure 4.8-13. The results indicate that both turbulence models yield conservative predictions for the temperature profiles and that both

the low Reynold's number k-ε and the k-ω models are appropriate for use in the analysis of air flow up through the annulus between the canister and the concrete cask. Since the use of the k-ω model provides conservative results for the canister shell and concrete cask for a test corresponding to 14.9 kW, the use of the k-ω model is also considered to be appropriate for analyses having larger heat loads. As the heat load is increased, the turbulence in the annulus air flow is also expected to increase. The results of the analysis for the thermal tests are considered as validation for the use of the k-ω turbulence model for the annulus region of MAGNASTOR.

The mesh for the annulus region of the CC3 model is similar to the mesh for the annulus region of the CC1/CC2 model that is shown in Figure 4.4-2. Increased cell density is used in the annulus region adjacent to the wall to allow the y+ at the wall to be on the order of unity, ensuring proper turbulence modeling.

The TSC model is included with the concrete cask model as shown in Figure 4.4-1. Boundary conditions at the edges of the model to the ambient are applied to the concrete cask surfaces. The heat flux being transferred from the helium internal to the TSC through the TSC shell and into the air annulus region is not considered to be a boundary condition for the concrete cask since all of these components are included in the same model. The boundary conditions applied to the outer surface of the concrete cask include the following.

- Solar insolation to the outer surfaces of the concrete cask.
- Natural convection heat transfer at the outer surfaces of the concrete cask.
- Radiation heat transfer at the concrete cask outer surfaces.

Solar Insolation

The solar insolation on the concrete cask outer surfaces is considered in the model. The incident solar energy is applied based on 24-hour averages as shown:

Side surface: $$\frac{1475\text{Btu/ft}^2}{24\text{hrs}} = 61.46\text{Btu/hr}\cdot\text{ft}^2$$

Top surface: $$\frac{2950\text{Btu/ft}^2}{24\text{hrs}} = 122.92\text{Btu/hr}\cdot\text{ft}^2$$

Natural Convection

Natural convection heat transfer at the outer surfaces of the concrete cask is evaluated by using the heat transfer correlation for vertical and horizontal plates. This method assumes a surface temperature and then estimates Grashof (Gr) or Rayleigh (Ra) numbers to determine whether a heat transfer correlation for a laminar flow model or for a turbulent flow model should be used. Since Grashof or Rayleigh numbers are much higher than the values defining the transition from

laminar to turbulent flow, correlation for the turbulent flow model is used as shown in the following.

Side surface (Kreith) [13]:

$$Nu = 0.13(Gr \cdot Pr)^{1/3} \qquad \text{for } Gr > 10^9$$
$$h_c = Nu \cdot k_f / H_{VCC}$$

Top surface (Incropera) [14]:

$$Nu = 0.15 Ra^{1/3} \qquad \text{for } Ra > 10^7$$
$$h_c = Nu \cdot k_f / L$$

where:

Gr	----------	Grashof number
h_c	----------	Average natural convection heat transfer coefficient
H_{vcc}	----------	Height of the concrete cask
k_f	----------	Conductivity
L	----------	surface characteristic length, L = area / perimeter
Nu	----------	Average Nusselt number
Pr	----------	Prandtl number
Ra	----------	Rayleigh number

All material properties required in these equations are evaluated based on the film temperature defined as the average value of the surface temperature and the ambient temperature.

Radiation Heat Transfer

The radiation heat transfer between the outer surfaces of the concrete cask and the ambient environment is evaluated in the model by calculating an equivalent radiation heat transfer coefficient.

$$h_{rad} = \frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{1/\varepsilon_1 + 1/\varepsilon_2 + 1/F_{12} - 2} \qquad [14]$$

where:

h_{rad}	----------	Equivalent radiation heat transfer coefficient
F_{12}	----------	View factor
T_1 & T_2	----------	Surface (T_1) and ambient (T_2) temperatures
ε_1 & ε_2	----------	Surface (ε_1) and ambient (ε_2=1) emissivities

σ ---------- Stefan-Boltzmann Constant

At the concrete cask side, an emissivity for a concrete surface of $\varepsilon_1 = 0.9$ is used and a calculated view factor (F_{12}) = 0.182 [14] is applied. The view factor is determined by conservatively assuming that the cask is surrounded by eight casks. At the cask top, an emissivity, ε_1, of 0.8 is conservatively used (emissivity for concrete is 0.9), and a view factor, F_{12}, of 1 is applied.

Modeling of the TSC

The TSC is a closed system designed so that pressurized helium can circulate inside the TSC and transfer heat from the fuel in the basket to the TSC shell. Circulating helium is modeled as laminar flow inside the TSC. Additionally, the basket permits heat to be conducted from the interior regions of the basket to the periphery of the basket, then radiated and convected to the TSC shell surface. The stiffeners at the periphery of the basket do provide a path of conduction to the TSC shell, even though a small gap exists between the stiffeners and the TSC shell. The heat conduction through these stiffeners is neglected in the evaluation, which is considered to be conservative. Radiation is modeled in the fuel assemblies, as well as in gaps in the basket. Heat transfer to the TSC lid and bottom plate is considered in the analysis, but it is not a major contributor to the heat-rejection process. Two separate models are generated for the CC1/CC2 concrete cask—one for the PWR fuel configuration and one for the BWR fuel configuration. The differences between the two models are in the dimensions of the basket region and the effective properties derived for each basket and fuel region. The TSC model for the CC3 concrete cask is identical to the model for the CC1 PWR configuration.

The TSC region consists of the following: the TSC shell, the TSC bottom plate, the TSC lid, the fuel basket region, and the helium-filled volume outside the fuel basket region. The fuel basket region is subdivided into three sections to reflect the location of the active fuel region with the associated heat generation and the fuel regions above and below the active fuel regions. These three separate regions are shown in Figure 4.1-1. In addition to the three sections to reflect the location of the active fuel region with the associated heat generation and the fuel regions above and below the active fuel regions, the fuel region for the DF basket assembly is modeled in two ways, which are differentiated by basket radial zones. One model considers the active fuel region as a single porous zone in the radial direction with resistance coefficients for the entire DF basket. The second model considers the active fuel region as two zones in the radial direction with two sets of flow resistances – an outer zone that models the outer 16 basket slots (which include the four damaged fuel can slots) and an inner zone that models the inner 21 basket slots. For both models, when computing the flow resistance at the basket slot for the DFC, helium flow is considered only at the gap between the DFC side plates and the basket corner support weldment. Note that the TSC lid in the model corresponds to the 9-inch thick stainless steel lid.

There is an insignificant effect on the thermal performance of the system if the lid is replaced by the optional 4-inch thick stainless steel lid with a 5-inch thick carbon steel shield plate.

The cross-section of the flow path for the helium in the fuel basket and TSC significantly changes between the flow up through the basket region and the flow down in the downcomer region next to the TSC shell. For the flow up through the basket, the outline of the cross-sectional area is comprised of the area between the square basket tubes and circular fuel pins. Additionally, as the helium flows up through the basket tube, the fuel assembly grids will provide resistance to the flow. No helium flow is considered through the damaged fuel cans. In the downcomer region, the exterior boundary is circular, while the interior boundary is the edge of the square fuel tubes. This is also an irregular-shaped area. In a two-dimensional representation of these areas, the concept of the hydraulic diameter is employed, which is commonly used to determine an equivalent cross-sectional area for a cross-section with complex shapes.

To account for the resistance to flow in the fuel region in the basket due to the wetted perimeter of the fuel region in the basket, the porous media option for fluids is used. The resistance to flow due to the fuel pins and the fuel assembly grids is represented in terms of a pressure drop included in the momentum equations for each cell in the model associated with porous media. The expression for the pressure drop used in FLUENT is given by:

$$\frac{\Delta P}{L} = \frac{\mu}{\alpha \cdot \varepsilon} V + C\left(\frac{1}{2}\rho V^2\right)$$

where:

$\Delta P/L$	----------	pressure drop per unit length (Pa/m)
V	----------	superficial fluid velocity (m/s)
μ	----------	fluid viscosity (kg/m-s)
ρ	----------	fluid density (kg/m^3)
$1/\alpha$	----------	viscous flow resistance (m^{-2})
ε	----------	porosity factor, which is the ratio of the cross-sectional area of the flow, to the cross-sectional area of the porous media region in the FLUENT model
C	----------	inertial resistance factor (m^{-1})

In this expression, the viscosity is input as a temperature-dependent material property for the helium, and the density is computed during the solution based on the ideal gas law. The permeability is based on the geometry of the fuel rods and the fuel assembly grid. Since the velocities are on the order of 0.03 m/s or less, the second term comprised of V^2 is considered to be insignificant as compared to the first term. Therefore, the calculation for the inertial

resistance factors is neglected. Details of the calculation of the viscous flow resistance factors are contained in Section 4.8.2. The values used for the evaluation are based on the bounding fuel parameters.

The downcomer region of the TSC does not use a porous media model. The areas of the downcomer regions are calculated to be 600 inches^2 and 550 inches^2 for the PWR and the BWR fuel baskets, respectively. These areas are used to calculate the effective outer diameter of the fuel basket region, which serves as the radial boundary for the porous media region for the fuel.

Due to the large cross-section for the flow up through the fuel basket, the helium velocity is expected to be sufficiently low to correspond to laminar flow. In the downcomer region, the gas velocities would result in the flow being in a transitional regime. Conservatively, all helium flow in the TSC is taken to be laminar.

The porous media representation of the fuel basket region incorporates orthotropic effective thermal conductivities. The axial conductance in the fuel basket region is due to the significant cross-sectional area of the fuel tubes and the fuel assemblies. The in-plane conductance is associated with the conductance of the fuel tubes, as well as the effective conductivities of the fuel assembly and neutron absorber. The effective conductivity of the fuel basket region is determined in two steps. Separate effective thermal conductivities for the two-dimensional fuel assembly and the neutron absorber are computed for the axial and the in-plane directions using two finite element models. Details for these models are described in Section 4.4.1.3 for the fuel assemblies and Section 4.4.1.4 for the neutron absorber. In these sections, both the PWR and the BWR effective properties calculations are performed.

The resulting conductivities for the fuel assemblies and neutron absorber are then used in a single two-dimensional planar model of the cross-section of the basket, which is used to determine the axial and in-plane conductivities for the fuel basket region associated with the porous media. This model is described in Section 4.4.1.2. The effective conductivity of the DF basket assembly is computed using a similar two-dimensional planar model of the basket cross-section with the four DFC locations conservatively assumed to be helium, i.e., the contents of the DFC location are not modeled. This assumption is conservative because the conductivity of helium is lower than that of the contents in the DFC locations. The effective conductivity for the porous media model uses two conductivities (k_f and k_s), as identified in the following equation.

$$K_{eff} = \varepsilon \times k_f + (1-\varepsilon) \times k_s$$

where:

ε ---------- porosity factor
k_f ---------- thermal conductivity of the helium

k_s ---------- thermal conductivity associated with the solid portion of the porous media model

The model of loaded TSC for the PWR minimum reduced cool time fuel is identical to the first model for standard PWR fuel, except for the mesh of the basket region. The basket zone is remeshed to match the variation of the heat generation of the preferential fuel heating pattern of the minimum reduced cool time fuel configuration.

Heat Generation

The heat generation for the fuel is applied to the active fuel region of the TSC model (see Figure 4.4-1) for the PWR and the BWR fuel assemblies. The maximum design basis heat loads to be considered for the PWR and the BWR fuel basket configurations are 35.5 kW and 33 kW, respectively. The maximum design basis heat load to be considered for the DF basket assembly is 35.5 kW.

For the PWR fuel basket, two patterns of heat generation are considered. First, a uniform loading of 35.5 kW or 959 W in each fuel location is considered. The axial power distribution for PWR fuel, as shown in Figure 4.4-3, is included in applying the heat generation. Second, an optional heat generation pattern, as shown in Figure 4.1-1 is also considered and has the same total heat load of 35.5 kW. The application of the heat generation for this condition incorporates an axial distribution and a radial distribution. The area over which each fuel assembly heat load is distributed in Figure 4.1-1 is determined on the basis of the cross-section of the fuel tubes containing the specific heat loads identified as A, B and C in Figure 4.1-1. The heat generation values specified in Figure 4.1-1 are considered to be the maximum permissible heat generation in each fuel location for this configuration. It is noted that maximum fuel assembly heat load in Figure 4.1-1 is 25% greater than the heat load for the uniform condition. The fuel heat load in the center of the basket in Figure 4.1-1, Zone A, at 0.922 kW is only 4% less than the uniform heat loading at 0.96 kW per assembly. The use of hotter assemblies in the Zone B ring results in slightly more flow in the Zone B region with the higher heat load, but simultaneously presents a bounding condition over the uniform loading of the entire basket since the edge of Zone A temperatures is increased by the influence from the higher heat in Zone B. An analysis using a 40 kW preferential loading with a more aggressive annular turbulence model (K-ε) and a reduced flow resistance showed that the preferential heat distribution increased the maximum fuel temperatures by 6°F. With the reduction of the maximum heat load to 35.5 kW, the 6°F difference in maximum fuel cladding temperature will decrease, but will still produce temperatures equal to or greater than the uniform heat load configuration. Third, an optional heat generation pattern, as shown in Figure 4.1-2 is also considered and has the same total heat load of 35.5 kW. The application of the heat generation for this condition incorporates an axial distribution and a radial distribution. The area over which each fuel assembly heat load is

distributed in Figure 4.1-2 is determined on the basis of the cross-section of the fuel tubes containing the specific heat loads identified as A, B, C and D in Figure 4.1-2. The heat generation values specified in Figure 4.1-2 are considered to be the maximum permissible heat generation in each fuel location for this configuration.

In one of the three analyses performed for the DF basket assembly, the uniform loading heat generation rate of undamaged fuel is applied to the standard fuel slots and a compacted heat generation rate (over the lower 103 inches of the active fuel region considering a 50% compaction of the fuel debris) is considered for the four damaged fuel can slots. In the other two analyses, the uniform loading heat generation rate of standard fuel assemblies is applied to the active fuel region of the basket.

For the BWR fuel basket, only a uniform thermal loading pattern is considered. The design basis heat load for BWR fuel is 33 kW, which corresponds to a maximum heat load of 379 watts for each of the 87 fuel assemblies. The axial power distribution for the BWR fuel is shown in Figure 4.4-4. For some BWR fuel assembly enrichments, the five fuel locations in the center of the BWR basket will not be loaded. In this configuration, the fuel assembly decay heat is limited to 379 watts. The configuration with a partially loaded fuel basket containing BWR fuel assemblies with a maximum heat load of 379 watts per assembly is considered to be bounded by the fully loaded BWR fuel basket configuration. Temperatures obtained from analyses performed using the maximum heat load in conjunction with a fully loaded BWR basket are considered to bound the results for a partially loaded basket.

Pressure of the Helium Backfill

To drive the convection internal to the TSC, it is necessary to increase the density of the helium. Since the free volume in the TSC remains constant, the density of the backfill gas can be increased by backfilling the TSC to a range of pressures and temperatures that would result in an increase in the density. In the MAGNASTOR design, the TSC is backfilled with helium to meet the density listed in Table 4.4-4. Since the gas in the model is characterized as an ideal gas, the increased density in the analysis can be indirectly obtained by specifying a pressure in the TSC region. For the PWR normal condition, the density of helium in the TSC associated with a pressure of 7 atm (g) is (0.76g/liter). It is important to assess the effect of the helium density on the performance of the system. The evaluation of the sensitivity of the peak fuel temperature to the pressure is performed using the PWR model described in this section. The condition requiring a change is the pressure that is applied to the TSC region of the model. The results of the model solutions for pressures of 1 atm (g), 3 atm (g), 5 atm (g) and 7 atm (g) are shown as a graph in Figure 4.4-5. As shown in Figure 4.4-5, the variation of the peak cladding temperature with the pressure specified inside the TSC is a nonlinear function. The peak cladding temperature decreases sharply when the pressure increases from 1 atm to 3 atm. Subsequent

increases in the pressure to 5 atm and 7 atm do not result in the same rate of decrease of the clad temperature as for the 1 atm and 3 atm cases. The model of the TSC in the concrete cask has two regions of convection separated by a TSC shell. Heat can only be transferred through the shell from the TSC internal region to the annulus region outside the TSC. The flow characteristics in the annulus region are primarily affected by the total heat generation being transferred through the TSC shell, as well as the geometry of the annulus. As the pressure (and the associated mass) of the gas in the TSC is increased, the buoyancy force inside the TSC is increased. This increases the mass flow rate of the TSC gas so that the ability to reject heat from the fuel is also increased. This would tend to reduce the maximum clad temperature. However, the flow in the annulus is not expected to be significantly affected by the velocity of the gas internal to the TSC. Therefore, regardless of the buoyancy force inside the TSC, the maximum clad temperature is limited by the shell temperature, which is controlled by the annulus flow. At some pressure level, an increase in the TSC pressure (and mass) of the gas would not significantly decrease the fuel clad temperature, which would imply a reduced derivative of the clad temperature with respect to the pressure. This is the characteristic of the curve in Figure 4.4-5, which implies that further increase in the pressure does not result in a significant reduction of the clad temperature. There is an advantage in operating in this regime of the curve in that the sensitivity of the clad temperature due to a reduction in the helium density is reduced. This evaluation demonstrates that even with a 10% loss of density, the peak clad fuel temperatures for the design basis heat load remain under 752°F (400°C). The calculated maximum temperatures from this evaluation show that there is an acceptable 10 psig tolerance for the minimum helium backfill pressure.

Modeling of the Air Inlet with Shield Bars

The inlet region of the CC3 concrete cask is designed with shield bars for enhanced shielding. The flow resistances of the inlet vent airway of the concrete cask, which includes shield bars, are calculated using a three-dimensional FLUENT CFD model (see Figures 4.4-20 and 4.4-21). Half of the inlet is modeled because of symmetry. The symmetry plane passes between the top and bottom walls of the air inlet. The computed viscous and inertial resistance coefficients are applied to the inlet region of the two-dimensional axisymmetric concrete cask and to the TSC model corresponding to the CC3 concrete cask. The inlet region is defined as a porous region without the geometric details of the inlet. For each applied pressure gradient between inlet and outlet boundaries, the average axial velocity in the model is determined. Five sets of the average static pressure drop between the flow inlet and outlet boundaries as a function of the average axial velocity in the domain are obtained and curve fitted as:

$$\Delta P = 0.1451 \times V + 1.222 \times V^2$$

where, ΔP is the average static pressure drop and V is the average axial velocity.

The pressure drop is related to the source term in the momentum equation for a homogenous porous medium according to:

$$\Delta P = (\frac{\mu}{\alpha} V + \frac{1}{2} C_p V^2) \Delta n$$

where Δn is the porous medium thickness, ρ is air density, μ is air viscosity, $1/\alpha$ is the viscous resistance coefficient, and C is the inertial resistance coefficient.

Comparing the previous equations and substituting the geometry of the inlet and the material properties of air at ambient temperature, the viscous resistance and inertial resistance coefficients are:

$$1/\alpha = 9051 \ 1/m^2 \quad C = 2.633 \ 1/m.$$

The viscous and inertial resistance coefficients are divided by the porosity and porosity squared, respectively, to get the resistance coefficient for the 100% open area used in modeling the inlet region as a porous zone in the concrete cask thermal analysis. The porosity of the model is determined to be 0.9282 for the air inlet with additional shield bars.

Mesh Sensitivity Evaluation

With respect to the sensitivity of the calculated fuel cladding, concrete cask and TSC temperatures to the number of divisions of the finite volume cells, this need only be addressed for the regions containing fluid flow. For the solid regions, such as the concrete or the steel components, the sensitivity evaluation of cell refinement is not required.

There are two fluid regions in the model: the airflow annulus region outside the TSC, and the helium region inside the TSC. Each of these fluid regions uses a different fluid flow model. The TSC internal flow is modeled utilizing a laminar flow model; the airflow in the annulus region is modeled using a turbulent flow model.

In the concrete cask annulus region, the modeling accuracy of the turbulent flow depends not on the usual refined mesh near the wall, as for a laminar flow condition, but on the value of y+, as previously discussed. The cell divisions in the annulus region have been set to permit the y+ to be less than unity, which is acceptable according to FLUENT documentation. Therefore, further refinement of the annulus region would not provide a more accurate temperature result.

For the helium flow in the TSC (laminar flow), the largest velocities are in the downcomer regions and, essentially, the entire heat load must be transferred to the TSC shell. The focus of the sensitivity evaluation is the number of cell divisions in the downcomer region. The largest velocity gradients in the downcomer regions occur in the radial direction, not in the axial direction. To determine the sensitivity of the radial divisions in the downcomer region, the

number of radial divisions modeled was increased by a factor of two. The axial divisions in the downcomer region remain the same. The mesh refinement in the air annulus and in the concrete cask remains unchanged. The condition used in the evaluation corresponded to the normal condition using a uniform heat loading of 40 kW, which bounds the design basis condition for the 35.5 kW. The results of this evaluation showed that the maximum fuel temperature changed by less than 1°F for the increased refinement mesh. The temperature of the TSC shell showed a decrease of 2°F for the mesh with the increased refinement. This indicates that the maximum fuel temperature is relatively insensitive to the mesh refinement in the downcomer region.

Heat Transfer by Radiation

Thermal radiation in all fluid (air and helium) regions has been considered in the model, specifically the following.

- Thermal radiation across the air annulus between the TSC shell and the concrete cask liner.
- Thermal radiation across the air gap above the TSC lid and in the isolated air region below the pedestal of the concrete cask.
- Thermal radiation across the helium downcomer region between the fuel basket and the TSC shell.

The discrete ordinates (DO) radiation model in FLUENT is used to solve the radiative heat transfer equation with emissivity values applied on the solid material surfaces.

Radiation in the porous media fuel region is modeled by using equivalent thermal conductivities that include the effects of heat transfer by radiation. The model of the porous media region in FLUENT is enclosed by a vertical wall that separates the porous region from the downcomer. The wall is comprised of two sides; one side facing the inner surface of the canister and the other facing the interior region of the porous media. An emissivity corresponding to electroless nickel is applied to the side facing the canister surface. On the side of the wall facing the interior region of the porous media, an emissivity of zero is applied to avoid incorporating the radiation already taken into account using the effective properties for the basket.

4.4.1.2 Two-Dimensional Fuel Basket Models

The purpose of the two-dimensional fuel basket model is to determine the effective thermal conductivity of the basket region in the axial and radial directions. The effective conductivities are used in the two-dimensional axisymmetric concrete cask and TSC models, and the two-dimensional axisymmetric transfer cask and TSC models. Two types of media are considered in the TSC: helium and water. The fuel assemblies and neutron absorbers in the fuel basket model are shown as homogeneous regions with effective thermal properties, which are determined by

the two-dimensional fuel assembly models and the two-dimensional fuel tube models described in Sections 4.4.1.3 and 4.4.1.4, respectively. The analyses performed in Section 4.4.1.3 identify that the PWR fuel assembly with the minimum conductivity is the 14×14. The properties of the PWR 14×14 fuel assembly are used in the evaluation of the effective properties for the PWR basket in this section. For the BWR assembly, the bounding fuel assembly type is the 10×10, which is used to determine the effective properties for the BWR basket.

Since the effective properties for the fuel basket correspond to the basket region, which is comprised of full-length fuel tubes, it is only necessary to consider a cross-section of the basket with a two-dimensional planar model. Due to symmetry of the basket designs, only a 1/8-section model is required for the PWR and the BWR fuel baskets. ANSYS is used to perform the conduction analysis using the models shown in Figure 4.4-6 for the PWR fuel basket and Figure 4.4-7 for the BWR fuel basket. The models include only radiation and conduction heat transfer. Radiation heat transfer is incorporated into the effective properties for the fuel assemblies and the neutron absorbers. Each fuel basket model takes into account the size of the cells in the basket – i.e., those cells formed directly by the fuel tube, and those cells formed by adjacent fuel tubes. The neutron poison is contained only on the inner surface of the basket tubes. The exterior tubes, which form the boundary of the downcomer region, may not have neutron absorbers on the adjacent surface of the interfacing fuel tubes. In the condition where the neutron absorber sheet is not required for criticality control, aluminum plates may be installed as an alternative to maintain thermal properties. The PWR and BWR fuel basket models evaluated in this section use the conductivity of the neutron poison defined in Chapter 8.

Additionally, it is conservatively assumed for both the PWR and BWR fuel baskets that a gap between the fuel tubes exists for the full length of the tube without any contact, as shown in Figure 4.4-6 and Figure 4.4-7. The gap between the fuel tubes is modeled as being 0.01 inch, and the conduction through the gap is based on the presence of either helium or water, depending on the condition.

The effective thermal conductivity (K_{eff}) of the fuel basket region in the radial direction is determined by considering the basket region as a solid cylinder with heat generation.

Considering the temperature at the center of the TSC to be T_{max}, the effective thermal conductivity (K_{eff}) is shown:

$$K_{eff} = \frac{Q}{4\pi H(T_{max} - T_o)} = \frac{Q}{4\pi H \Delta T} \quad [15]$$

where:

Q ---------- total heat generated by the fuel (Btu/hr)

H ---------- length of the active fuel region (in)
T_o ---------- boundary temperature of the basket
ΔT ---------- $T_{max} - T_o$ (°F)

The value of ΔT is obtained from thermal analysis using the two-dimensional models shown in Figure 4.4-6 and Figure 4.4-7, with the boundary temperature constrained to be T_o. The effective conductivity (K_{eff}) is then determined by using the stated expression. The analysis is repeated by applying different boundary temperatures so that temperature-dependent conductivities can be determined.

The effective properties for the DF basket assembly are determined using the same methodology as used for the standard PWR basket, except for the modification to the model, as listed.

1. A ¼-section model is used as shown in Figure 4.4-22.
2. The contents of the DFC locations in the DF basket assembly are conservatively modeled as helium, which has a lower conductivity.
3. Thermal conductivities of the steel plates forming the basket corner slot in the model are factored to reflect the actual plate thickness.

4.4.1.3 Two-Dimensional Fuel Assembly Models

The two-dimensional fuel assembly models include the fuel pellets, cladding, and the media occupying the space between fuel rods. The media is considered to be helium for storage conditions, and water or helium for transfer conditions. The two-dimensional finite element models of the fuel assemblies are used to determine the effective conductivities for the PWR and BWR fuel assemblies. The effective conductivities are used in the two-dimensional fuel basket models described in Section 4.4.1.2. For the PWR fuel assemblies, four separate types are considered: 14×14, 15×15, 16×16 and 17×17. For the BWR fuel assemblies, four separate types are considered: 7×7, 8×8, 9×9 and 10×10. For the BWR fuel assembly, a fuel channel is considered since it may be present and it will result in bounding fuel cladding temperatures. Therefore, it is only necessary to address a single fuel configuration for each of the fuel assembly types.

The two-dimensional fuel assembly models include the fuel pellets, cladding, media between fuel rods, media between the fuel rods and the inner surface of the fuel tube (PWR), or between the fuel rods and the inner surface of the fuel channel (BWR), and a gap between the fuel pellets and cladding. The media are considered to be helium for storage, and water or helium for transfer conditions. Modes of heat transfer modeled include conduction and radiation between individual fuel rods for the steady-state condition. ANSYS PLANE55 conduction elements and MATRIX50 radiation elements are used to model conduction and radiation. (Radiation is not considered for the water condition.) Radiation elements are defined between fuel rods and

between the fuel rods and the fuel tube (PWR) or the fuel channel (BWR). A typical PWR fuel assembly finite element model is shown in Figure 4.4-8, which corresponds to the 14×14 fuel assembly. The BWR fuel assembly model only considers the region up to the inner surface of the channel, and a typical BWR fuel assembly is shown in Figure 4.4-9, which corresponds to the 10×10 fuel assembly.

The effective conductivity for the fuel is determined by using an equation defined in a Sandia National Laboratory Report [15]. The equation is used 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 temperature at the center of the fuel is given by:

$$T_c = T_e + 0.29468\ (Qa^2 / K_{eff})$$

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 (Btu/hr-in-°F)

Volumetric heat generation (Btu/hr-in^3) based on the design heat load 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. Temperature-dependent effective properties are established by performing multiple analyses using different boundary temperatures. The effective conductivity in the axial direction and the effective density of the fuel assembly are calculated on the basis of the material area ratio. The effective specific heat is computed on the basis of a weighted mass average.

For the PWR fuel assemblies, the 14×14 fuel assembly is shown to have the effective properties that correspond to the minimum values, as shown in Table 4.4-1 for both fuel tube configurations, i.e., with and without neutron absorber.

For the BWR fuel assemblies, the 10×10 fuel assembly is shown to have the effective properties that correspond to the minimum values, as shown in Table 4.4-2.

4.4.1.4 Two-Dimensional Neutron Absorber Models

The two-dimensional neutron absorber model is used to calculate the effective conductivities of the neutron absorber, the neutron absorber retainer, and the fuel channel (for BWR only). These

effective conductivities are used in the two-dimensional fuel basket models (Section 4.4.1.2). A total of three neutron absorber models is required: one PWR model (for the PWR 14×14) and two BWR models—one with the neutron absorber plate and channel, and one with the channel but without the neutron absorber plate, corresponding to the enveloping configurations of the 10×10 BWR fuel assembly.

The configurations shown in the neutron absorber models in Figure 4.4-10 and Figure 4.4-11 for PWR and BWR fuel, respectively, incorporate the neutron absorber (and the channel for the BWR). The configuration shown in Figure 4.4-12 is for the BWR fuel tube with the channel, but without the neutron absorber.

As shown in Figure 4.4-10, the PWR fuel tube model includes the neutron absorber, the stainless steel retainer, and the gaps between the neutron absorber and the stainless steel retainer and the surface of the fuel tube. Two conditions of media are considered in the gaps: helium and water.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the model. The model consists of four layers of conduction elements and two sets of radiation elements (radiation elements are not used for the water condition) that are defined at the gaps (two for each gap). The thickness of the model (x-direction) is the distance measured from the outside surface of the stainless steel retainer to the inside surface of the fuel tube (assuming the neutron absorber is centered between the retainer and the fuel tube, and there is no contact for the length of the basket). The gap size between the neutron absorber and the adjacent surfaces is 0.002 inch.

The BWR fuel assemblies may include a fuel channel, as compared to the PWR assemblies, which have no fuel channel. Therefore, two effective conductivity models are necessary for the BWR: one model with the neutron absorber plate (a total of six layers of materials) and a fuel channel; and the other model with a fuel channel, but with a gap replacing the neutron absorber plate (a total of two layers of materials).

As shown in Figure 4.4-11, the first BWR neutron absorber model includes the fuel channel, the retainer, the neutron absorber and associated gaps. As shown in Figure 4.4-12, the second BWR neutron absorber model includes the fuel channel and the gap between the fuel channel and the fuel tube surface.

Heat flux is applied at the left side of the model (retainer for PWR model and fuel channel for BWR model), and the temperature at the right boundary of the model is specified. The heat flux is determined based on the design heat load. The maximum temperature of the model (at the left boundary) and the temperature difference (ΔT) across the model are calculated by the ANSYS model. The effective conductivity (K_{xx}) is determined using the following formula.

$$q = K_{xx} (A/L) \Delta T$$

or

$$K_{xx} = q \ L / (A \ \Delta T)$$

where:

K_{xx} ---------- effective conductivity (Btu/hr-in-°F) in X direction in Figure 4.4-10 through Figure 4.4-12

q ---------- heat rate (Btu/hr)
A ---------- area (in^2)
L ---------- length (thickness) of model (in)
ΔT ---------- temperature difference across the model (°F)

The temperature-dependent conductivity is determined by varying the temperature constraints at one boundary of the model and solving for the temperature difference. The effective conductivity for the parallel path (the Y direction in Figure 4.4-10) is calculated by the following.

$$K_{yy} = \frac{\sum K_i \, t_i}{L}$$

where:

K_i ---------- thermal conductivity of each layer (Btu/hr-in-°F)
t_i ---------- thickness of each layer (in)
L ---------- total length (thickness) of the model (in)

4.4.1.5 Two-Dimensional Transfer Cask and TSC Model for Operations Involving 24-Hour Cooling

During the transfer condition, the TSC in the transfer cask is subjected to four separate conditions.

- The water phase when the lid is being welded to the TSC.
- The drying phase during which helium is present while vacuum drying to remove moisture from the TSC and the annulus circulating water cooling system is operating.
- The helium backfilled phase when the TSC closure is completed and the transfer cask cooling water system is operating (24 hours of cooling).
- The operation of transferring the helium-backfilled TSC into the concrete cask with the transfer cask annulus circulating water cooling system drained.

In this section, analyses are performed to support the use of 24-hour cooling after the drying phase and prior to loading of the canister into the concrete cask. The use of the 24-hour cooling

permits the maximum time for the drying phase and the maximum time to transfer the canister into the concrete cask. Section 4.4.1.6 describes the evaluation of an alternate system drying operational cycle permitting the cool time to be minimized and the loading of the canister into the concrete cask to be limited to eight hours.

The first step is considered to be steady-state conditions for all heat loads. For vacuum drying operations, there is no time limit for the PWR basket with heat loads less than or equal to 25 kW, and no time limit for the BWR basket with heat loads less than or equal to 29 kW. The time in vacuum drying is administratively controlled for the PWR basket with heat loads greater than 25 kW, and for the BWR basket with heat loads greater than 29 kW, to ensure the maximum fuel cladding temperature is less than the allowable temperature. For high heat loads greater than 25 kW for the PWR basket and greater than 29 kW for the BWR basket, the 24-hour helium-backfilled phase is needed for both systems. The maximum time allowed for loading the helium-backfilled TSC into the concrete cask without operating the transfer cask annulus circulating water cooling system is determined by transient analyses. During the operational sequence of TSC loading, an Annulus Circulating Water cooling System (ACWS) may be used to flow water through the annulus to cool and maintain a specified temperature for the TSC external shell. Alternative cooling methods, such as reverse ACWS, or any other equivalent site-approved annulus cooling system or by fully submerging the TSC with the lid removed or the transfer cask annulus seals deflated, may also be used. The annulus cooling methods, when used, are designed to accommodate design basis heat loads without additional heat rejection from the transfer cask to the environment. The annulus cooling methods, i.e., ACWS and reverse ACWS, may be generically referred to as "ACWS" for discussion purposes.

Note that the MAGNASTOR transfer cask is provided in two configurations, MTC1 and MTC2. The main difference between these two configurations is the material used for the cask shells and shield door (carbon steel for MTC1 and stainless steel for MTC2). The thermal models described in the following sections consider carbon steel properties for the cask shells and shield door. Since the radial conductance of the cask body is governed by the NS-4-FR material, and the water or air in the annulus between the canister and the cask shells carries out the majority of the heat, the cask shell material has an insignificant effect on the TSC and its contents. Therefore, the thermal models are applicable to both the MTC1 and MTC2 configurations.

Evaluation of the Water Phase With Annulus Circulating Water Cooling System

The model that includes water in the TSC treats the entire cavity as though it is filled with water. Since it is necessary to remove some water from the TSC during the closure lid welding operation, the water level in the TSC may be below the top of the fuel basket. The fuel tubes are designed with holes in the sides to permit the water to flow from the center of the TSC to the downcomer region of the TSC. The two-dimensional axisymmetric transfer cask and TSC

models are used to evaluate the transfer operation for PWR fuels and BWR fuels. The components comprising the transfer cask and TSC model are shown in Figure 4.4-13 for the PWR configuration. The BWR model is identical to the PWR model except for a slight difference in the dimensions. The TSC portion of the model is identical to the model employed in Section 4.4.1.1, with the exception that one of the conditions in the transfer operations uses water in the TSC instead of helium. The model for the TSC, described in Section 4.4.1.1, uses effective properties for the fuel basket region. For the water condition, the methodology described in Sections 4.4.1.2, 4.4.1.3, and 4.4.1.4 is used to determine the effective properties for the fuel basket region. For the condition of water in the TSC, no contribution due to radiation was considered; only conduction was taken into account for the effective properties. The porous media constants for the fuel basket region need not be recomputed since they are dependent on the fuel assembly and fuel basket geometry only. However, during the analytical evaluation of the water phase, the pressure drop in the fuel basket region due to the water requires the use of the viscosity, which is input as a material property. Since the maximum water temperature in the TSC is significantly below 212°F, the water is expected to remain in the liquid state, and the use of properties for the liquid state is acceptable. The transfer cask and the water annulus between the transfer cask and the TSC are also included in the model. The transfer cask is represented by effective properties. The transfer cask wall is comprised of four different materials: 1) a carbon steel inner shell; 2) a lead gamma shield layer; 3) an NS-4-FR neutron absorber layer; and 4) a carbon steel outer shell. Effective thermal conductivity for the transfer cask in the radial direction treats the four different cask wall materials as being in series. The effective thermal conductivity for the transfer cask wall in the axial direction treats the four different cask wall materials as being in parallel. The model also contains the shield doors of the transfer cask. While the inlets to the transfer cask are tubes in the side walls of the transfer cask, they are included in the model as straight sections parallel to the annulus. The following conditions are applied to the model for the steady-state evaluation of the water phase with the annulus circulating water cooling system.

- The outer surfaces of the transfer cask are considered to be adiabatic and without the application of solar insolance.
- The inlet water temperature for the annulus between the TSC and the transfer cask is specified to be 100°F.
- The driving force for the water flow in the annulus between the TSC and the transfer cask is natural convection. Water is supplied to the annulus inlets by an annulus circulating water cooling system.
- The heat generation internal to the TSC is modeled as 15, 20, 25, 30 and 35.5 kW for PWR fuels. The heat loads in Zones A, B and C, as defined in Figure 4.1-1, are factored based on the heat load for heat loads other than 35.5 kW. For the heat load of 35.5kW, the heat loads in Zones A, B and C are 0.922 kW, 1.20 kW and 0.80 kW, respectively.

The heat generation internal to the TSC is modeled as 15, 20, 25, 30 and 33 kW for BWR fuels with a uniform heat distribution.

- The flow in the TSC and in the annulus region is treated as being laminar for both the water and helium conditions of the TSC.
- Radiation heat transfer is removed from the solution.

[redacted]

Evaluation of the Drying Phase-Vacuum Drying System

A Vacuum Drying System (VDS) is used to evacuate and dry the TSC cavity by vaporization and removal of the water vapor and other gases from the cavity through the vent and drain port openings. During the vacuum drying phase, convection is not considered in the TSC cavity region. Conduction helium properties are utilized during the low-pressure drying process [27].

The transfer cask model used for the thermal transient analysis is comprised of a three-dimensional ANSYS model, as shown in Figure 4.4-16 and Figure 4.4-17 for PWR fuel and Figure 4.4-18 and Figure 4.4-19 for BWR fuel. During the vacuum drying phase, the annulus circulating water cooling system is a normal operating system that allows the heat from the TSC to be rejected in the same manner as for the water phase. The transfer cask annulus circulating water cooling system is an operational convenience and not a safety-related system, since the transfer cask can be submerged in the spent fuel pool (with the annulus seals deflated) at any point in time during the vacuum drying operation without resulting in thermal shock to the transfer cask system. The temperature profile on the TSC outer diameter from the water phase analysis is applied to the TSC surface for each heat load.

Effective properties for the PWR and BWR fuel regions, the neutron absorber, and the helium inside the TSC are employed, and they are described in Sections 4.4.1.3 and 4.4.1.4, respectively. These two models are used to determine the allowable time in vacuum, depending on the heat load, to ensure that the fuel cladding temperature limit of 752°F (400°C) is not exceeded. [redacted]

Transient analyses are performed to determine the maximum system temperature following the backfill helium condition for heat loads greater than 25 kW for PWR fuel and greater than 29 kW for BWR fuel. Analyses are performed for the 35.5 kW PWR and the 33 kW BWR design basis heat loads using the same two-dimensional FLUENT model used for analysis of the water phase condition with modified material properties and boundary conditions. The initial temperature field of the transient evaluation to simulate the helium backfill condition is obtained from the analysis results at the end of the vacuum drying process (ANSYS results) for the respective heat load.

The FLUENT model used to analyze the cooldown transient defines the locations at which initial temperatures are required from the ANSYS results. For each node in the FLUENT model, there are eight node points in the circumferential direction in the ANSYS 45-degree symmetry model to compute the average temperature for the respective locations. The ANSYS model employs linear temperature shape functions across each element, so that interpolation between nodes and within an element provides temperatures that are consistent with the nodal temperature in the ANSYS results. The peak temperatures, which occur at the center line of the model, are transferred to the respective FLUENT node locations as initial temperatures in order to provide an upper bounding initial condition, conserving system heat provided to the FLUENT model.

The design basis heat load provides bounding temperatures and minimum times for vacuum and the longest time for helium cooling when needed. With the identification of the temperature after the backfill condition, the time in vacuum for the potential cooling cycles can be determined, since the temperature time history will follow the same time dependency as for the initial vacuum condition.

The system thermal transient history may be represented by an initial vacuum drying cycle followed by a postulated system cooling cycle of 24 hours, followed by a second system vacuum drying cycle that is followed by a second 24-hour cooling period preceding the TSC transfer to the concrete cask. It is noted that the 24-hour cooling period returns the system to a steady-state condition for the design basis heat load, providing a bounding operating cycle for all heat loads less than the design basis. Similarly, cooling the system for a period of 24 hours provides maximum TSC transfer time from the transfer cask to the concrete cask when the water is drained from the annulus cooling system. Additional analyses defining system response to these conditions are addressed in the following discussions.

Mesh Sensitivity Evaluation

The vacuum drying operation uses a three-dimensional ANSYS model to determine the thermal response of the fuel, shown in Figure 4.4-16 and Figure 4.4-18 for PWR and BWR fuel, respectively. Sensitivity of the mesh density is performed for the PWR design basis heat load of 35.5 kW. The finite element model uses an ANSYS element with a linear shape function for calculating the temperature within each element and uses a minimum of six elements in the fuel assembly cross-section plane. Temperature variation in the fuel region is expected to be parabolic since the heat generation is constant within any specified axial cross-section. Using a minimum of six elements permits development of an analytical parabolic distribution. To confirm the adequacy of the mesh density for the axial divisions, the number of elements in the basket region shown in Figure 4.4-16 was doubled, and the transient condition using design basis heat was rerun. The maximum fuel clad temperature was determined to be 1°F less than the

temperature for the solution with one-half the element density. The results from this mesh sensitivity evaluation validate that the maximum fuel temperature is relatively insensitive to mesh refinement in the fuel region.

Evaluation of the Helium Phase With Annulus Circulating Water Cooling System

Following the completion of vacuum drying and final cavity evacuation, the TSC is backfilled and pressurized with a measured mass of helium per the Technical Specifications to establish the cavity atmosphere for the normal condition of storage. The transfer cask and TSC remain in this helium phase condition until the TSC is placed into the concrete cask. During the helium phase, the transfer cask annulus cooling system will be used until the TSC preparations for transfer to the concrete cask are completed. Steady-state analyses for heat loads of 15, 20, 25, 30 and 35.5 kW for PWR fuel, and with heat loads of 15, 20, 25, 30 and 33 kW for BWR fuel, are performed using the model for the helium phase. The evaluation of this condition is performed to determine the initial condition for the operation in which the TSC is placed into the concrete cask with the transfer cask annulus cooling system drained.

[redacted]

[redacted]

Evaluation of Moving the TSC into the Concrete Cask

The transfer cask is used to load the TSC into the concrete cask. During this phase, there is no active auxiliary annulus cooling of the transfer cask, i.e. annulus cooling water system disconnected from the transfer cask, seals deflated, and annulus water drained. The transfer cask annulus is filled with ambient air, which is allowed to flow in through the reduced annulus inlet. This operation is time-limited to control the fuel cladding temperature to less than 752°F (400°C). The thermal performance of the transfer cask in this operation is evaluated for four transient conditions. Two transient conditions are for the PWR fuels with heat loads of 25 kW and 35.5kW, and two cases are for the BWR fuels with heat loads of 25 kW and 33 kW. The initial conditions for the four transient analyses are obtained from the steady-state analyses with water in the transfer cask annulus described previously in the section titled "Evaluation of the Helium Phase with Annulus Circulating Water Cooling System" for the corresponding heat load.

[redacted]

4.4.1.6 Two-Dimensional Transfer Cask and TSC Model for Operations Involving Minimum Cooling Time and a Loading Time of Eight Hours

Operational experience can lead to enhancement in the draining, vacuum drying and welding operations to minimize the need for maximum times for drying and loading operations or the potential need for cycles in the vacuum drying phase. Operational experience will reduce loading times and reduce staff radiation exposure. The following discussion presents the operational controls to be implemented.

Even with the absence of additional cycles for vacuum drying or the use of the 24-hour cool time, the TSC in the transfer cask is still subjected to four separate operational boundary conditions.

- The water phase when the lid is being welded to the TSC.
- The drying phase during which helium is present while vacuum drying to remove moisture from the TSC.
- The helium-backfilled phase is minimized to seven hours or less. It is during this time that the TSC port covers are welded and the transfer cask annulus circulating water cooling system (or equivalent) is operating, or the TSC is submerged in the spent fuel pool (with the annulus seals deflated).
- The eight hours for the operation of transferring the helium-backfilled TSC into the concrete cask with the transfer cask annulus circulating water cooling system drained.

Regardless of the time in the vacuum drying or loading operation, the response of the TSC and transfer cask in the water phase (inside the TSC) is not affected. With cooling water in the annulus, the time to remain in this condition is not altered from the system analyses or results reported in Section 4.4.1.5 for the water phase.

Without the additional cool time (of 24 hours), the initial temperatures of the TSC and fuel are significantly increased upon entering the loading phase (where the water in the annulus is drained and replaced by air). Reducing the time in the vacuum phase, as compared to the times shown in Table 4.4-9 (PWR) and Table 4.4-10 (BWR), the temperatures at the start of the condition leading to the transfer of the TSC to the concrete cask can be reduced to a level that allows eight hours for the transfer loading time.

To determine the vacuum and cool time limits, the models and their results described in Section 4.4.1.5 are used. The temperature time histories computed for the heat loads identified in Table 4.4-9 (PWR) and Table 4.4-10 (BWR) are used to identify the maximum fuel clad temperatures at the end of the reduced vacuum times for the individual heat loads. The transient analyses for the condition of the helium backfill, in conjunction with water in the annulus as described in Section 4.4.1.5, identify the temperature increase expected for the fuel clad for the range of heat loads upon backfilling the TSC with helium. Analyses in Section 4.4.1.5 identify that the maximum increase in the temperature of the fuel for the bounding PWR and BWR heat loads is 44°F and 34°F, respectively. The 44°F PWR increase and the 34°F BWR increase correspond to the design basis heat load bound the temperature for all other heat loads of the PWR or BWR fuel assemblies. The maximum temperature increase is conservatively added to the maximum fuel clad temperature occurring at the end of the reduced time in vacuum. This temperature is used to confirm that an additional eight hours for the TSC in the transfer cask with air in the annulus is equal to, or less than, the maximum fuel clad temperatures determined in Section 4.4.1.5.

Evaluation of TSC Loaded with DF Basket Assembly

The flow resistance for a single zone DF basket assembly is slightly lower than the flow resistance for the standard PWR basket. The thicker side plates forming the basket corner slots for the damaged fuel can enhance the basket assembly conductance in the basket axial direction. Therefore, the thermal analysis results for the standard PWR basket bound the results for the DF basket assembly, as demonstrated by three representative analyses performed for the DF basket assembly for the transfer condition. Maximum fuel temperatures for all three analyses for the DF basket assembly are lower than those for the standard PWR basket. The three analyses are: 1) For the water phase, the 35.5 kW steady-state case (FLUENT CFD analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell; 2) For the drying phase, the 25 kW steady-state case (ANSYS analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell; 3) For the drying phase, the 35.5 kW transient case (ANSYS analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell. Cases with helium inside the canister are selected because they yield higher fuel temperatures than cases with water inside the canister.

Evaluation of TSC Loaded with PWR Minimum Reduced Cool Time Fuel Basket Assembly

The PWR minimum reduced cool time fuel basket assembly loads the four (4) hottest fuel of 1.8kW at the outer zone of the basket (Zone C, Figure 4.1-2), in addition to all center nine (9) fuels with low heat loads of 513Watts. This loading pattern significantly removes the heat from the basket center, consequently, reduces the maximum fuel temperature, compared with the maximum fuel temperature for the standard PWR basket assembly with the same total heat load. Therefore, the thermal analysis results for the standard PWR basket bound the results for the PWR minimum reduced cool time fuel basket assembly, as demonstrated by the analysis performed for the PWR minimum reduced cool time fuel basket assembly for the vacuum drying condition. The transient analysis (ANSYS analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell is performed for the same duration (24 hours) of vacuum drying and same heat load (35.5kW) for the PWR minimum reduced cool time fuel basket assembly as for the standard PWR basket assembly. The maximum fuel temperature for the vacuum transient analysis is 630°F or 10°F lower than the standard PWR basket assembly at the end of 24 hour vacuum drying of 640°F (Table 4.4-9). The vacuum transient analysis for the canister is selected because it yields higher fuel temperatures than the steady state analyses with helium (with convection) or water inside the

canister for the same heat load. The reduction in the maximum temperature is expected since the maximum heat load is removed from the center of the basket.

4.4.1.7 Two-Dimensional Transfer Cask and TSC Model for Increased Loading Times of PWR 20 kW and 25kW Heat Loads

Reduced heat loads can minimize the requirement for TSC cooling prior to the operation of transferring the helium-backfilled TSC into the concrete cask with the transfer cask ACWS drained.

Regardless of the heat load, the TSC in the transfer cask is still subjected to four separate operational boundary conditions.

- The water phase when the lid is being welded to the TSC. The ACWS or the site equivalent is active during this phase.
- The drying phase during which helium is present while vacuum drying to remove moisture from the TSC. For the 20kW heat load, the vacuum time is unlimited (Table 4.4-9). For 25 kW, the vacuum time is limited to 50 hours to reduce the fuel clad temperature at the vacuum condition (Table 4.4-16). The ACWS or the site equivalent is active during this phase.
- The helium-backfilled phase is minimized so that for 20 kW, there is no additional cooling time, and for the 25 kW heat load, the cooling time is limited to a minimum of seven hours. It is during this time that the TSC port covers are welded and the transfer cask ACWS or site equivalent is operating.
- Transferring the helium-backfilled TSC into the concrete cask with the transfer cask ACWS drained.

To determine the cool time limits, the PWR TSC/transfer cask model described in Section 4.4.1.5 is used. Due to the minimum 20 kW heat load, the transfer cask model with air in the annulus was solved as a steady state problem. For this solution, there was no additional time with the TSC backfilled with helium and the operating ACWS.

Using the PWR TSC/transfer cask model described in Section 4.4.1.5, a transient evaluation is performed using an initial cooling period of 7 hours. During this 7 hour period the ACWS or its site equivalent is operated to reduce the fuel clad temperature prior to the transfer condition. After the 7 hours of cooling, the water in the annulus between the TSC and the transfer cask is replaced with air. During the transfer phase of the TSC into the concrete cask, air is allowed to flow up through the annulus. The transient is continued until the fuel clad temperature reaches 730°F.

4.4.2 Test Model

MAGNASTOR is conservatively designed by analysis. Therefore, no physical model is employed for thermal analysis. The benchmark provided in Section 4.8.1 provides confirmation that the analysis methodology employed for the MAGNASTOR design is conservative.

4.4.3 Maximum Temperatures for PWR and BWR Fuel Configurations

Normal Conditions of Storage

The temperature distributions and maximum component temperatures for MAGNASTOR for normal conditions of storage are provided in this section. System components of the CC1/CC2 concrete cask containing a PWR and BWR TSC and the CC3 concrete cask containing a PWR TSC are addressed separately. The temperature distributions in the CC1/CC2 concrete cask containing the BWR TSC are similar to those of the same system with the PWR TSC and are, therefore, not presented.

The temperature distribution in the CC1/CC2 concrete cask and the TSC containing the PWR design basis fuel (uniform heat load) for normal conditions of storage is shown in Figure 4.4-14. The air velocity distribution in the annulus between the TSC and the concrete cask liner for the normal conditions of storage for PWR fuel for the CC1/CC2 configuration is shown in Figure 4.4-15. The maximum component temperatures for the normal conditions of storage are summarized in Table 4.4-3. Note that the bounding temperatures from CC1/CC2 and CC3 analyses are conservatively used as the maximum component temperatures for the CC4 configuration. It is noted that these system thermal performance results are based on an average annual ambient temperature of 76°F at sea level pressure and standard air density properties. Site-specific conditions are to be evaluated to assure thermal margins are maintained for steady-state storage conditions at the intended MAGNASTOR ISFSI site.

As shown in Figure 4.4-14, the peak fuel temperature for the normal storage condition occurs near the top of the fuel basket and, based on the uniform spacing of the isotherms at the centerline of the TSC, the temperature varies monotonically from the TSC bottom to the peak near the top of the fuel basket. This is indicative that the dominant mode of heat rejection from the fuel is by convection due to the helium flow circulating within the TSC.

The calculated temperatures at the TSC surface for the normal storage condition are higher than the concrete liner or surface, indicating that radiation heat transfer occurs across the concrete cask to TSC annulus.

To confirm that the concrete cask heat removal system is operable, one of the following two surveillance options with a frequency of 24 hours is required: (1) Visually verify all concrete

cask air inlet and outlet screens are free of blockage; (2) Verify the difference between the concrete cask air outlet average temperature and the ambient temperature is less than 119°F, 127°F, 134°F and 119°F for the concrete cask configuration CC1/CC2-PWR, CC1/CC2-BWR, CC3-PWR and CC4-PWR, respectively. The allowable temperature differences are determined based on the maximum calculated temperature difference between air outlet and ambient and the calculated minimum temperature margin for concrete and fuel temperatures for all normal and off-normal conditions.

Normal Conditions of Storage – PWR Configuration with DF Basket Assembly

The thermal evaluation for the concrete cask loaded with a TSC containing a DF basket assembly in storage conditions is performed based on configuration CC3 using the two-dimensional axisymmetric FLUENT CFD models described in Section 4.4.1.1. Three cases are considered:

Case 1: The active fuel region is modeled as a single porous zone with a single lumped resistance coefficient. The uniform loading heat generation rate (based on a total heat load of 35.5 kW) is applied to the active fuel region. The calculated maximum fuel temperature is 704°F.

Case 2: The active fuel region is modeled as two parallel porous zones radially, with a resistance coefficient for the outer zone of 16 basket slots (which include the four damaged fuel can slots) and a separate resistance coefficient for the inner zone of 21 basket slots. The uniform loading heat generation rate is applied to the active fuel region. The calculated maximum fuel temperature is 707°F.

Case 3: The active fuel region is modeled the same way as in Case 2. The uniform loading heat generation rate is considered for the standard fuel assemblies. The decay heat is considered to be concentrated at the lower 103 inches of the active fuel region based on a 50% compaction ratio of debris for the four damaged fuel can slots. The calculated maximum fuel temperature is 709°F.

The maximum fuel temperatures from the Case 1 through Case 3 analyses are lower than the maximum fuel temperature (718°F) for the corresponding standard PWR basket, as shown in Table 4.4-3. Therefore the standard PWR basket analyses bound those for the DF basket assembly.

Normal Conditions of Storage – PWR Minimum Reduced Cool Time Fuel Basket Assembly

The thermal evaluation for the concrete cask loaded with a TSC containing the PWR minimum reduced cool time fuel basket assembly for normal storage condition is performed based on configuration CC3 using the modified two-dimensional axisymmetric FLUENT CFD model described in Section 4.4.1.1. The model used for the analysis of the TSC containing PWR minimum reduced cool time fuel basket assembly for normal storage conditions is identical to the model described in Section 4.4.1.1, except for the re-meshed basket zones in the basket radial direction to match locations of the heat generation due to the preferential loading.

The maximum fuel temperature of the analysis is 698°F, 20°F lower than the maximum fuel temperature (718°F) for the corresponding standard PWR basket, as shown in Table 4.4-3. The maximum temperature for the fuel heat load in Figure 4.1-2 is lower since the maximum fuel heat load is no longer at the center of the basket. Therefore the standard PWR basket analyses bound those for the PWR minimum reduced cool time fuel basket assembly.

Transfer Condition for 24-Hour Cooling and Multiple Vacuum Drying Cycles

The maximum component temperatures for MAGNASTOR during the transfer operation are reported in this section for operational procedures using 24 hours of cooling. The transfer operation is comprised of four separate phases: the water phase, the drying phase, the helium phase, and the TSC transfer phase. The water phase and the helium phase are not time limited due to the normal use of the transfer cask annulus cooling water system (ACWS), reverse ACWS, or site-approved ACWS equivalent. The transfer cask annulus cooling system is an operational convenience and not a safety-related system, since the transfer cask can be fully submerged (with the annulus seals deflated) in the spent fuel pool at any point in time during the transfer operation without resulting in thermal shock to the transfer cask system. The annulus cooling system maintains the TSC shell at a temperature significantly lower than the temperature corresponding to the normal conditions of storage. The maximum temperatures for the water phase are listed in Table 4.4-5 and Table 4.4-6 for PWR fuel and BWR fuel, respectively. The maximum temperatures for the helium phase are listed in Table 4.4-7 and Table 4.4-8 for PWR fuel and BWR fuel, respectively. Using the reverse ACWS model described in Section 4.4.1.5, [redacted] method. Table 4.4-9 and Table 4.4-10 present times for the vacuum drying for heat loads greater than 25 kW for PWR fuel and

greater than 29 kW for BWR fuel that are administratively controlled to maintain the fuel cladding temperature below the 752°F limit.

If additional vacuum drying is required for heat loads requiring administrative controls to meet the specified cavity dryness criteria, additional drying cycles can be performed following 24 hours of cooling the TSC, either with the annulus cooling water system or by returning the transfer cask and TSC to the spent fuel pool. Table 4.4-11 and Table 4.4-12 show the second vacuum time and maximum fuel temperatures at the end of the duration for PWR fuel and BWR fuel, respectively. Note that the PWR fuel cladding temperatures shown in Table 4.4-5, 4.4-7, and 4.4-9 are bounded by the PWR fuel cladding temperatures for the normal storage steady-state conditions in Table 4.4-3. Therefore, the normal condition design bases PWR heat load fuel cladding and component temperatures, such as for the fuel basket (including damaged fuel cans, as applicable) and the TSC, bound the maximum temperatures for any phase of the transfer condition for the fuel basket and TSC components.

The time for TSC transfer to the concrete cask is administratively limited to ensure that the maximum fuel cladding temperature is bounded by the design bases heat load normal condition storage temperature. Table 4.4-13 and Table 4.4-14 show the duration and the maximum fuel temperature at the end of the TSC placement in the concrete cask for both PWR fuel and BWR fuel, respectively. The time duration for the transfer operation is determined by modeling the water material properties in the annulus as air, as described in Section 4.4.1.5.

[redacted]

The off-normal condition for use of the annulus cooling system corresponds to loss of cooling by the ACWS, or equivalent site-approved annulus cooling system. This can occur during the water phase or the drying phase of transfer operations.

[redacted]

[redacted]

In the event of loss of cooling occurring during the vacuum drying phase, the TSC is first backfilled with 75 psig (+10, -0 psi) helium, and is then returned to the pool, where it is cooled for a minimum of 24 hours prior to continuing vacuum drying operations.

The loading procedures in Chapter 9 provide normal operational loading sequences. The MAGNASTOR System Operating Manual prepared in accordance with the FSAR analyses provides cask loading and unloading sequence alternatives, including time limitations for all evaluated loss of cooling and off-normal conditions. [redacted] These operational sequences, time limits and corrective actions will ensure that the fuel cladding and system component temperatures do not exceed design allowable values.

Transfer Condition for Minimum Cooling Time and Eight Hours of Canister Transfer

The maximum component temperatures for MAGNASTOR during the transfer operation are reported in this section for operational procedures using the minimum cooling time and eight hours of TSC transfer time (as determined by the evaluation in Section 4.4.1.6). The transfer operation is comprised of four separate phases: the water phase, the drying phase (reduced time as compared to the evaluations in Section 4.4.1.5), the helium phase (minimized cooling time), and the TSC transfer phase (limited to eight hours). The water phase and the helium phase permit indefinite time due to the normal use of the transfer cask annulus cooling system, or an equivalent cooling system. The annulus cooling system maintains the TSC shell at a temperature

significantly lower than the temperature corresponding to the normal conditions of storage. The maximum temperatures for the water phase are listed in Table 4.4-5 and Table 4.4-6 for PWR fuel and BWR fuel, respectively.

Heat load-dependent vacuum drying times reported in Table 4.4-9 and Table 4.4-10 confirm that for the same heat loads, the PWR fuel clad temperatures bound the BWR fuel clad temperatures. The temperatures reported in Table 4.4-16 and Table 4.4-17 are for the maximum PWR and BWR clad temperatures, respectively, at the end of the reduced vacuum time, the reduced cool time, and the eight hours of transfer time. These results confirm that the maximum clad temperatures have significant margin relative to the 752°F fuel clad temperature limit.

For system operations that are outside the sequence presented in Table 4.4-16 or Table 4.4-17, as a result of equipment failure or some other event that extends drying and transfer operations, additional vacuum drying, helium cooling, and/or transfer times will be implemented in accordance with the actions described in the preceding section, "Transfer Condition for 24-Hour Cooling and Multiple Vacuum Drying Cycles."

Maximum TSC Transfer Temperatures for PWR 20 kW (no additional cooling) and 25kW Heat Loads with 7 hours of cooling

[redacted]

4.4.4 Maximum Internal Pressures for PWR and BWR TSCs

The maximum TSC internal operating pressures for normal conditions of storage are calculated in the following sections for the TSCs containing PWR and BWR design basis fuel assemblies.

Maximum Internal Pressure for the TSC Containing PWR Fuel

The internal pressure of a TSC containing PWR fuel assemblies is a function of fuel type, burnup, initial enrichment, cool time, fuel condition (failure fraction), presence or absence of nonfuel hardware, TSC length, and the backfill gases in the TSC. Gases included in the pressure evaluation of a TSC containing PWR fuel include fuel rod fission, decay, backfill gases and integral fuel burnable absorber (IFBA) generated gas, gas generated by the nonfuel hardware components (assembly control components contain boron as the absorber material), and TSC backfill gases. Each of the PWR fuel types is separately evaluated to determine a bounding pressure for a TSC containing PWR fuel assemblies. Evaluations are performed for all contents in the standard basket (undamaged fuel) and in the damaged fuel basket configuration. The damaged fuel basket represents a bounding configuration due to the additional volume displacement by the thicker corner weldment plates and the presence of the DFC canisters themselves.

Fission gases include all fuel material generated gases, including helium generated by long-term actinide decay. Based on detailed SAS2H calculations, the quantity of fission and decay gases rises as burnup and cool time are increased and enrichment is decreased. The maximum gas available for release is calculated based on 70,000 MWd/MTU burnup cases at an enrichment of 1.9 wt % ^{235}U and a cool time of 40 years for maximum fissile material assemblies in each major PWR fuel class. For other PWR fuel assembly types, fission and decay gases are determined by ratioing the fissile material mass to the maximum fissile material mass assemblies.

Fuel rod backfill pressure varies significantly among the PWR fuel types. Based on a literature review, a 500 psig backfill is assigned to Westinghouse and CE core fuel types. A maximum backfill pressure of 435 psig is assigned to B&W core assemblies. Backfill gas quantities are based on the fresh fuel free volume between the fuel pellet stack and the fuel rod cladding, including the plenum volume, and a backfill temperature of 68°F.

Burnable poison rod assemblies (BPRAs) placed within the TSC may contribute additional gas quantities due to n-alpha reaction of ^{10}B during in-core operation. A portion of the neutron poison population is formed by ^{10}B. Other neutron poisons, such as gadolinium and erbium, do not produce a significant amount of helium nuclides (alpha particles). BPRAs in this section is a general term used to describe a range of absorbers including, but not necessarily limited to,

Westinghouse Pyrex (borosilicate glass) BPRAs and WABA (wet annular burnable absorber) configurations, as well as B&W BPRAs and shim rods used in CE cores. The CE shim rods replace standard fuel rods to form a complete assembly array. The quantity of helium available for release from the BPRAs is directly related to the initial boron content of the fuel rods and the release fraction of gas from the matrix material. The gas released from either of the low-temperature, solid matrix BPRA materials is likely to be limited, but no release fractions were available in open literature. Consequently, a 100% release fraction is applied. Initial boron content in the Westinghouse and B&W BPRAs is based on a uniform absorber concentration of 0.0063 g/cm ^{10}B. The maximum number of poison rods is 16 for Westinghouse 14×14 fuel assemblies, 20 for Westinghouse and B&W 15×15 fuel assemblies, and 24 for Westinghouse and B&W 17×17 fuel assemblies. The length of the absorber rods is conservatively taken as the active fuel length. CE core shim rods are modeled at 0.0126 g/cm ^{10}B for 16, 12, and 12 rods applied to CE-manufactured 14×14, 15×15, and 16×16 fuel assemblies, respectively.

Fuel rods may contain integral fuel burnable absorbers (IFBAs). The absorber is typically zirconium diboride and, as such, will generate helium gas as part of the neutron capture process. IFBA assemblies are generally used as an alternative or augmentation to BPRA use. The IFBA loading employed in the pressure analysis is based on NUREG-6760 as 2.355 mg ^{10}B/inch in 156 rods. To bound the presence of both BPRA and IFBA materials in a fuel assembly, when loaded, the cask pressure calculations assume a design basis IFBA loading in the fuel assembly with a design basis BPRA inserted into the assembly guide tubes prior to loading into the storage system. Rather than accounting for the IFBA rods as an individual component, the pressure calculations double the BPRA gases for non-CE fuel assembly types (bound the combined inventory of IFBA and BPRA based on linear loading and number of rods affected).

Under normal operating conditions, the helium backfill for a TSC containing PWR fuel assemblies is at a maximum average gas temperature of 465°F and a pressure of 103 psig. Nominal helium densities for both PWR and BWR fuel types are shown in Table 4.4-4. Maximum system backfill pressure at operating conditions is set by the use of the operating procedures documented in Chapter 9. This approach ensures that an acceptable helium density is established in the canister prior to sealing. Free volumes inside the two classes of TSCs containing PWR fuel are 9,900 and 10,300 liters for TSCs containing the undamaged fuel basket and 9,600 liters for the TSCs containing the damaged fuel basket. The free volumes do not include PWR fuel assembly and nonfuel hardware components, since these vary for each assembly type, but do account for axial spacers and DFC displaced volume in the case of the damaged fuel basket. The free volume of the TSC is obtained by subtracting the assembly volume. The assembly volume includes the fuel skeleton, fuel rods and nonfuel hardware. For

the Westinghouse BPRAs, the Pyrex volume is employed since it displaces more volume than the WABA rods.

The TSC internal pressure is determined by summing the partial pressures of the TSC helium backfill gas and the released gases from the fuel and the poison rods. The partial pressure due to the fuel and neutron poison rod gases is determined by the ideal gas correlation (PV=nRT) and the applicable rod release fractions and failure rates. For normal conditions, a 1% rod failure fraction is applied. For failed fuel rods, the releasable molar quantity of the fission and actinide decay gas is 30%, with 100% of the rod backfill gas being released. The normal condition average temperature of the gases released from the fuel rods and neutron poison inserts is conservatively set to 485°F (525 K) in the partial pressure calculation.

The TSC is evaluated for normal condition pressure for each of the PWR fuel types, with insert. The maximum normal condition pressure for a TSC containing PWR fuel assemblies is 104 psig. At a 1% rod failure fraction, the quantity of gas released from the fuel and neutron poison rods is minimal, resulting in no significant effect on system pressure.

The calculated maximum pressure of 104 psig allows for a 6 psig tolerance on the TSC helium backfill prior to reaching the 110 psig system pressure used in the Chapter 3 normal condition structural evaluations. Significantly higher pressure margins exist in the off-normal and accident pressures. Off-normal and accident pressures were calculated at 119 psig (10% fuel failure and off-normal thermal conditions) and 226 psig (100% fuel failure, see Section 4.6.4), and these calculated values are significantly lower than the established pressure limits of 130 psig for off-normal and 250 psig for accident condition pressures that are used in the structural calculations.

Maximum Internal Pressure for the TSC Containing BWR Fuel

Maximum internal pressures are determined for the BWR fuel in the same manner as those documented for the TSC containing PWR fuel. Primary differences for the BWR evaluations, versus those for the PWR, include a rod backfill gas pressure of 132 psig, a maximum burnup of 60,000 MWd/MTU used to generate fission gases, and the absence of neutron poison gases (no nonfuel hardware in the BWR system). The 132 psig rod backfill pressure used in this analysis is significantly higher than the 6 atmosphere (g) maximum pressure reported in open literature. Free volumes, without fuel assemblies, in the TSC containing BWR fuel types are 9,900 and 10,300 liters.

A bounding normal condition average temperature of 525 K is used for the partial pressure analysis of the fuel rod gases. The maximum normal condition pressure for a TSC containing BWR fuel is 104 psig.

The calculated maximum pressure of 104 psig allows for a 6 psig tolerance on the TSC helium backfill prior to reaching the 110 psig system pressure employed in the Chapter 3 normal

condition structural evaluations. Significantly higher pressure margins exist in the off-normal and accident pressures. Off-normal and accident pressures were calculated at 112 psig (10% fuel failure and off-normal thermal conditions) and 159 psig (100% fuel failure, see Section 4.6.4) and are conservatively bounded by the 130 psig off-normal and 250 psig accident condition pressures that were employed in the structural calculations.

TSC Backfill Helium Tolerances

Due to measurement and instrument uncertainties in the canister backfill operation, a range of allowed helium backfill density (g/liter) is determined in this section.

Any increase in backfill density is limited by the associated rise in pressure, which in turn is limited to the structural analysis inputs (110 psig for the limiting normal condition). As documented in the pressure evaluations, a 6 psi tolerance is acceptable prior to reaching system pressures employed in the structural analysis. Assuming a constant temperature, which is conservative as increased backfill density would enhance heat transfer and increase system pressure, and applying the ideal gas law make backfill density directly proportional to pressure. Relying on a 6 psi tolerance on a nominal pressure of 104 psig (119 psia) allows for a 5% increase in backfill density.

A decrease in backfill density is limited by thermal constraints. Lower helium density reduces convective heat capability of the system and, thereby, raises fuel clad temperature. Thermal analysis in Section 4.4.1.1 states that a 10% decrease in backfill density is acceptable while remaining below the maximum allowed clad temperature limit of 752°F.

Table 4.4-4 lists the pressure and temperature limited upper and lower bound helium backfill densities.

Figure 4.4-1 Two-Dimensional Model of Concrete Cask Loaded with PWR TSC

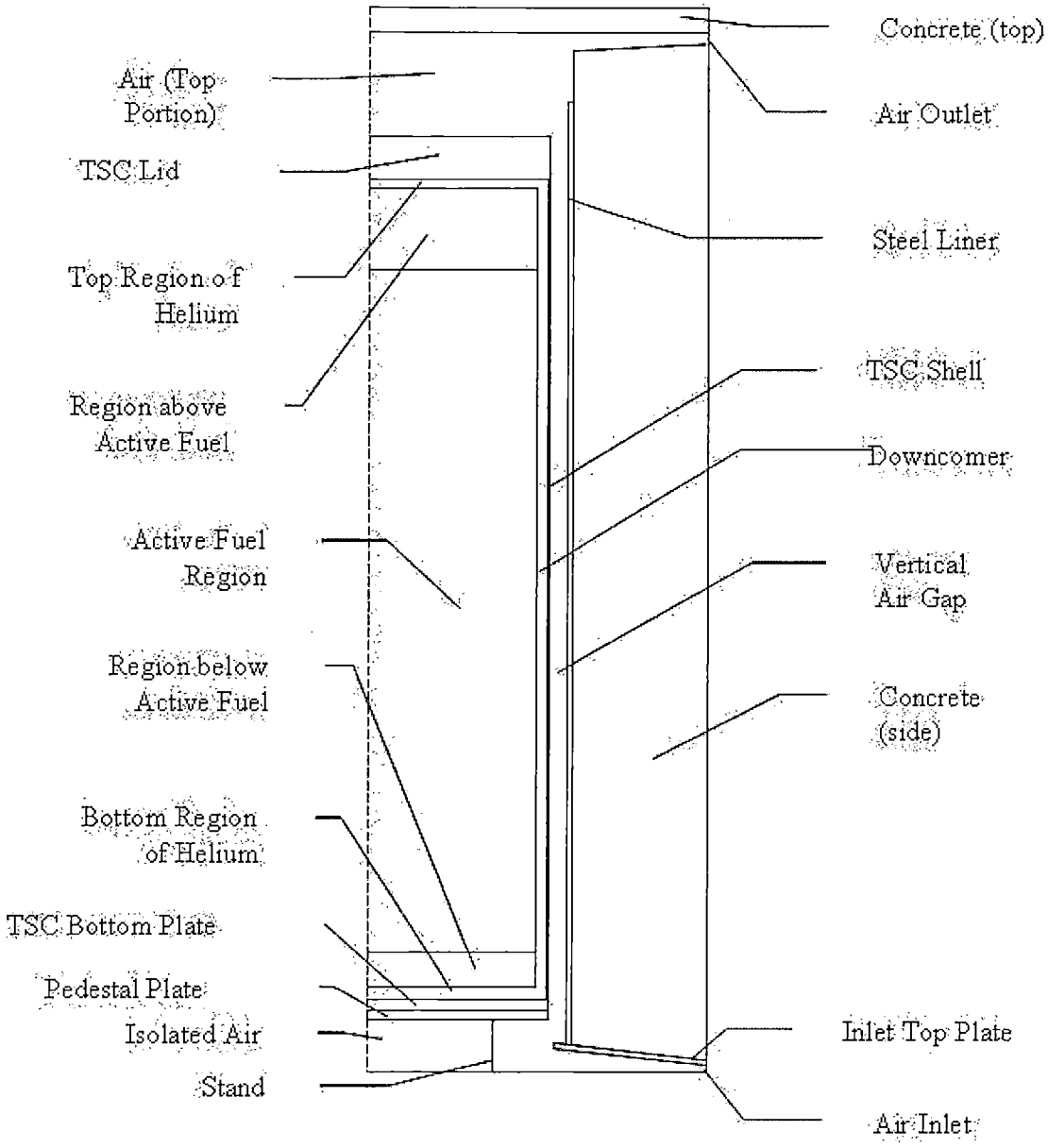


Figure 4.4-2 Computational Mesh for the Two-Dimensional Axisymmetric CFD Model of the Concrete Cask

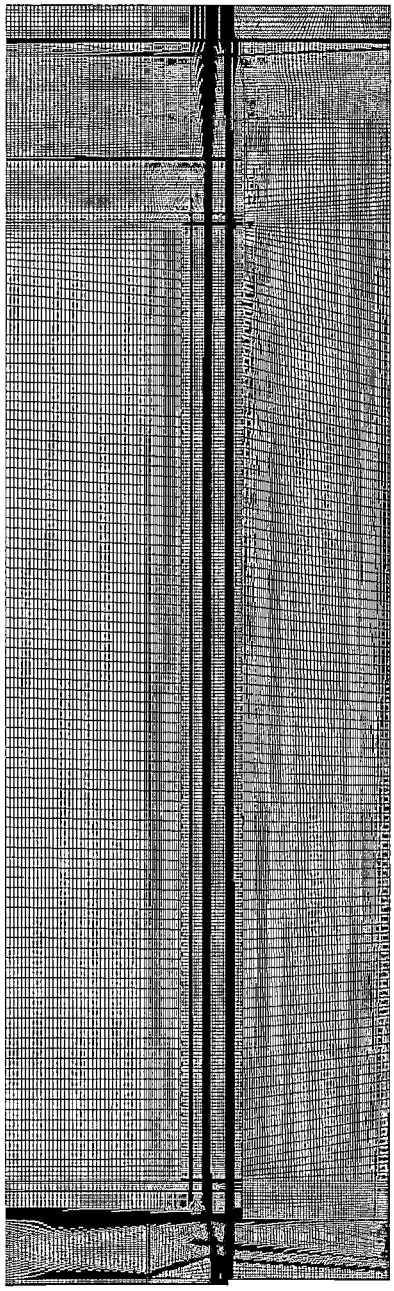


Figure 4.4-3 Axial Power Distribution for the PWR Fuel Assembly

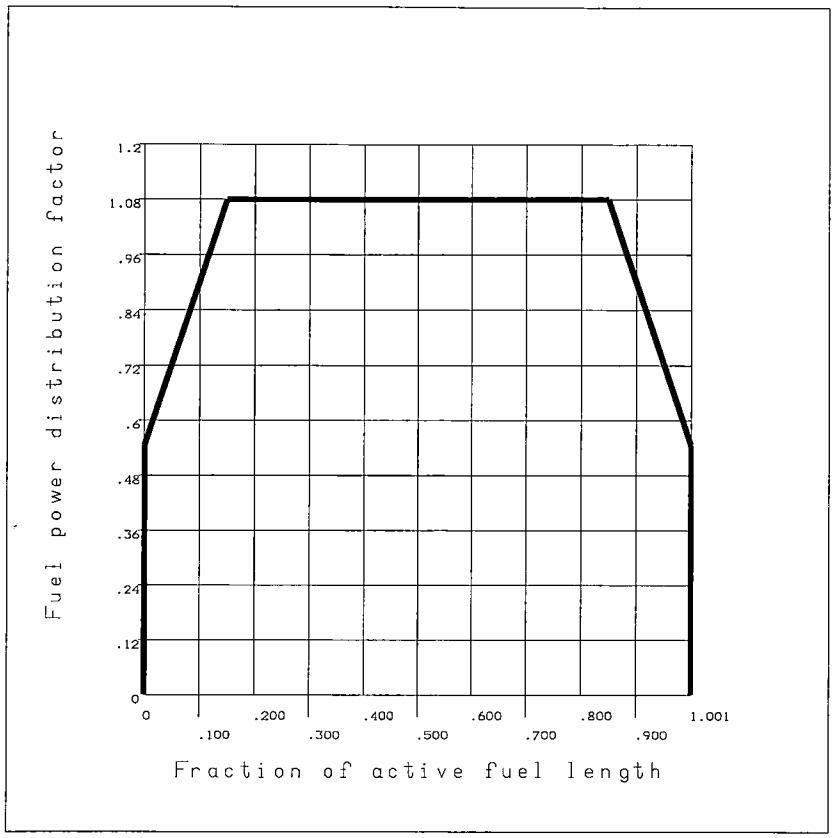


Figure 4.4-4 Axial Power Distribution for the BWR Fuel Assembly

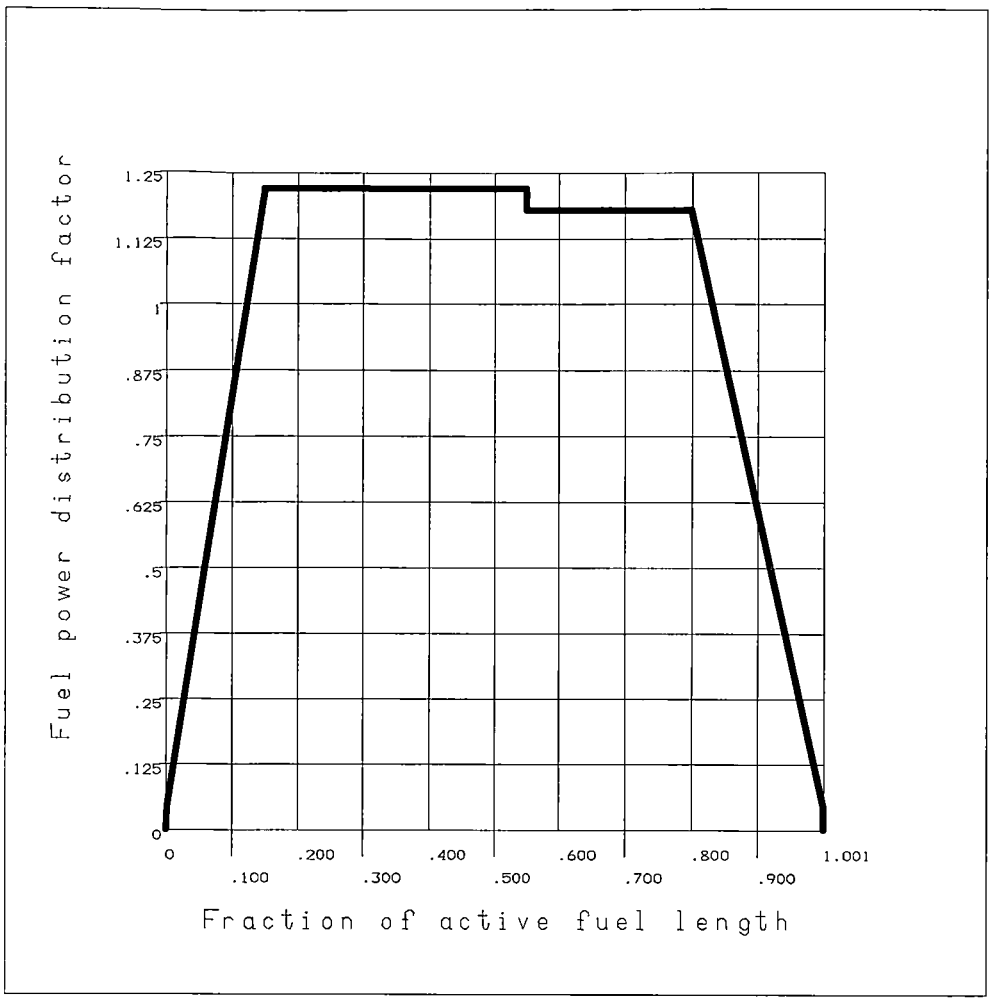


Figure 4.4-5 PWR Peak Fuel Cladding Temperature versus TSC Internal Pressure

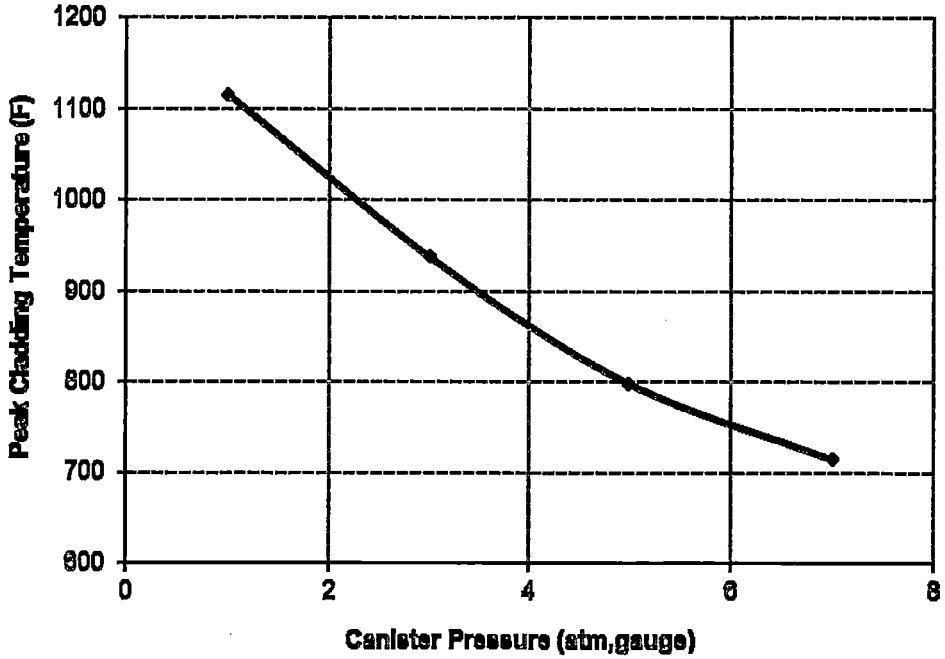


Figure 4.4-6 Two-Dimensional Finite Element Model of the PWR Fuel Basket

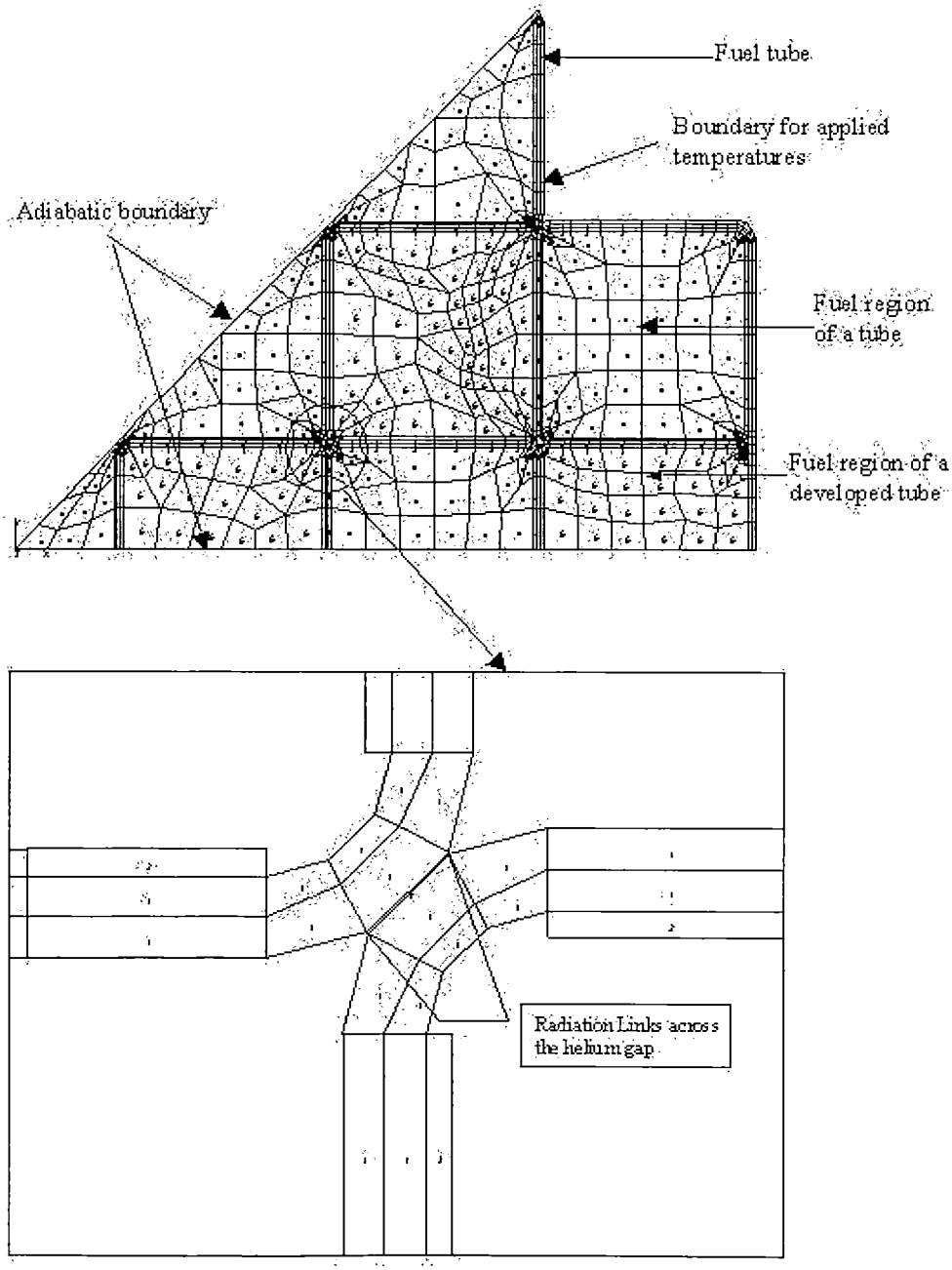


Figure 4.4-7 Two-Dimensional Finite Element Model of the BWR Fuel Basket

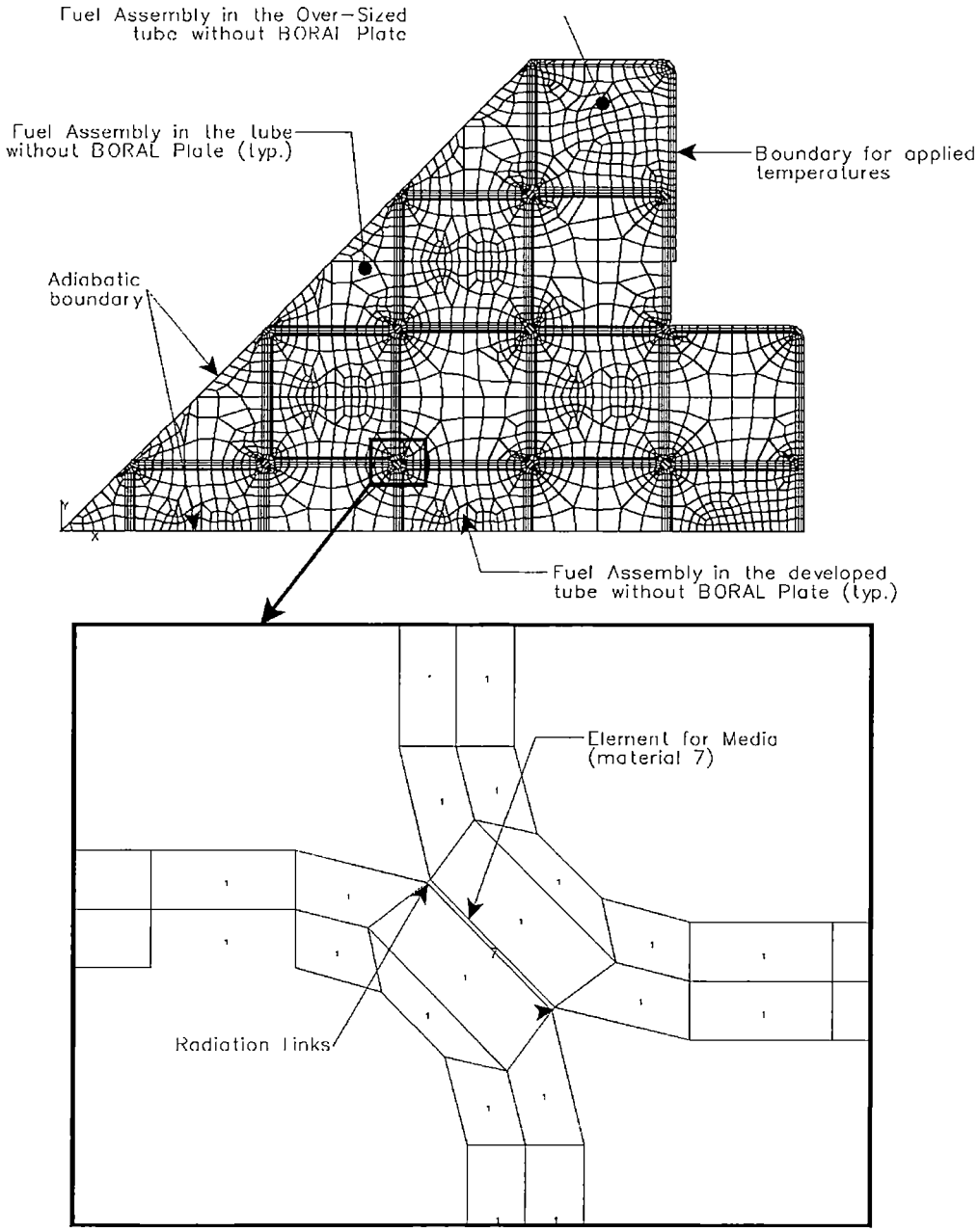
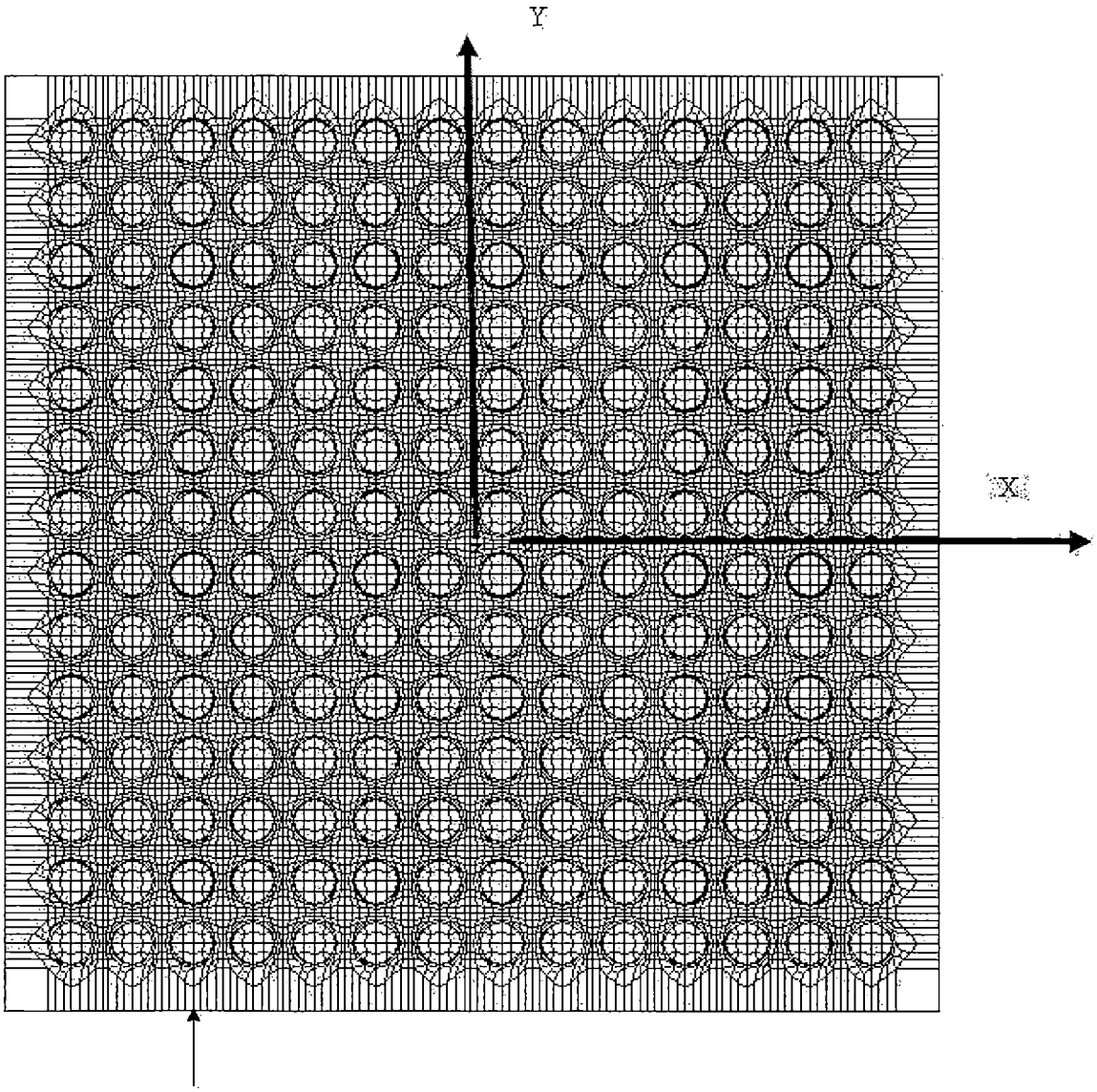


Figure 4.4-8 14×14 PWR Fuel Assembly Two-Dimensional Model



Temperature boundary condition applied along the edge of the model.

Note: X and Y correspond to the in-plane directions of the fuel assembly, while Z is out of the plane and corresponds to the axial direction of the fuel assembly.

Figure 4.4-9 10×10 BWR Fuel Assembly Two-Dimensional Model

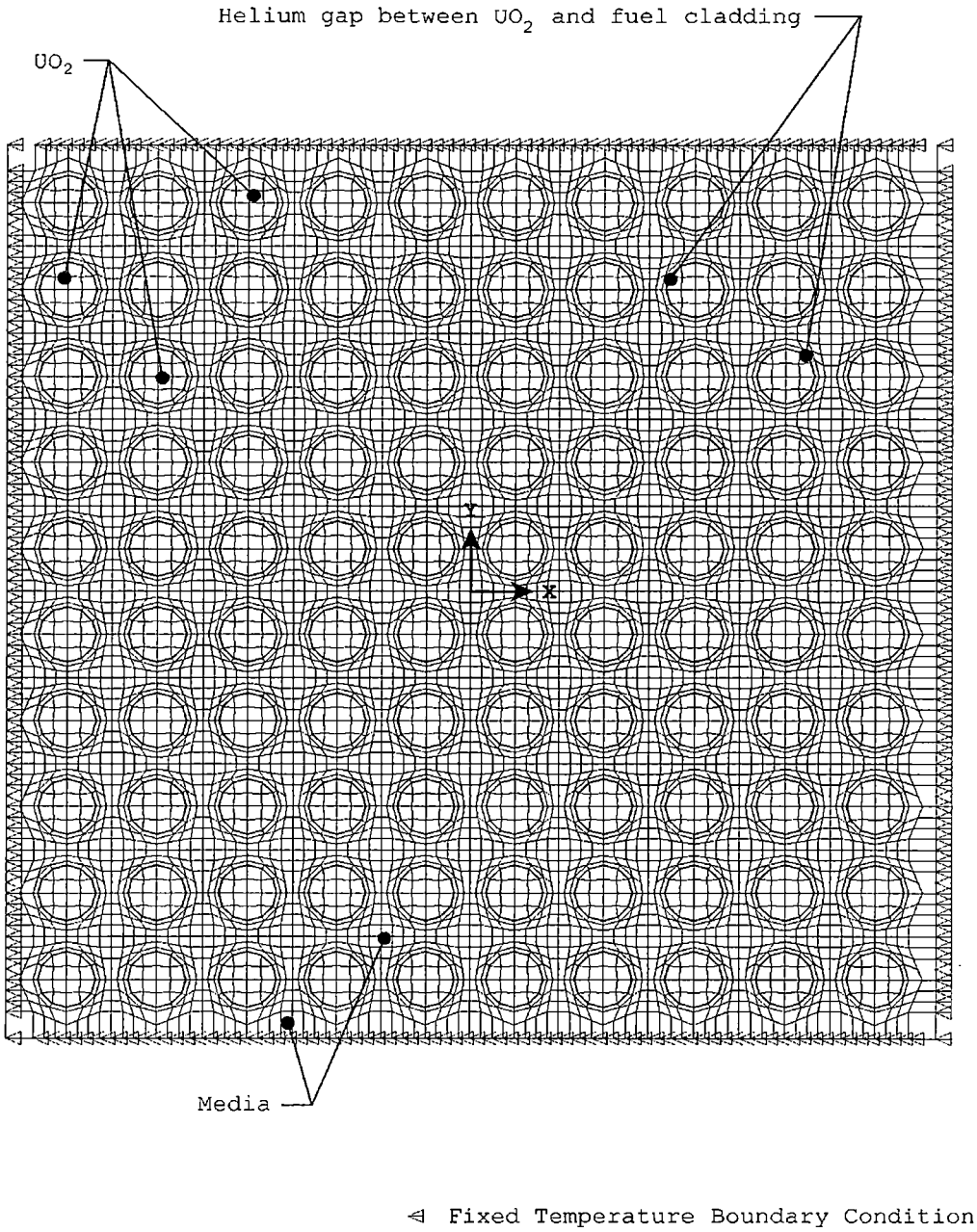
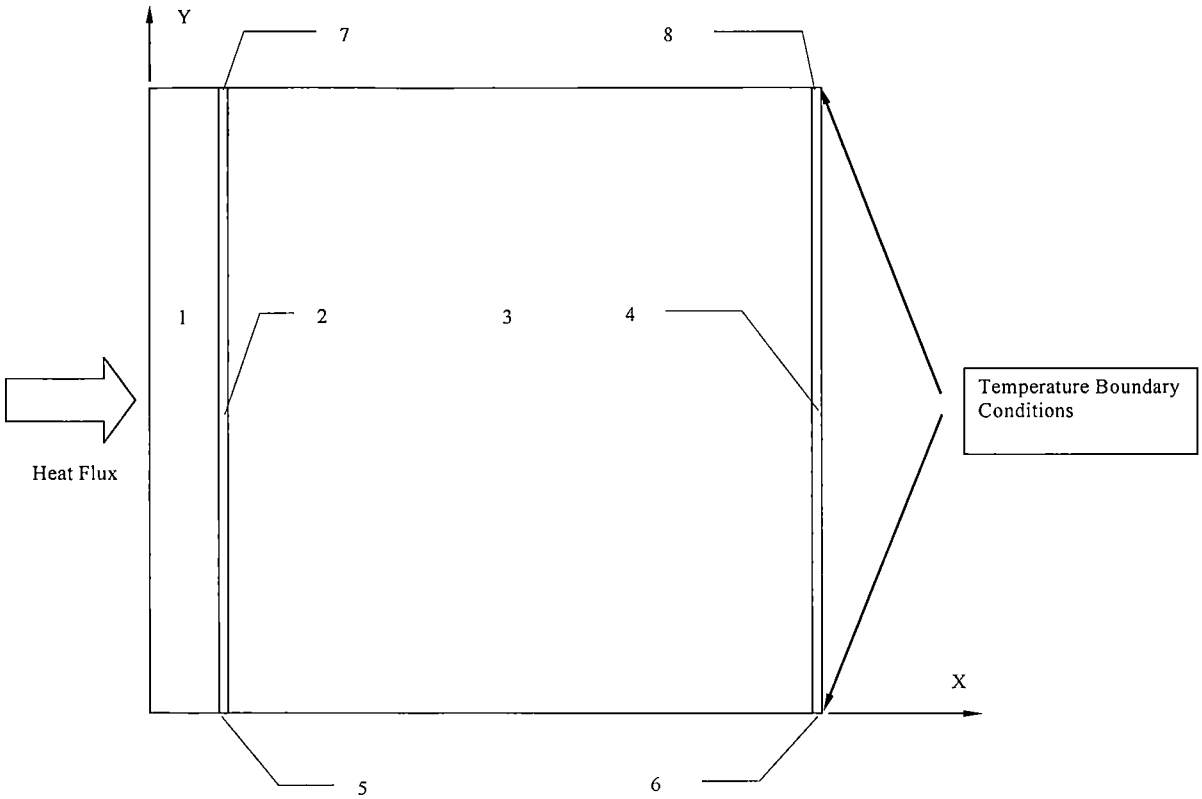
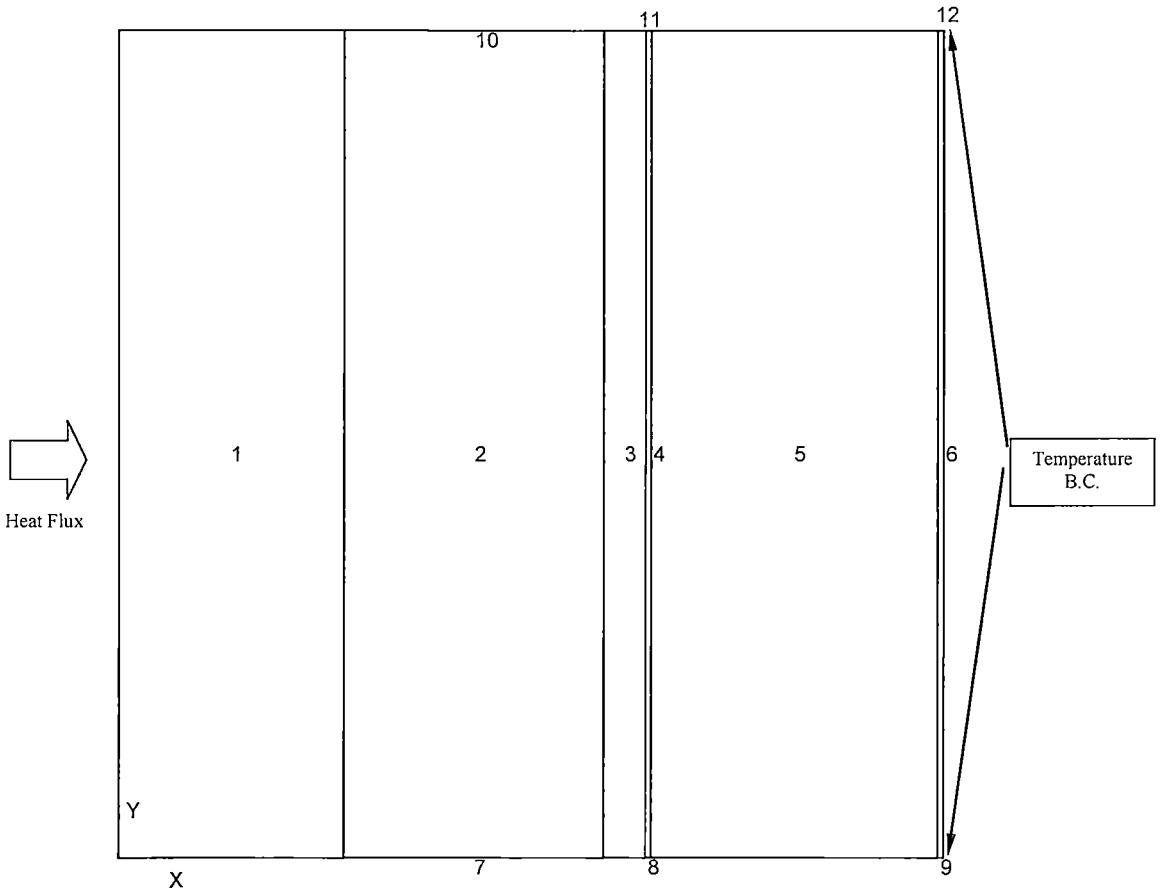


Figure 4.4-10 Neutron Absorber Model for PWR Fuel Tube



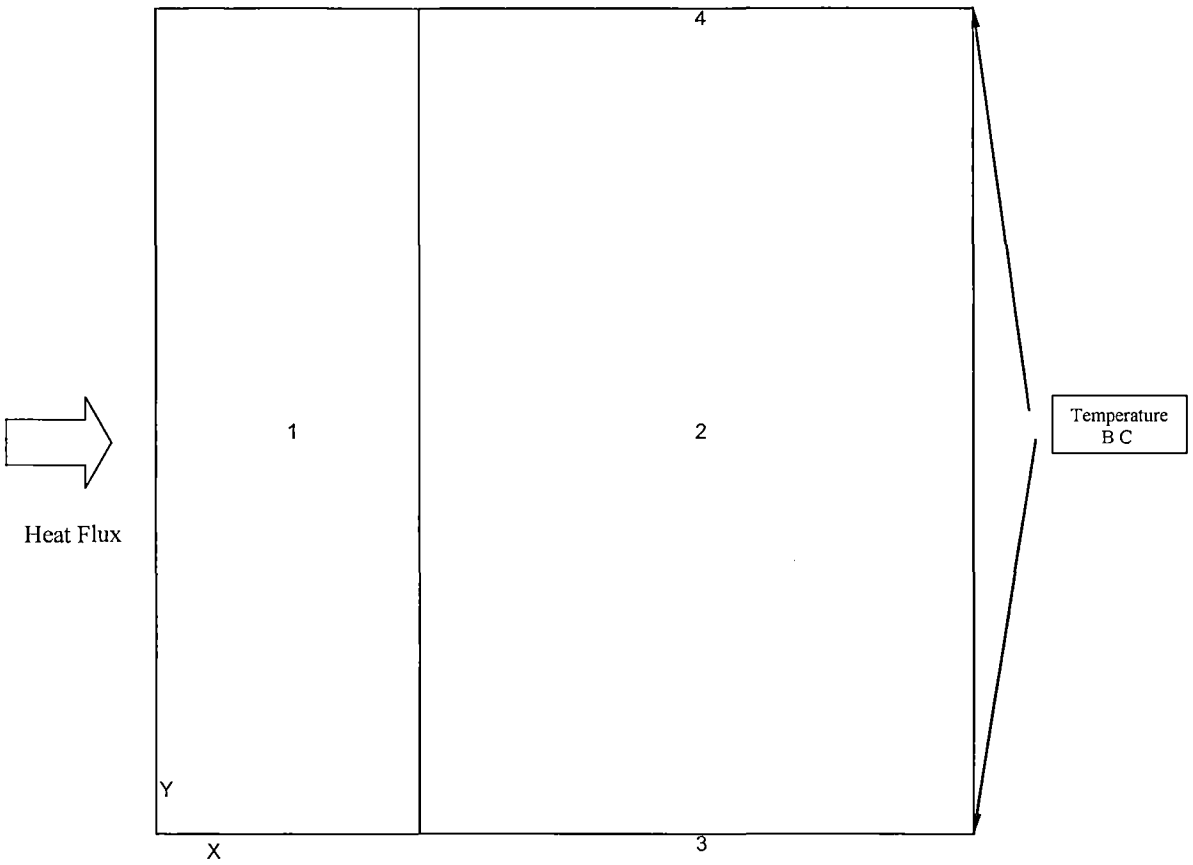
Element Number	Description
1	Stainless Steel Retainer Strip
2	Media – Helium or water
3	Neutron Absorber
4	Media – Helium
5,7	Radiation Links (between stainless steel and neutron absorber)
6,8	Radiation Links (between aluminum and nickel plated carbon steel)

Figure 4.4-11 BWR Fuel Tube Configuration with Channel and Neutron Absorber



Element Number	Description
1	Zirconium-based alloy (BWR fuel channel)
2, 4, 6	Media – Helium or water
3	Stainless Steel Retainer Strip
5	Neutron Absorber
7, 10	Radiation Links (between zirconium-based alloy and stainless steel)
8, 11	Radiation Links (between stainless steel and aluminum)
9, 12	Radiation Links (between aluminum and nickel-plated carbon steel)

Figure 4.4-12 BWR Fuel Tube Configuration with Channel, but without the Neutron Absorber



Element Number	Description
1	Zirconium-based alloy (BWR fuel channel)
2	Media ---- Helium or water
3, 4	Radiation Links (between zirconium-based alloy and nickel-plated carbon steel)

Figure 4.4-13 Two-Dimensional Model of Transfer Cask Loaded with a PWR TSC

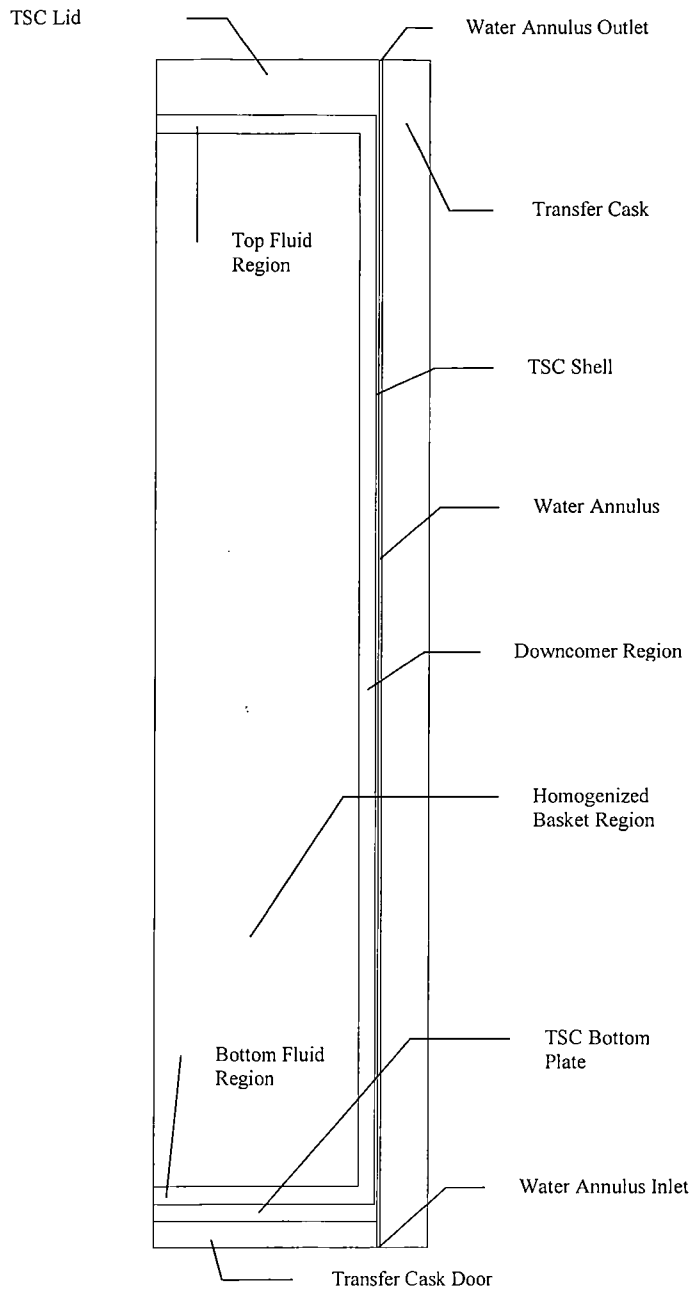


Figure 4.4-14 Temperature (°F) Distribution for the CC1/CC2 Concrete Cask and TSC Containing a Design Basis PWR Heat Load

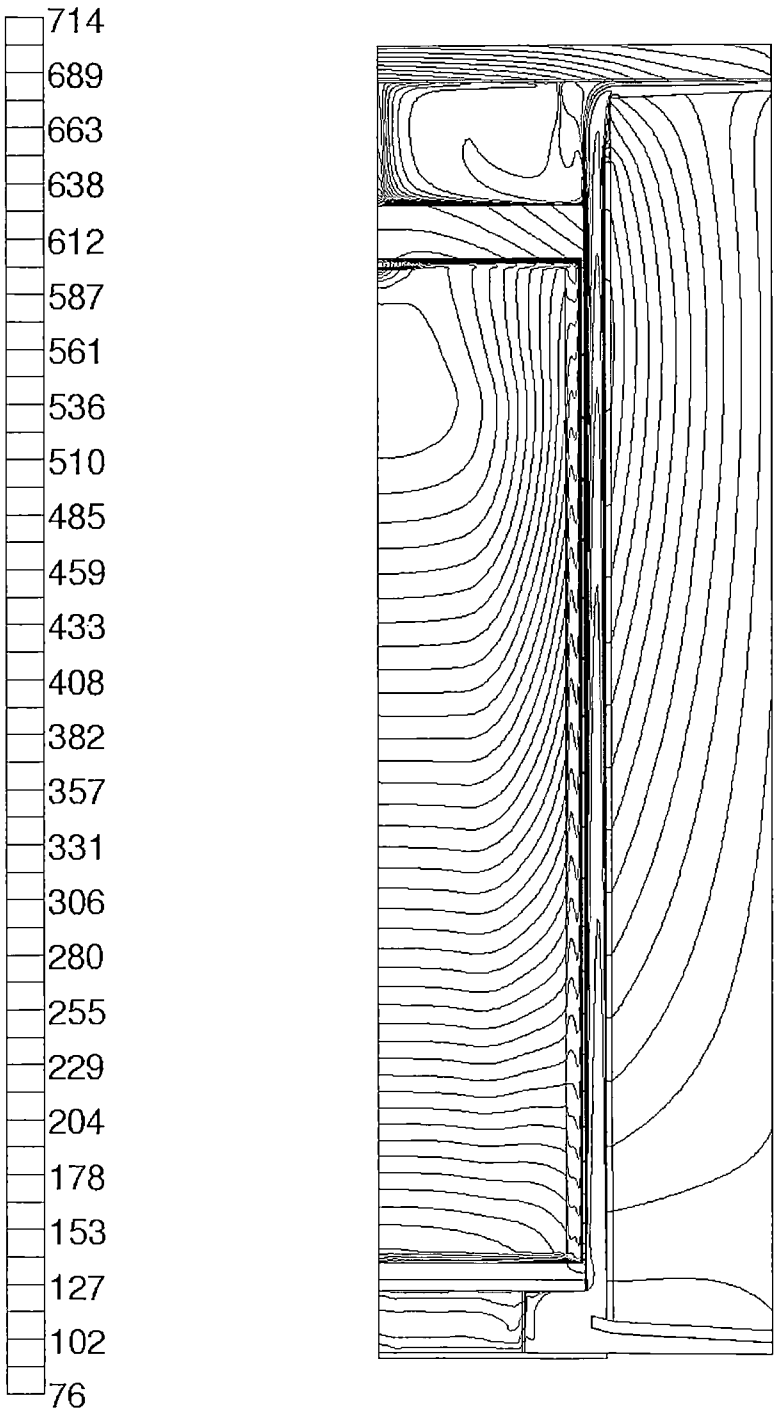


Figure 4.4-15 Air Velocity (m/s) in the CC1/CC2 Concrete Cask Annulus for the Design Basis PWR Heat Load

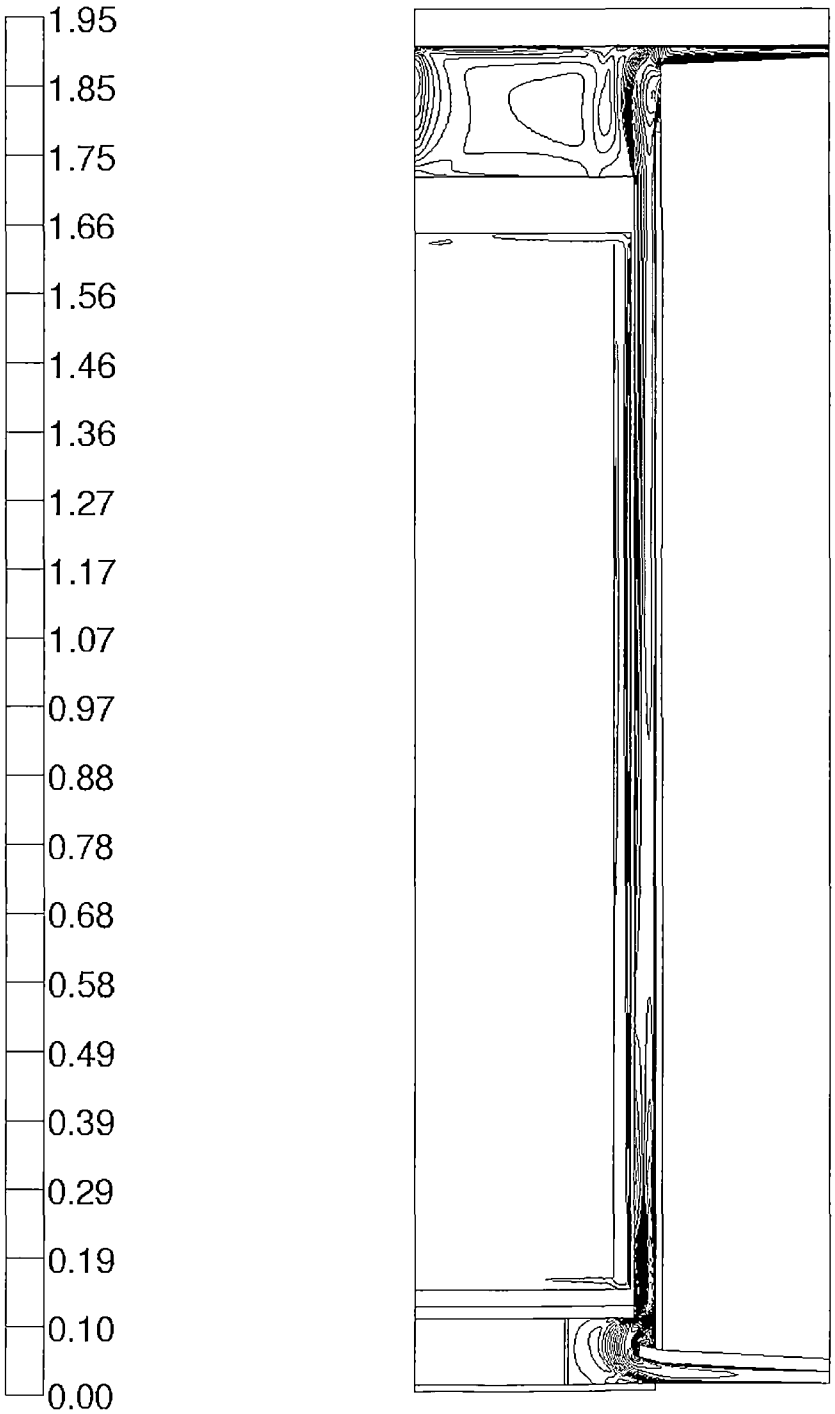


Figure 4.4-16 Three-Dimensional ANSYS Model of the PWR Canister for Vacuum Drying Condition

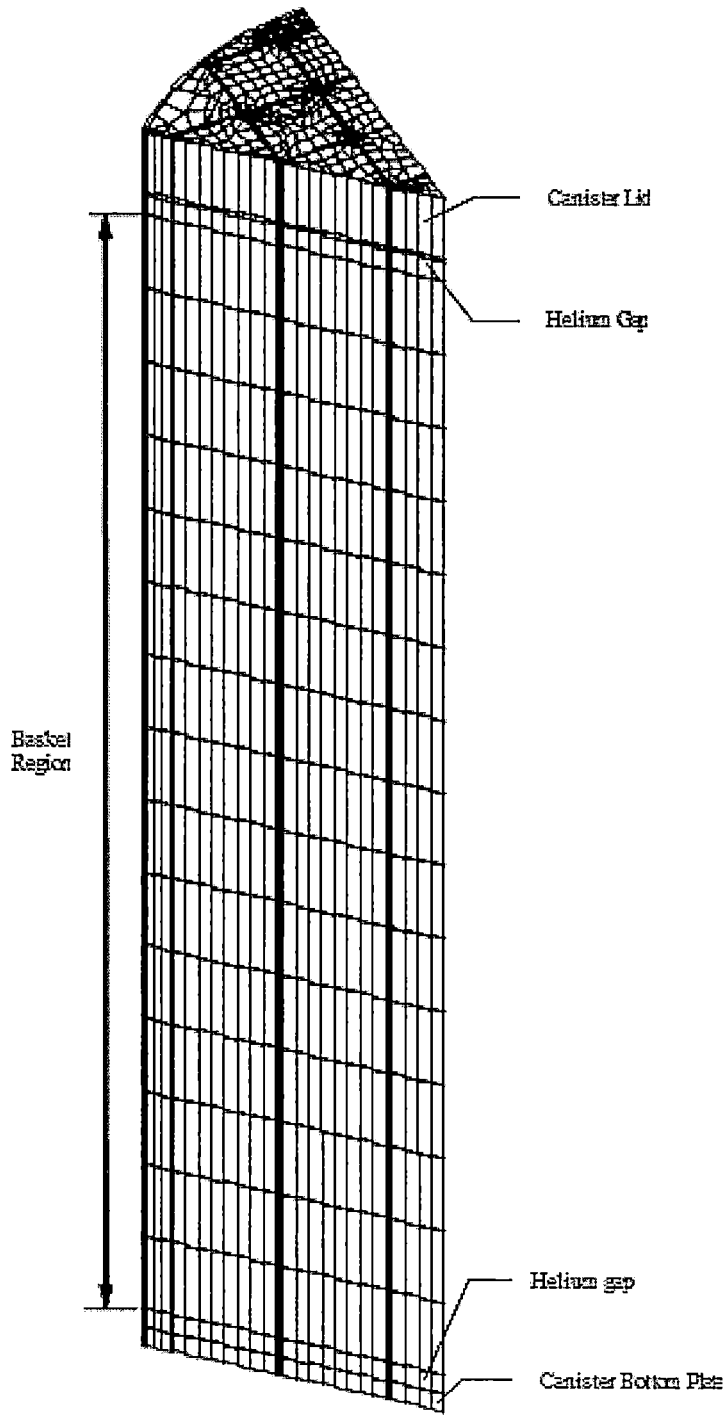


Figure 4.4-17 Detailed View of the Three-Dimensional ANSYS Model of the PWR Canister for Vacuum Drying Condition

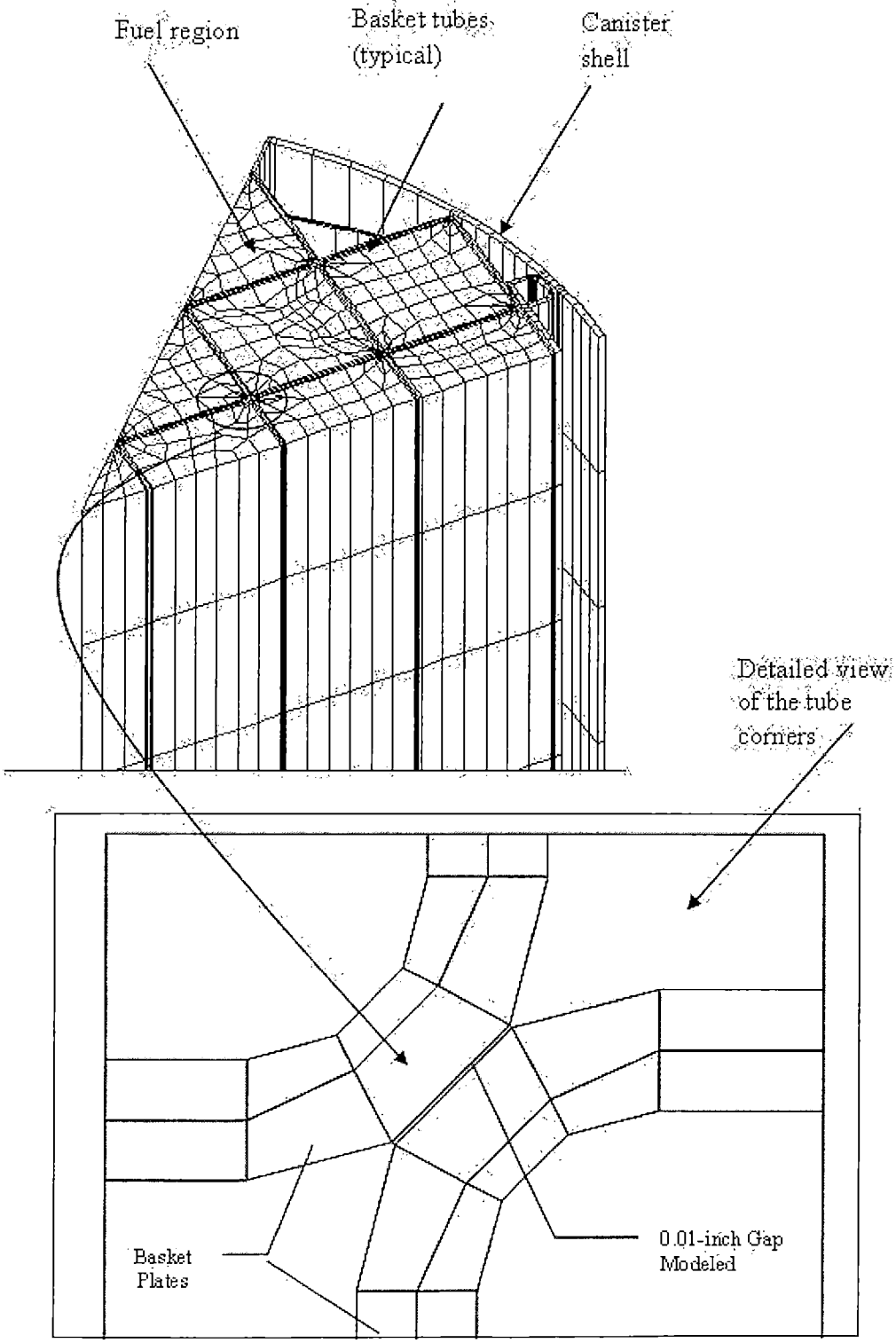


Figure 4.4-18 Three-Dimensional ANSYS Model of the BWR Canister for MTC Vacuum Drying Analyses

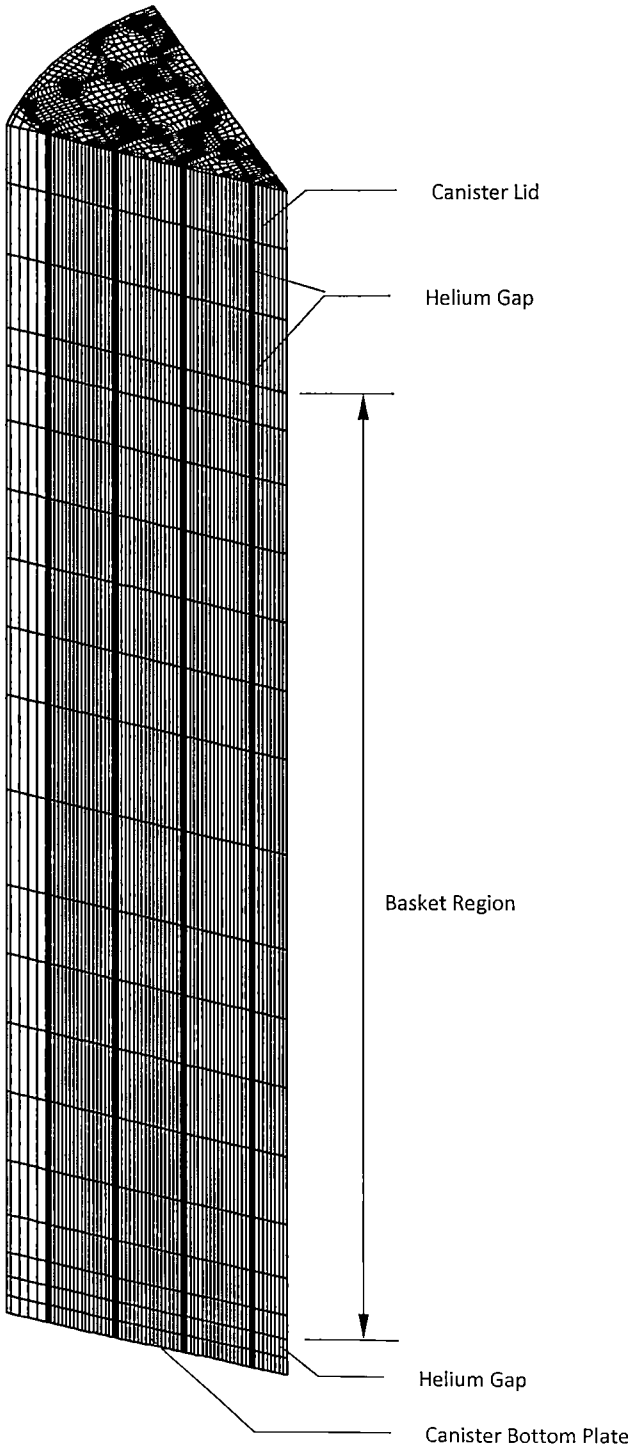


Figure 4.4-19 Detailed View of the Three-Dimensional ANSYS Model of the BWR Canister for MTC Vacuum Drying Analyses

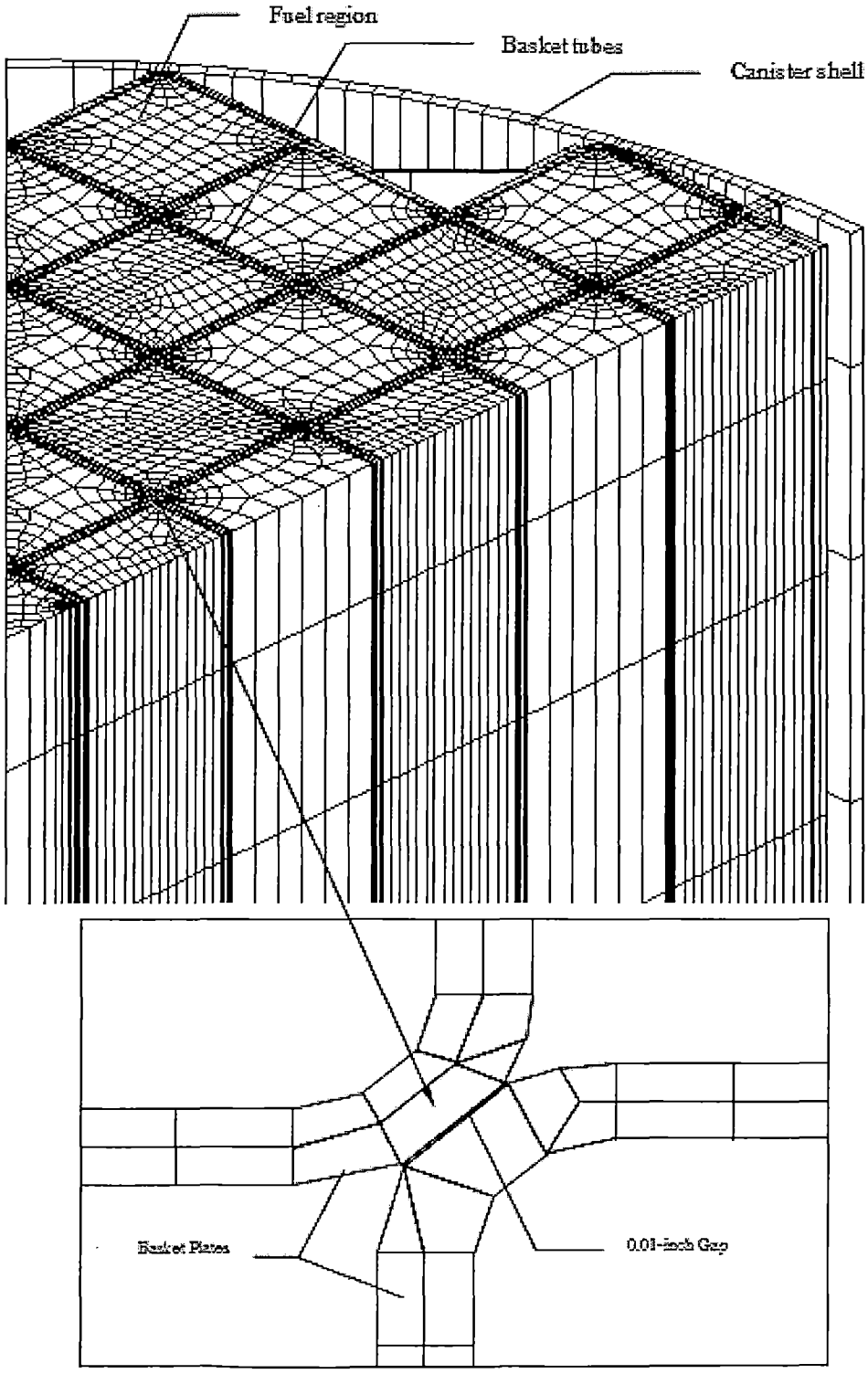
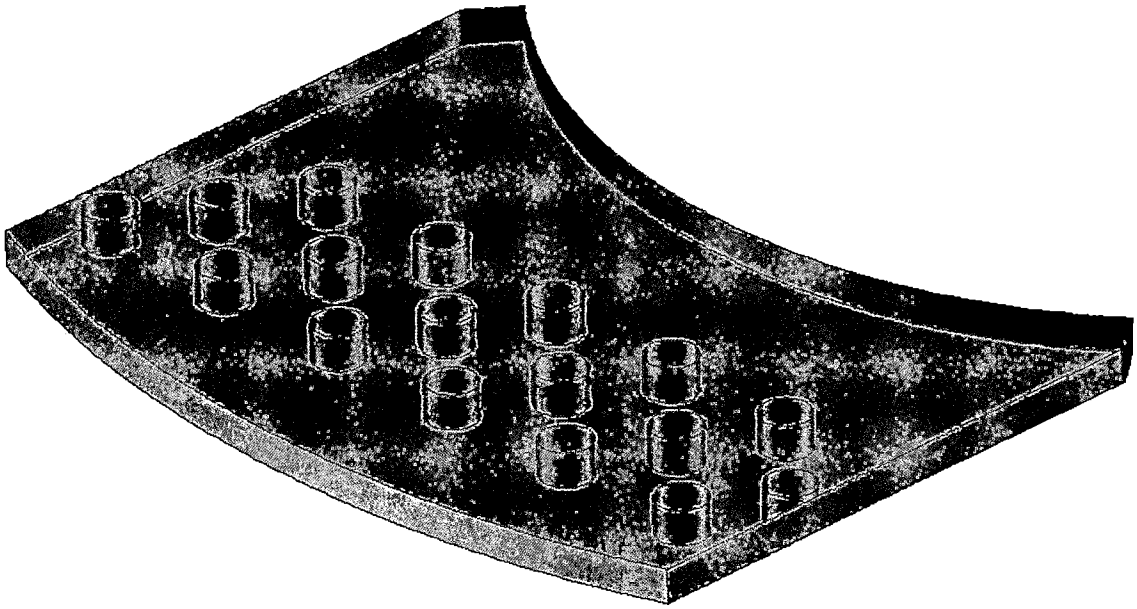


Figure 4.4-20 CC3 Concrete Cask Inlet Model Geometry



Note: The symmetry plane is the top surface (not shown).

Figure 4.4-21 CC3 Concrete Cask Inlet Model Mesh (Bottom Surface)

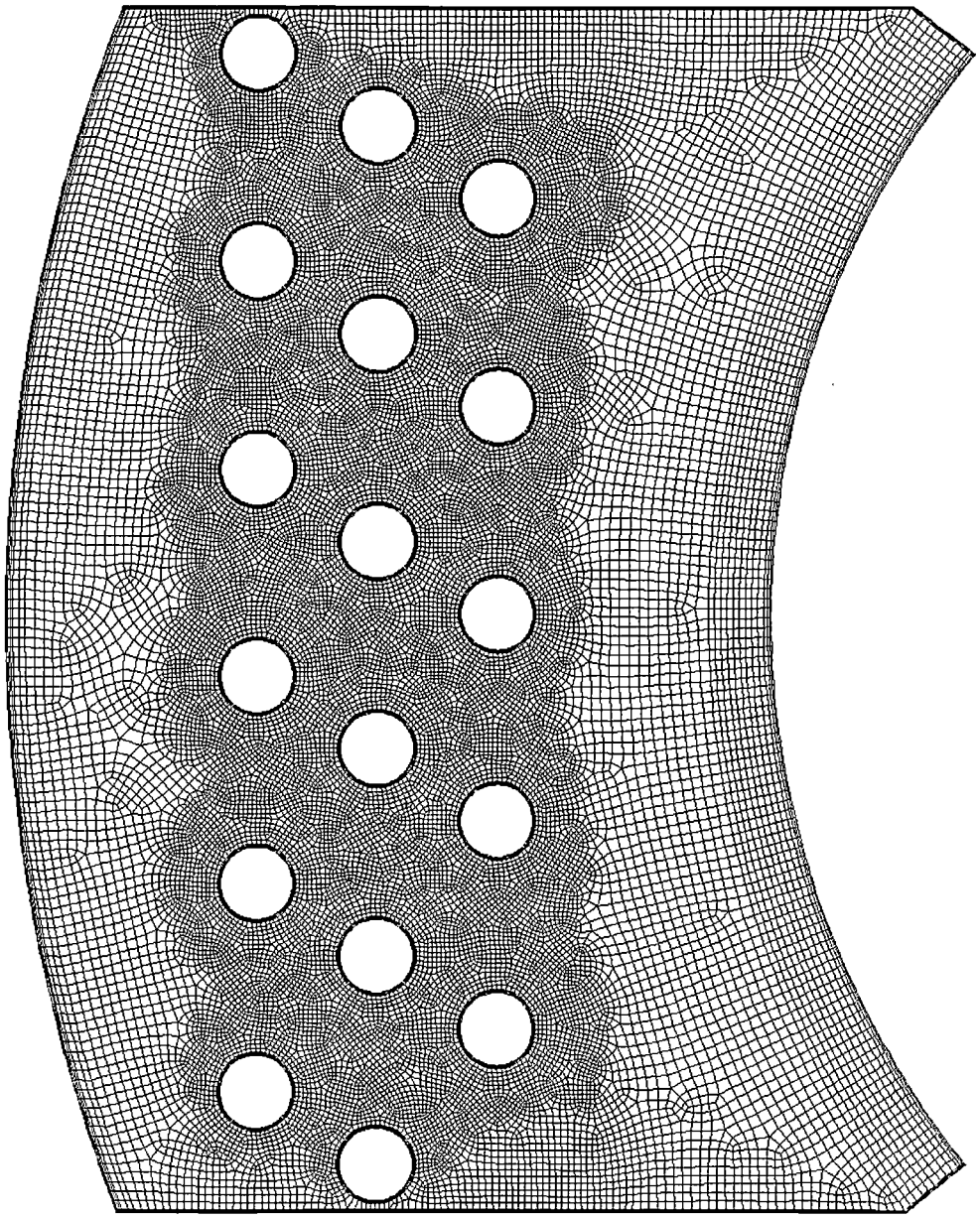


Figure 4.4-22 Two-Dimensional Finite Element Model of the DF Basket Assembly

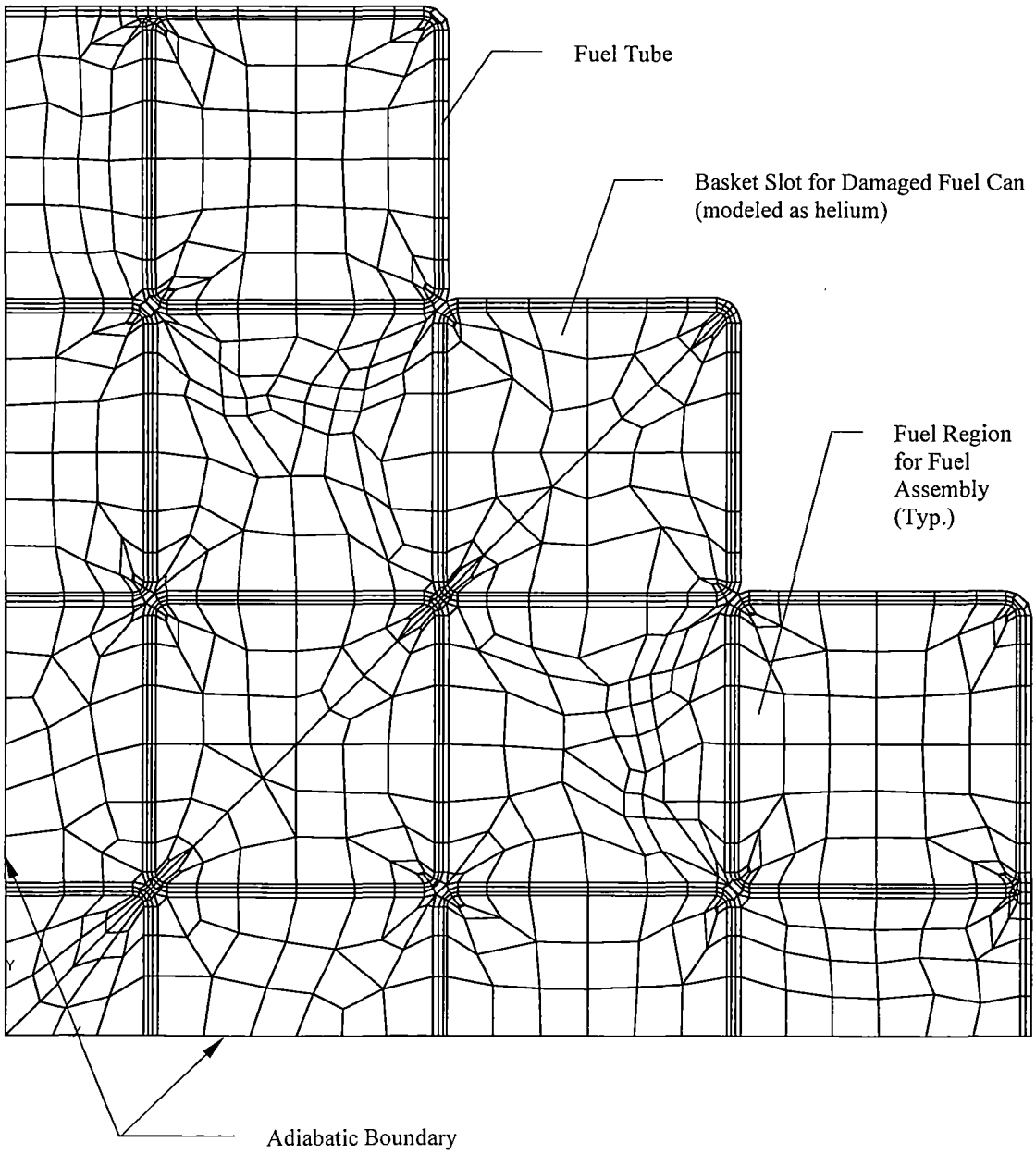


Table 4.4-1 Effective Thermal Conductivities for 14×14 PWR Fuel Assemblies for Helium Backfill

For fuel assemblies in fuel tubes with the neutron absorber:

Conductivity [a] (Btu/hr-in-°F)	Temperature (°F)			
	221	415	612	813
K_{xx}	0.019	0.026	0.036	0.048
K_{yy}	0.019	0.026	0.036	0.048
K_{zz}	0.124	0.115	0.111	0.112

For fuel assemblies in positions without the neutron absorber:

Conductivity [a] (Btu/hr-in-°F)	Temperature (°F)			
	222	417	615	816
K_{xx}	0.019	0.025	0.034	0.044
K_{yy}	0.019	0.025	0.034	0.044
K_{zz}	0.127	0.117	0.114	0.115

Table 4.4-2 Effective Thermal Conductivities for 10×10 BWR Fuel Assemblies for Helium Backfill

Conductivity [a] (Btu/hr-in-°F)	Temperature (°F)			
	192	394	597	801
K_{xx}	0.020	0.028	0.039	0.052
K_{yy}	0.020	0.028	0.039	0.052
K_{zz}	0.134	0.125	0.122	0.125

[a] K_{xx} and K_{yy} correspond to the in-plane directions and K_{zz} corresponds to the axial direction in the basket.

Table 4.4-3 Maximum Component Temperatures for Normal Condition Storage of Design Basis PWR and BWR Heat Loads

Component		Maximum Temperatures (°F) CC1/CC2 PWR	CC1/CC2 BWR	CC3 PWR	CC4 PWR	Allowable Temperature (°F)
Fuel Cladding		714	695	718	718	752
Fuel Basket [a]		714	695	718	718	800
TSC Shell		457	436	462	462	800
Concrete	local	271	241	256	271	300
	bulk	160	153	155	160	200

Table 4.4-4 Helium Mass Per Unit Volume for MAGNASTOR TSCs

Fuel Type	Helium Density (g/liter) Nominal	Lower Bound	Upper Bound
PWR	0.763	0.694	0.802
BWR	0.774	0.704	0.814

[a] The maximum fuel cladding temperature is conservatively used.

Table 4.4-5 Maximum Fuel Temperature for Water Phase – PWR

HEAT LOAD (KW)	T_{MAX} OF FUEL (°F)	T_{MAX} OF CANISTER OD (°F)
35.5	131	118
30	127	116
25	124	114
20	120	112
15	116	109

Table 4.4-6 Maximum Fuel Temperature for Water Phase – BWR

HEAT LOAD (KW)	T_{MAX} OF FUEL (°F)	T_{MAX} OF CANISTER OD (°F)
33	129	117
30	127	116
25	124	114
20	120	112
15	116	109

Table 4.4-7 Maximum Fuel Temperature for Helium Phase – PWR

HEAT LOAD (KW)	T_{MAX} OF FUEL (°F)	T_{MAX} OF CANISTER OD (°F)
35.5	424	124
30	388	122
25	350	119
20	311	116
15	273	113

Table 4.4-8 Maximum Fuel Temperature for Helium Phase – BWR

HEAT LOAD (KW)	T_{MAX} OF FUEL (°F)	T_{MAX} OF CANISTER OD (°F)
33	419	123
30	396	122
25	358	119
20	319	116
15	279	116

Table 4.4-9 Durations and the Temperature at the End of the Duration for the First Vacuum Stage (PWR)

Heat Load (kW)	Vacuum Duration (hours)	T_{MAX} at Steady State or at the End of the Duration (°F)	
		Fuel	Basket
15	No limit	509	483
20	No limit	627	599
25	No limit	739	709
30	32	643	614
35.5	24	640	612

Table 4.4-10 Durations and the Temperature at the End of the Duration for the First Vacuum Stage (BWR)

Heat Load (kW)	Vacuum Duration (hours)	T_{MAX} at Steady State or at the End of the Duration (°F)	
		Fuel	Basket
15	No limit	444	431
20	No limit	547	532
25	No limit	647	630
29	No limit	723	706
30	44	656	639
33	33	645	628

Table 4.4-11 Durations and the Temperature at the End of the Duration for the Second Vacuum Stage* (PWR)

Heat Load (kW)	Helium Backfill Duration (hours)	T_{MAX} of Fuel/Basket at the End of the Helium Backfill (°F)	Second Vacuum Duration (hours)	T_{MAX} of Fuel/Basket at the End of the Second Vacuum (°F)
35.5	24	460	11	640

* For the cases with heat load higher than 25 kW, the duration and temperatures at the end of the duration shown in this table can be conservatively used.

Table 4.4-12 Durations and the Temperature at the End of the Duration for the Second Vacuum Stage* (BWR)

Heat Load (kW)	Helium Backfill Duration (hours)	T_{MAX} of Fuel/Basket at the End of the Helium Backfill (°F)	Second Vacuum Duration (hours)	T_{MAX} of Fuel/Basket at the End of the Second Vacuum (°F)
33	24	447	16	645

* For the cases with heat load larger than 29 kW, the duration and temperatures at the end of the duration shown in this table can be conservatively used.

Table 4.4-13 MTC to Concrete Cask (PWR) Transfer Times and Temperatures

[redacted]

Table 4.4-14 MTC to Concrete Cask (BWR) Transfer Times and Temperatures

[redacted]

Table 4.4-15 TFR to Concrete Cask (PWR) Transfer Times and Temperatures for 20 kW (no cooling) and 25 kW (7 hours of cooling)

Heat Load (kW)	Allowed Duration (hours)	T_{MAX} of Fuel/Basket at the End of the Transfer from TFR to Concrete Cask (°F)
≤ 20	No Limit	[redacted]
≤ 25	70.5	

Table 4.4-16 Durations Allowed and the Maximum PWR Fuel Clad Temperatures for the Operation Using Reduced Vacuum Times, Reduced Cooling Time and Eight Hours of Handling

[redacted]

Table 4.4-17 Durations Allowed and the Maximum BWR Fuel Clad Temperatures for the Operation Using Reduced Vacuum Times, Reduced Cooling Time and Eight Hours of Handling

[redacted]

4.5 Off-Normal Events

This section evaluates postulated off-normal storage and off-normal transfer phase events that might occur once during any calendar year of operation. The actual occurrence of any of these events is, therefore, infrequent.

4.5.1 Off-Normal Storage Events

The concrete cask and TSC model described in Section 4.4.1.1 is used for the evaluation of the concrete cask and TSC for the off-normal events: severe ambient temperature conditions (106°F and -40°F) and the half-blocked air inlets condition. The evaluation of the off-normal events for variations in the ambient temperature only requires a change to the boundary condition temperature. For the half-blocked air inlets condition, the air inlet condition is modified to permit only half of the air flow into the inlet. The design basis heat loads of 35.5 kW and 33 kW are used in the evaluations of the concrete cask and TSC containing PWR and BWR fuels, respectively. As shown in Section 4.4.1 and Section 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the DF basket assembly for normal conditions due to the higher thermal conductivity of the DF basket assembly. This conclusion is valid for the off-normal conditions for the same reasons. As shown in Section 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the PWR minimum reduced cool time fuel basket assembly for normal conditions due to the heat distribution of the preferential loading of the PWR minimum reduced cool time fuel basket assembly. The heat distribution for the preferential loading removes the maximum heat load from the basket center. This conclusion is valid for the off-normal conditions for the same reasons.

The principal component temperatures for each of the off-normal events, discussed previously, are summarized in the following tables, along with the allowable temperatures. Note that the maximum fuel cladding temperatures are conservatively used as the maximum fuel basket temperatures. As the tables show, the component temperatures for the concrete cask and TSC containing PWR and BWR fuels are within the allowable values for the off-normal storage events.

Principal Component Temperatures – Off-Normal Storage of CC1/CC2 with PWR TSC

Component	106°F Ambient, Maximum Temperatures (°F)	-40°F Ambient, Maximum Temperatures (°F)	76°F Ambient/Half Blocked Air Inlets Temperatures (°F)	Allowable Temperature (°F)
Fuel Cladding	752	603	717	1,058
Fuel Basket	752	603	717	1,000
TSC Shell	485	336	459	800
Concrete	311	118	274	350

Principal Component Temperatures – Off-Normal Storage of CC3 with PWR TSC

Component	106°F Ambient, Maximum Temperatures (°F)	-40°F Ambient, Maximum Temperatures (°F)	76°F Ambient/Half Blocked Air Inlets Temperatures (°F)	Allowable Temperature (°F)
Fuel Cladding	756	617	720	1,058
Fuel Basket	756	617	720	1,000
TSC Shell	490	353	465	800
Concrete	296	96	259	350

Principal Component Temperatures – Off-Normal Storage of CC4 with PWR TSC

Component	106°F Ambient, Maximum Temperatures (°F)	-40°F Ambient, Maximum Temperatures (°F)	76°F Ambient/Half Blocked Air Inlets Temperatures (°F)	Allowable Temperature (°F)
Fuel Cladding	756	617	720	1,058
Fuel Basket	756	617	720	1,000
TSC Shell	490	353	465	800
Concrete	311	118	274	350

Principal Component Temperatures – Off-Normal Storage of CC1/CC2 with BWR TSC

Component	106°F Ambient, Maximum Temperatures (°F)	-40°F Ambient, Maximum Temperatures (°F)	76°F Ambient/Half Blocked Air Inlets Temperatures (°F)	Allowable Temperature (°F)
Fuel Cladding	733	585	698	1,058
Fuel Basket	733	586	698	1,000
TSC Shell	464	318	438	800
Concrete	282	99	247	350

There are no adverse consequences due to these off-normal events. The maximum component temperatures are less than the allowable temperature limits.

Off- Normal Event TSC Internal Pressures

Off-normal event TSC internal pressures are evaluated using the method and inputs documented in the normal condition pressure evaluations (Section 4.4.4). The off-normal event TSC internal pressure analysis considers a 10% rod failure fraction and a TSC backfill temperature at 495°F and a pressure of 106 psig. The higher backfill temperature, and associated pressure, is the result of the "severe heat" off-normal thermal evaluation. The maximum TSC internal pressures calculated for off-normal events are 118 psig for the PWR system, 119 psig for the damaged fuel PWR system, and 112 psig for the BWR system.

4.5.2 Off-Normal Transfer Phase Events for PWR Fuel

Crane Failure During Transfer Cask Movements

While maneuvering the transfer cask in preparation for transfer operations, a mechanical or electrical malfunction could temporarily disable the crane and inhibit movement of the transfer cask and TSC. Such an occurrence would eliminate the option of submerging the transfer cask and TSC in the spent fuel pool for cooling and might make it difficult to establish an annulus cooling system flow. If operability of the crane can be restored within the normal transfer time limits, the transfer operation may be completed and no special actions are required. However, if the crane cannot be repaired in a timely manner it may not be possible to complete or abort the transfer operation within the normal limits. This condition is considered an off-normal event.

The two dimensional FLUENT model of the TSC and transfer cask with reduced annulus inlet, described in the transfer phase evaluation in Section 4.4.1.5, is used to perform steady state evaluations to determine the maximum heat load at which steady state fuel temperatures are below the off-normal allowable temperature limits. [redacted]

Crane/Hoist System Failure During TSC Transfer to VCC

With the transfer cask in place on top of the VCC, the TSC is lifted, the transfer cask doors are opened, and the TSC is lowered into the VCC. A mechanical or electrical malfunction of the

crane could strand the TSC in the transfer cask/VCC cavity. Such an occurrence would eliminate the option of submerging the transfer cask and TSC in the spent fuel pool for cooling, and might make it difficult to establish an annulus cooling water flow. If operability of the crane can be restored within the normal transfer time limits, transfer of the TSC into the VCC may be completed, and no special actions are required. However, if the crane cannot be repaired in a timely manner it may not be possible to complete or abort the transfer operation within the normal limits. This condition is considered an off-normal event.

Since the transfer cask doors are open, the air flow through the annulus region is greater than that in the off-normal event discussed in the preceding section (if the doors cannot be opened then the results of the preceding section apply). The two dimensional FLUENT model used in the preceding evaluation, configured with the full annulus inlet, is used to perform steady state evaluations to determine the maximum heat load at which steady state fuel temperatures are below the off-normal allowable temperature limits. [redacted]

Retrieving a TSC from a VCC for Unloading

If a TSC must be returned to the spent fuel pool for wet unloading, an off-normal event, it will be lifted out of the VCC into the transfer cask. Considering the initial conditions to be the steady state condition in the VCC, the transient results from the transfer phase evaluation in Section 4.4.1.5 for the design basis heat load are used to determine that the normal allowable temperature limits for the TSC and its PWR contents are reached 3 hours after the TSC is removed from the VCC and off-normal allowable temperature limits for the TSC and its PWR contents are reached 11 hours after the TSC is removed from the VCC. Annulus cooling flow, or an equivalent cooling method, must be established within this time limit to maintain the TSC and its contents below the off-normal allowable temperature limits.

4.6 Accident Events

This section presents the evaluations of the thermal accident design events, which address very low probability events that might occur once during the lifetime of the ISFSI or hypothetical events that are postulated because their consequences may result in the maximum potential impact on the surrounding environment. Three thermal accident events are evaluated in this section: maximum anticipated heat load, fire accident and full blockage of the air inlets. The maximum TSC internal pressure for the bounding accident conditions is evaluated in Section 4.6.4.

The concrete cask and TSC model described in Section 4.4.1.1 is used for the evaluation of the concrete cask and TSC for these thermal accident events. Since the CC3 concrete cask containing the PWR TSC has the same heat load and almost the same thermal mass as the CC1/CC2 concrete cask containing the PWR TSC, the thermal response is essentially the same for CC1/CC2 and CC3 for the fire accident and the full blockage event.

As shown in Section 4.4.1 and Section 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the DF basket assembly for normal conditions due to the higher thermal conductivity of the DF basket assembly. This conclusion is valid for the accident conditions for the same reasons.

As shown in Section 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the PWR minimum reduced cool time fuel basket assembly for normal conditions due to the heat distribution of the preferential loading of PWR minimum reduced cool time fuel basket assembly. This conclusion is valid for the accident conditions for the same reasons.

4.6.1 Analysis of Maximum Anticipated Ambient Heat Load

This section evaluates the concrete cask and the TSC for the postulated accident event of an ambient temperature of 133°F. A steady state condition is considered in the thermal evaluation of the system for this accident event.

Using the same methods and thermal models described in Section 4.4.1.1 for the normal conditions of storage, thermal evaluations are performed for the concrete cask and the TSC with its contents for this accident condition. All boundary conditions in the model are the same as those used for the normal condition evaluation, except that an ambient temperature of 133°F is used. The maximum calculated temperatures of the principal PWR and BWR cask component, with the corresponding allowable temperatures, are as follows.

Component	Maximum Temperature (°F)				Allowable Temperature (°F)
	CC1/CC2		CC3	CC4	
	PWR	BWR	PWR	PWR	
Fuel Cladding	786	767	790	790	1,058
Fuel Basket	786	767	790	790	1,000
TSC Shell	510	489	514	514	850
Concrete	347	318	332	347	350

Note that the maximum fuel cladding temperatures are conservatively considered to be the maximum basket temperatures. This evaluation shows that the component temperatures are within the allowable temperatures for the extreme ambient temperature conditions.

4.6.2 Fire Accident

A fire may be caused by flammable material or by a transport vehicle. While it is possible that a transport vehicle could cause a fire while transferring a loaded storage cask at the ISFSI, this fire will be confined to the vehicle and will be rapidly extinguished by the persons performing the transfer operations or by the site fire crew. Fuel in the fuel tanks of the concrete cask transport vehicle and/or prime mover (maximum 50 gallons) is the only flammable liquid that could be near a concrete cask, and potentially at, or above, the elevation of the surface on which the cask is supported. The fuel carried by other onsite vehicles or by other equipment used for ISFSI operations and maintenance, such as air compressors or electrical generators, is considered not to be within the proximity of a loaded cask on the ISFSI pad. Site-specific analysis of fire hazards will evaluate the specific equipment used at the ISFSI and determine any additional controls required.

The analyzed area is a 15×15-foot square, less the 136 in-diameter footprint of the concrete cask, corresponding to the center-to-center distance of the concrete casks on the ISFSI pad. The potential depth (D) of the 50-gallon pool of flammable liquid is calculated as follows.

$$D = \frac{50 \times 231}{15 \times 15 \times 144 - 3.14 \times 128^2 / 4} = 0.6 \text{ in.}$$

With a burning rate of 5 in/hr, the fire would continue for 7.2 minutes. The fire accident evaluation in this section conservatively considers an 8-minute fire. The temperature of the fire is taken to be 1,475°F, which is specified for the fire accident event in 10 CFR 71.73c [3].

The fire condition is an accident event and is initiated with the concrete cask in a normal operating steady-state condition. To determine the maximum temperatures of the concrete cask components, the two-dimensional axisymmetric model of the concrete cask and TSC for the PWR configuration described in Section 4.4.1.1 is used to perform a transient analysis. The PWR

configuration is considered to bound the BWR configuration due to the higher initial temperatures of the normal condition.

The initial condition of the fire accident transient analysis is based on the steady-state analysis results for the normal condition of storage, which corresponds to an ambient temperature of 100°F in conjunction with solar insolation (as specified in Section 4.4.1.1). The fire condition is implemented by applying a boundary temperature condition of 1,475°F at the air inlet and the lower surface of the steel plate forming the top of the air inlet for eight minutes. This boundary condition temperature is applied as a stepped boundary condition. During the eight-minute fire, solar insolation is also applied to the outer surface of the concrete cask. At the end of the eight minutes, the temperature at the inlet is reset to the ambient temperature of 100°F. The cooldown phase is continued for an additional 10.7 hours to observe the maximum TSC shell temperature and the average temperature of the TSC contents.

The maximum fuel temperature increased by less than 3°F, thus remaining well below the accident event temperature limit of 1,058°F. The maximum temperature of the TSC shell increases to 512°F due to the fire condition. The limited duration of the fire, the large thermal capacitance of the concrete cask, and the minimal thermal conductivity limit the local region where the concrete temperatures exceed 300°F to less than 10 inches above the top surface of the air inlets. These results confirm that the operation of the concrete cask is not adversely affected during and after the fire accident condition.

4.6.3 Full Blockage of Concrete Cask Air Inlets

This section evaluates the concrete cask for the transient condition of full blockage of the air inlets at the normal storage condition temperature (100°F).

The accident temperature conditions are evaluated using the concrete cask and TSC thermal models described in Section 4.4.1.1. The transient analysis assumes initial normal storage conditions, with the sudden loss of convective cooling of the TSC. This is simulated by removing the inlet and outlet conditions from the model. Heat is then rejected from the TSC to the concrete cask liner only by radiation and convection. The loss of convective cooling to the ambient environment results in a sustained heat-up of the TSC and its contents and the concrete cask. The maximum fuel cladding temperature, maximum basket temperature, and the maximum concrete bulk temperature remain less than the allowable accident temperatures for approximately 72 hours after the initiation of the event. However, the internal pressure in the TSC cavity will reach the analyzed maximum pressure condition of 250 psig in approximately 58 hours after the initiation of a complete blockage event.

The evaluation demonstrates that there are no adverse consequences due to this accident, provided that debris is cleared from at least two air inlets within 58 hours based on the steady-state evaluation of the half-blocked air inlet condition in Section 4.5.

4.6.4 Maximum TSC Internal Pressure for Accident Events

Accident event pressures are evaluated with the method and inputs documented in the normal condition pressure evaluation (Section 4.4.4). System conditions incorporated in the accident analysis are an increased rod failure fraction and an increase in the average gas temperature of the TSC. A 100% rod failure fraction is applied in the system pressure calculation in conjunction with normal system temperatures. The second accident pressure evaluation applies the bounding thermal accident TSC average gas temperature to a TSC with a 1% (normal condition) fuel failure fraction. The bounding thermal accident, and associated pressure increase, is the result of the air inlets full blocked thermal evaluation. The average TSC gas temperature applied in the thermal accident pressure evaluation is a conservative 684°F compared to 677°F calculated for this condition. Maximum calculated TSC internal pressures for the PWR and BWR systems are documented as follows.

System	100% Fuel Failure	Inlets Blocked
PWR (undamaged fuel basket)	221 psig	130 psig
PWR (damaged fuel basket)	226 psig	130 psig
BWR	159 psig	129 psig

4.7 References

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4.8 Thermal Evaluation Detail

This section contains thermal evaluation detail not found in the preceding sections.

4.8.1 Benchmark of the Two-Dimensional Axisymmetric Methodology for TSC Thermal Analyses for MAGNASTOR

In this section, a benchmark evaluation is performed. A thermal evaluation using two-dimensional modeling methodology is performed for a system for which a thermal test has been conducted. Convection, conduction and radiation within the confinement boundary are considered in this evaluation. The thermal test is described in EPRI NP-5128 [16]. The results of the thermal evaluation using the two-dimensional methodology performed in this section show that the two-dimensional methodology is conservative and, therefore, acceptable for use in the thermal evaluation of MAGNASTOR.

4.8.1.1 Introduction

The thermal design of MAGNASTOR involves all three modes of heat transfer to reject heat from the fuel into the ambient. The most dominant mode of heat transfer is by convection, which involves helium removing heat from the fuel assembly as it flows up through the fuel tubes and transferring the heat to the TSC shell as it flows down through the basket weldment (downcomer) region. The heat transferred to the TSC shell is then rejected into the concrete cask annulus airflow and transported to the ambient environment. The design of the concrete cask annulus to permit airflow between the TSC and the concrete cask to transfer heat to the ambient is in numerous licensed spent fuel storage system designs. The most significant difference with the MAGNASTOR design is the inclusion of convection in the TSC as a means of removing heat from the fuel assemblies.

The geometry of the MAGNASTOR fuel basket is an array of square tubes in a cylindrical outer boundary, the TSC shell. This implies that the flow of the helium upward in the basket is through a complex cross-section of squares, less the circular cross-sections of the fuel rods. The downward flow of the helium on the outside of the fuel basket next to the TSC shell is also through an area with a complex cross-section, since the outer boundary is circular and the inner boundary of the downcomer is the outer perimeter of the square array of fuel tubes. While this has the characteristics of a three-dimensional system, it is evaluated as a two-dimensional axisymmetric system. Even as a three-dimensional system, the complex flow area for the fuel region is impractical to be incorporated into a fluid flow analysis with detailed modeling for each fuel rod. Additionally, due to the design of the fuel basket and the range of fuel temperatures expected, conduction and radiation heat transfer throughout the fuel basket cannot be neglected. The methodology adopted for this analysis includes the determination of effective properties for thermal conduction and radiation, as well as for fluid flow resistances, which are to be

implemented in a two-dimensional axisymmetric model. The end result of the two-dimensional evaluation is to determine the maximum temperatures for the fuel rod cladding.

For this reason, a benchmark is performed to demonstrate that two-dimensional methodology is acceptable to determine the maximum fuel cladding temperatures for MAGNASTOR.

4.8.1.2 Purpose

The purpose of this section is to provide a benchmark, which demonstrates that the two-dimensional methodology employed in the MAGNASTOR thermal evaluation is conservative.

4.8.1.3 Description of the Thermal Test

In EPRI NP-5128 [16], thermal testing was performed for a vertical metal cask containing 24 PWR (15×15) assemblies with a total heat load of 20.6 kW. The variation of the heat loads between the assemblies was less than 6%, which can be approximated as a uniform heat load. The basket contained in the cask during testing was comprised of an array of 24 square slots in which the basket walls were constructed of aluminum. While there were a series of tests performed, the test of interest for this evaluation was the test corresponding to vertical orientation of the cask in which the cask was backfilled with nitrogen to one atmosphere. Axial profiles of the temperature data were obtained in the tests for the inner surface of the cask, as well as for various radial locations in the basket. Temperature data was not obtained for the center of any fuel assembly, but rather on the basket.

4.8.1.4 FLUENT Model Description

The two-dimensional axisymmetric model for this evaluation only needs to consider the cavity of the metal cask. Modeling of the cask wall and surface is not considered necessary since the temperatures at the cask inner surface from the test are being applied as the boundary conditions for the model. The various regions of the model are shown in Figure 4.8-1. Regions 2 through 5 comprise the full length of the basket of the cask. Regions 2 through 4 represent the fuel in the basket, and Region 3 corresponds to the 144-inch active fuel region. Region 5 is considered to be within the length of the basket, but outside the length of the fuel assembly. Regions 1, 6 and 7 correspond to the backfill gas, nitrogen. For Regions 1, 6 and 7, it is only necessary to input the material properties for nitrogen to simulate the flow of nitrogen in the cask cavity. The gas is modeled as an ideal gas in FLUENT and all regions in the model utilized laminar flow conditions.

4.8.1.4.1 Effective Properties for the Basket and Fuel Regions

For the regions corresponding to the basket, effective properties are employed in the analysis. To account for the flow resistance of the wetted perimeter of the fuel and the fuel assembly grids, the porous media option in FLUENT is used. The determination of the porous media constants depends on the radius assigned to the basket region, which also must be associated with the effective cross-section area of the downcomer region. The cross-section for the downcomer region is used to compute the outer radius of the basket region in the two-dimensional axisymmetric model (Regions 2 through 5). Calculation of these constants for the porous media is described in Section 4.8.2. The methodology applied for this benchmark follows the same methodology described for the MAGNASTOR TSC model in Section 4.4.1.1.

The effective thermal properties for the basket region are computed using an ANSYS model shown in Figure 4.8-2. This model contains the aluminum basket and the fuel regions, which are modeled with homogeneous orthotropic thermal conductivities. To determine the temperature-dependent effective thermal conductivity of the basket region, a series of temperatures is applied to the boundary of the model. Solutions for each boundary condition determine the maximum temperature of the basket and the associated change in temperature from the boundary to the maximum temperature location. The effective thermal conductivities are determined using the same expression employed for MAGNASTOR in Section 4.4.1.2.

4.8.1.4.2 Boundary Conditions

The outer edges of the model correspond to the inner surface of the cask cavity. The following boundary conditions were applied to the model.

Temperature Specification

To remove any uncertainties in the model due to the cask wall conductance, the convection condition at the cask surface, or the variations in the ambient conditions, the temperatures from the test corresponding to the inner surface of the cavity were applied to the outer surface of the model. The temperature profile is shown in Figure 4.8-3.

Heat Generation

The total heat load applied to Region 3 of the model in Figure 4.8-1 was 20.6 kW. The heat generation was assumed to be uniformly distributed over the radial direction from the basket centerline to the outer radius of the porous media region (Region 3). In the axial direction, the power distribution as shown in Figure 4.8-4 was applied, which shows a peaking factor of 1.2.

Buoyancy

Since the backfill gas was specified as an ideal gas, the only condition required to enact buoyancy as a driving force for the nitrogen is to set the gravity acceleration as –9.8 m/sec^2.

Cavity Pressure

To be consistent with the boundary conditions used in the analyses for MAGNASTOR, a pressure was applied to the cavity region. For the benchmark, the pressure in the cavity was set to zero (gauge).

4.8.1.5 Analysis Results

The temperature contour corresponding to the applied conditions is shown in Figure 4.8-5. The distribution of the contours along the centerline shows the maximum temperature is close to the top of the basket, which is characteristic of baskets in which the dominant heat transfer is by convection. The maximum basket temperature reported in the thermal test was 232°C, as compared to a maximum basket temperature of 233°C obtained from the analysis. This indicates that the analysis temperature is 1°C conservative with respect to the test data.

4.8.1.6 Application of the Benchmark to the MAGNASTOR Evaluation

The benchmark thermal test cask contained PWR assemblies and was backfilled with nitrogen. The force driving the movement of the backfill gas is buoyancy. A common metric employed to compare buoyancy driven systems is the Rayleigh Number (Ra), which can be computed for both systems. The Ra is expressed as follows.

$$Ra = (\rho^2 \beta g \Delta T L^3/\mu^2) \times Pr \quad [14]$$

where:

ρ ---------- density (kg/m^3)
β ---------- coefficient of expansion (1/K)
g ---------- gravitational constant = 9.8 m/sec^2
ΔT ---------- temperature difference = max. centerline temperature–basket bottom temperature (K)
L ---------- height of basket (m)
μ ---------- viscosity (N-sec/m^2)
Pr ---------- Prandtl number

Using the data from the benchmark thermal test and the analysis of the normal condition for MAGNASTOR, the Ra of the backfill gas can be computed for each analysis.

Design	Gas T_{ave} (K)	ρ (kg/m³)	β(1/K)	ΔT (K)	μ (N-sec/m²)	Pr	L (m)	Ra
MAGNASTOR	520	0.7501	1/520	222	2.63×10^{-5}	0.668	4.420	1.97×10^{11}
Benchmark	426	1.213	1/426	142	2.30×10^{-5}	0.703	4.076	4.33×10^{11}

Note: T_{ave} is the average gas temperature (helium for MAGNASTOR and nitrogen for the benchmark) used to evaluate the properties in this table.

As indicated by the preceding table, the Ra for MAGNASTOR is the same order of magnitude as that for the benchmark. This indicates that the buoyancy forces driving the flow in the benchmark are essentially identical to the buoyancy force in the MAGNASTOR design. Additionally, both models employ a laminar flow model inside the cavity. While the benchmark cask thermal test design stores 24 PWR fuel assemblies and the MAGNASTOR PWR design can store 37 PWR fuel assemblies, the arrays of both designs are comprised of square slots of nearly the same dimensions. The geometry of the flow area in the basket region is similar for both, since PWR fuel assemblies occupy a square slot in a square design. This is indicated in the following table, which contains the slot dimensions. These values indicate that the porous media parameters would also be similar, and in both analyses, the porous media parameters are computed using the same methodology.

Design	Fuel Assembly Width (inch)	Slot Size (inch)
MAGNASTOR	8.426	8.86/8.76
Benchmark	8.304	8.99

This indicates the high degree of similarity of both configurations. Additionally, in both designs, the downcomer region is comprised of a circular outer boundary and an inner boundary consisting of a series of edges of squares.

In both designs, the basket is formed of plates (or tubes for MAGNASTOR), which also serve as conductors to the periphery of the basket. In the benchmark evaluation and in the MAGNASTOR evaluation, the porous media material is modeled to represent the conduction in the basket as well, since the basket plates were not modeled explicitly. The conductivity for the porous media region represents the radial conductance, as well as the axial conductance of the baskets. The method used to compute the effective thermal conductivities for both baskets was identical.

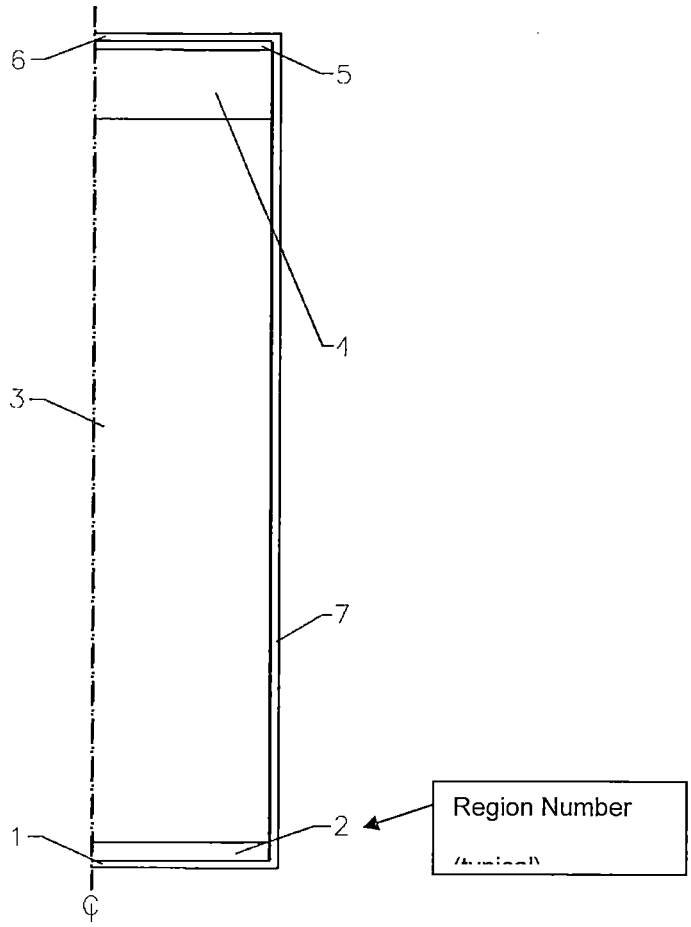
The reported results of the thermal test indicate that the two-dimensional modeling using FLUENT is conservative, since the FLUENT simulation of the benchmark predicted a higher temperature than the reported test data. It is important to note that the thermal boundary conditions for the FLUENT analysis of the benchmark thermal test employed the temperatures from the benchmark test directly, which eliminates any uncertainties in the analysis due to the

conduction through the benchmark cask body, convection from the cask surface, or variations in the ambient conditions over the cask. The analysis associated with the thermal test focused only on the convection internal to the cask cavity. This confirms that the axisymmetric modeling, in conjunction with the use of porous media material characterization, is an acceptable methodology for the computation of maximum fuel cladding temperatures.

4.8.1.7 Conclusions

In this section, a thermal evaluation has been performed for the thermal test described in EPRI N-5128 [16]. The analysis results indicate that the two-dimensional axisymmetric modeling methodology incorporating effective thermal properties and the flow resistance in the fuel region is acceptable to determine a bounding maximum fuel temperature. The benchmark also confirms the use of the hydraulic diameter for the representation of the nonaxisymmetric downcomer region, as well as the use of orthotropic properties for the basket conductance.

Figure 4.8-1 Two-Dimensional Model of the 24 PWR Assembly Thermal Test Configuration



Region Number	Description	Dimension (mm)
1	Bottom nitrogen region	45
2	Region below active fuel region in the basket	152
3	Active fuel region	3658
4	Region above active fuel region in the basket	248
5	Basket region without fuel	18
6	Top nitrogen region	29
7	Equivalent radial gap (downcomer region)	64

Figure 4.8-2 ANSYS Model for Determination of the Benchmark Basket Thermal Properties

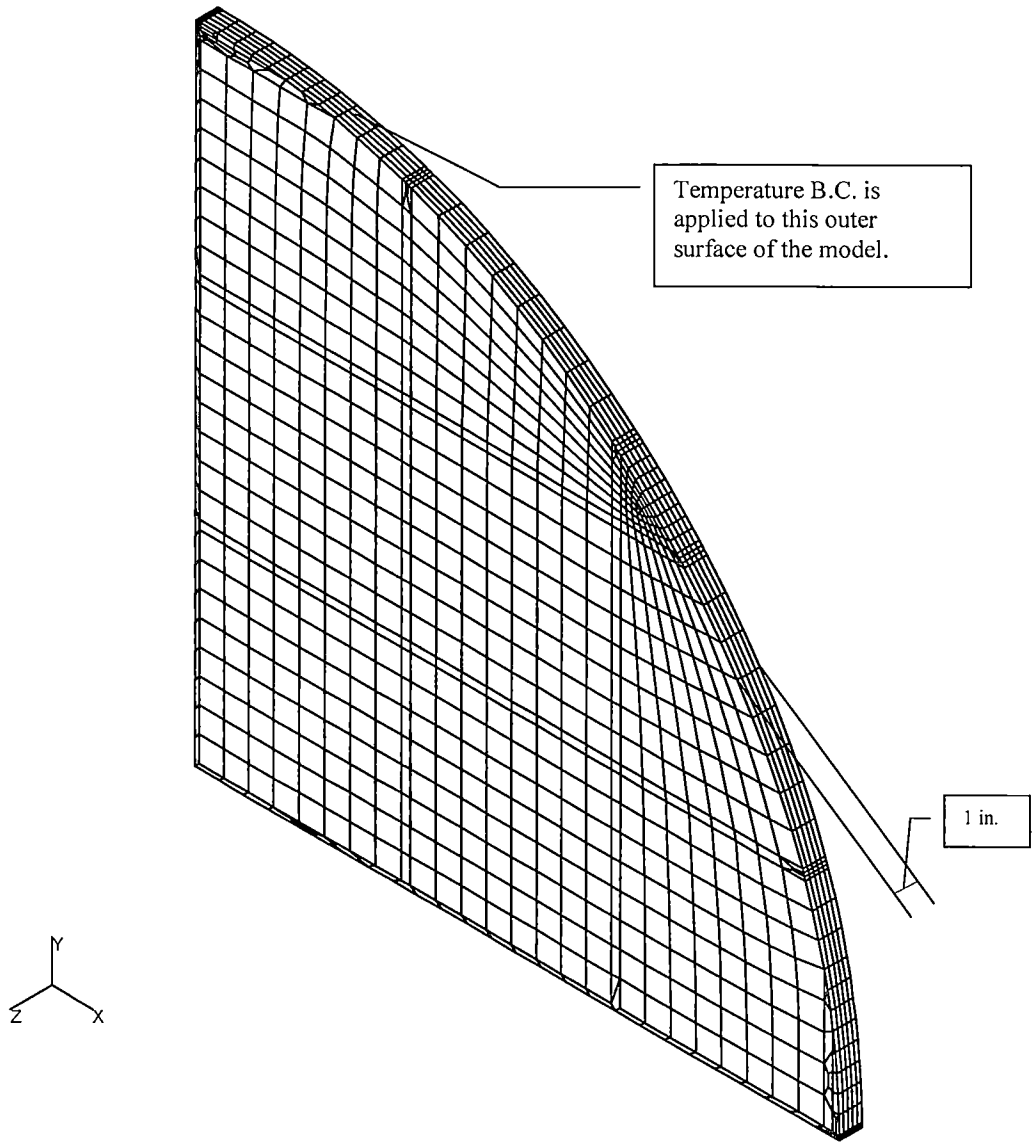


Figure 4.8-3 Temperature Profile from the Benchmark Cask Cavity Inner Surface

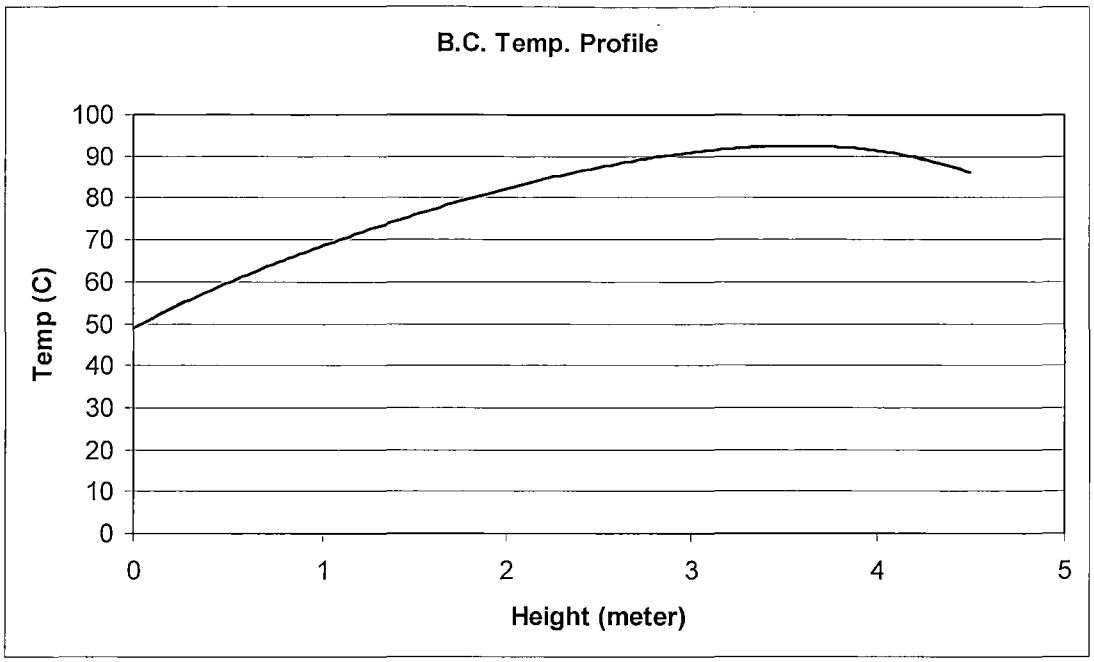


Figure 4.8-4 Axial Power Distribution Curve for the 15×15 PWR Fuel Assembly

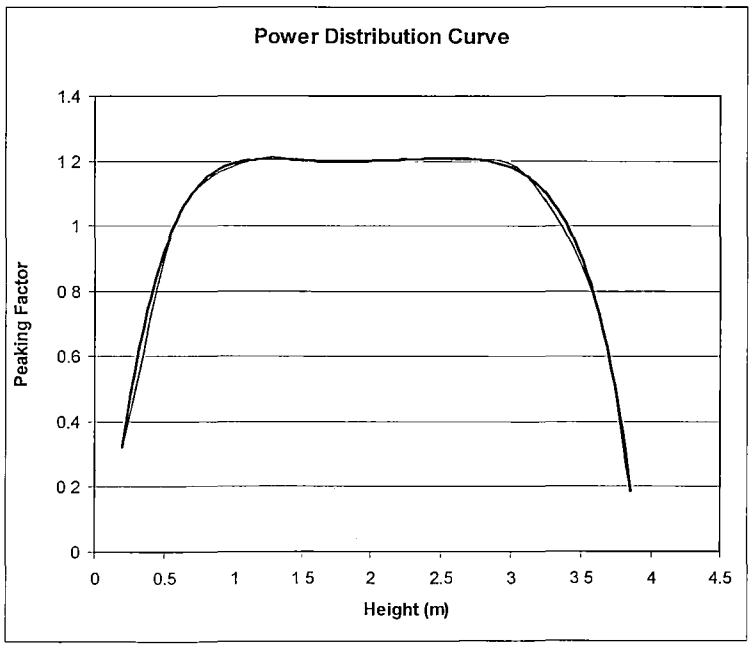
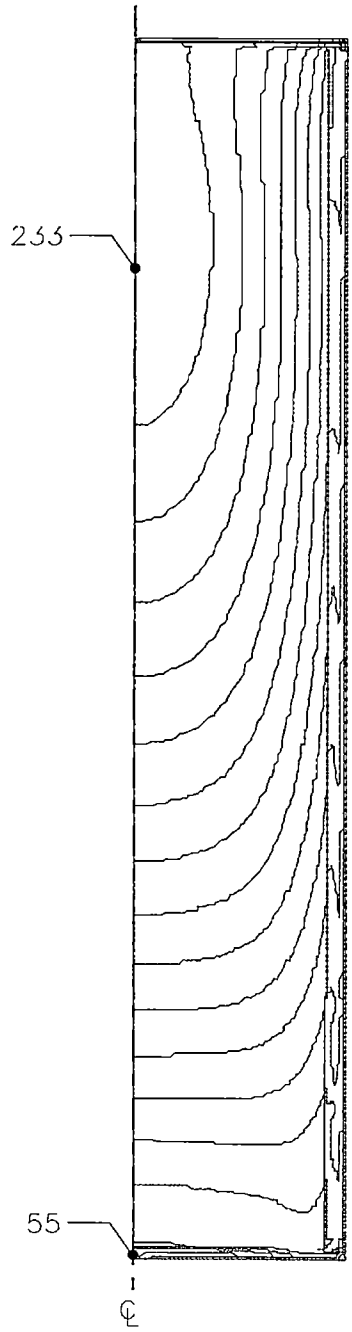


Figure 4.8-5 Temperature Contours for the Benchmark Cask Thermal Test



4.8.2 Methodology to Compute the Porous Media Constants

This section presents the methodology used to determine the porous media constants, which will simulate the flow resistance due to the fuel assembly and fuel assembly grids to be taken into account for the basket tube/fuel region of the two-dimensional axisymmetric TSC model.

To simulate the flow resistance in the porous media models, the following FLUENT porous media pressure drop [12] is employed.

$$\frac{\Delta P}{L} = \frac{\mu}{\alpha\varepsilon} V + C\left(\frac{1}{2}\rho V^2\right)$$

where:

$\Delta P/L$ ---------- pressure drop per unit length (Pa/m)
V ---------- superficial fluid velocity (m/s)
μ ---------- the fluid viscosity (kg/m-s)
ρ ---------- fluid density (kg/m^3)
α ---------- permeability parameter (m^2)
C ---------- inertial resistance factor (m^{-1})

In this representation, the pressure drop for the porous media consists of two terms: one being proportional to the velocity and the other proportional to the velocity squared. Since the velocities are on the order of 0.03 m/s in the porous media region, the contribution due to the V^2 term is neglected. The pressure drops for the fuel rods and the fuel assembly grids are taken into account in the first term. For the first term, the viscosity (μ) is obtained from the material properties defined for the gas, while the factor (α), referred to as the permeability, is computed on the basis of laminar flow. The purpose of this section is to determine an α for the BWR and the PWR fuel assemblies, which represents not only the resistance for the axial flow along the fuel rods, but also the additional resistance through the fuel assembly grids. The porous cells in the FLUENT program are 100% open in the porous media model [12]. Therefore, the factor for V must include the porosity factor with the values specified for $1/\alpha$. The input of $1/\alpha$ into FLUENT is adjusted based on the porosity of the porous media [12]. The permeability for the BWR and the PWR fuel assemblies is determined separately. Separate models are considered for the spacing, size of the fuel rods, and the number of fuel rods in the PWR and the BWR fuel assemblies.

Permeability (α) for the PWR Fuel Assembly

For the PWR fuel assembly, the configuration that is considered to provide a bounding value for α is the 17×17 fuel assembly. The calculation for the $1/\alpha$ for the entire PWR fuel assembly requires three FLUENT models. A quarter-symmetry model of the cross-section of the 17×17

fuel assembly is generated using FLUENT and the cross-section of the model is shown in Figure 4.8-6. The length of this fuel assembly model is 0.20 m in the axial direction, and consists of approximately 1.3 million cells. The purpose of this model is to determine the pressure drop per unit length $(\Delta P/L)_{ROD}$ along the fuel rod. For this reason, only the momentum equation is required to be solved. A velocity (U) for the gas entering the model is specified to be 0.03 m/s, which represents the velocity observed in the canister evaluation. Since the flow is considered to be laminar, the actual value used in the evaluation is not significant. Using the $\Delta P/L$ determined from the three-dimensional model, the $1/\alpha$ for the fuel rods is computed by

$$1/\alpha_{ROD} = (\Delta P/L)_{ROD} / (\mu\ U)$$

A second three-dimensional model is generated to determine the pressure drop of the gas through a 60 mm-long fuel assembly grid. A periodic model of a single cell is considered, which is shown in Figure 4.8-7, and consists of approximately 199,000 cells. The length of the model is 60 mm, which represents the full length of the 60 mm grid. The boundary conditions on the axial faces used in the fuel rod model are applied to each end of the periodic model of the fuel assembly grid. The model result is the determination of the average pressure at the outlet end of the grid, which is determined by computing the area averaged pressure acting on the outlet. This is used to compute the pressure drop per unit length $(\Delta P/L)_{GRID}$, which is used to compute the $1/\alpha_{GRID}$ for the fuel assembly grid by

$$1/\alpha_{GRID} = (\Delta P/L)_{GRID} / (\mu\ U)$$

Since the grid model is periodic, it simulates the condition in which the fuel assembly grid extends for the entire width of the basket slot region. This is not the geometry of the PWR fuel assembly grid in the basket, but rather there is a minimum of a 0.17-inch gap between the largest PWR fuel assembly and the smallest basket slot in the PWR basket. As the helium gas flows vertically up through the fuel rods, gas will not only flow through the fuel assembly grid, but also around the grid. To determine the distribution of the flow, a third three-dimensional quarter-symmetry FLUENT model consisting of approximately 332,500 cells is developed, as shown in Figure 4.8-8. A porous region with a length of 9.37 inches represents a section of fuel rods of 9.37 inches prior to the fuel assembly grid, and a section corresponding to a length of 9.37 inches is modeled after the fuel assembly grid. Both of these regions use the porous media constants determined for the bounding PWR fuel rod configuration. The bounding configuration was identified in two DOE reports ([23] and [24]) for the configuration with the largest combined grid length for all PWR assemblies. As shown in Figure 4.8-8, a nonporous gas region with a thickness of 0.17 inch is modeled in parallel with the region representing the fuel assembly grid. The porous media data for this model uses the results of the calculation of the porous media just for the fuel assembly grid. From the solution of the momentum equation, the

effective $1/\alpha_{EFF}$ corresponding to the pressure drop $(\Delta P/L)_{EFF}$ over the axial region containing the fuel assembly grid is computed using

$$1/\alpha_{EFF} = (\Delta P/L)_{EFF} / (\mu\ U)$$

The pressure drop is the difference between the averaged pressure on the outlet surface (area averaged) and the inlet, which is set to zero. To combine the permeabilities into a single quantity, the pressure drops over all the grids $[(\Delta P/L)_{EFF}]$ are added to the pressure drop $[(\Delta P/L)_{ROD}]$ over the remaining length of the fuel assembly (total fuel assembly length less the length of the fuel assembly grids) to calculate the total pressure drop due to fuel assembly grids and the fuel rods. Using an expression similar to the ones above, the $1/\alpha$ for the PWR fuel assembly is computed to be

$$1/\alpha_{PWR} = (\Delta P_{tot}/L_{tot}) / (\mu\ U) = 462{,}087\ 1/m^2$$

Permeability (α) for the BWR Fuel Assembly

For the BWR fuel assembly, the configuration that is considered to provide a bounding value for α is the 10×10 fuel assembly. The calculation for the $1/\alpha$ for the entire BWR fuel assembly requires two FLUENT models. A quarter-symmetry model of the fuel rods of the 10×10 fuel assembly was generated using FLUENT, and the cross section of the model is shown in Figure 4.8-9. The length of this fuel assembly model is 0.20 m in the axial direction, and consists of approximately 0.6 million cells. The walls of this model correspond to the BWR channel. This assumes that no helium gas flow is occurring between the BWR channel and the wall of the fuel tube. The model in Figure 4.8-9 does not contain any water tubes that are present in the BWR fuel assembly design. This is considered to be conservative since the cross-sectional area for flow is reduced by not considering gas flow through the water tubes.

This model is used to determine the pressure drop per unit length $(\Delta P/L)_{ROD}$ along the fuel rod, as was performed for the PWR fuel. A velocity (U) for the gas entering the model was specified to be 0.03 m/s, which represents the velocity observed in the canister evaluation. Since the flow is considered to be laminar, the actual value employed in the evaluation is not significant. Using the $\Delta P/L$ determined from the three dimensional model the $1/\alpha$ for the fuel rods is computed by

$$1/\alpha_{ROD} = (\Delta P/L)_{ROD} / (\mu\ U)$$

For the fuel assembly grid for the BWR, the pressure drop determined for the PWR fuel assembly grid was used. The evaluation of the effect of the grid for the PWR corresponds to a 17×17 fuel assembly which would inherently have more obstructions for flow as compared to a worst case 10×10 BWR fuel assembly. The pressure drop across the PWR fuel assembly grid is therefore considered to bound the pressure drop associated with the fuel assembly grid for the BWR design.

To combine the permeabilities into a single quantity, the pressure drop over multiple grids is computed. The bounding configuration was identified in references [23] and [24] for the configuration with the largest combined grid length for all BWR assemblies. The combined pressure drop was calculated by adding $((\Delta P/L)_{GRID})$ to the pressure drop $((\Delta P/L)_{ROD})$ over the remaining length of the fuel assembly (total fuel assembly length less the total length of the fuel assembly grids). The $1/\alpha$ for the entire BWR fuel assembly is computed to be

$$1/\alpha_{BWR} = (\Delta P_{tot}/L_{tot}) / (\mu\ U) = 566{,}550\ \ 1/m^2$$

Figure 4.8-6 Cross-Sectional View of the Three-Dimensional FLUENT Model of a 17×17 PWR Fuel Assembly

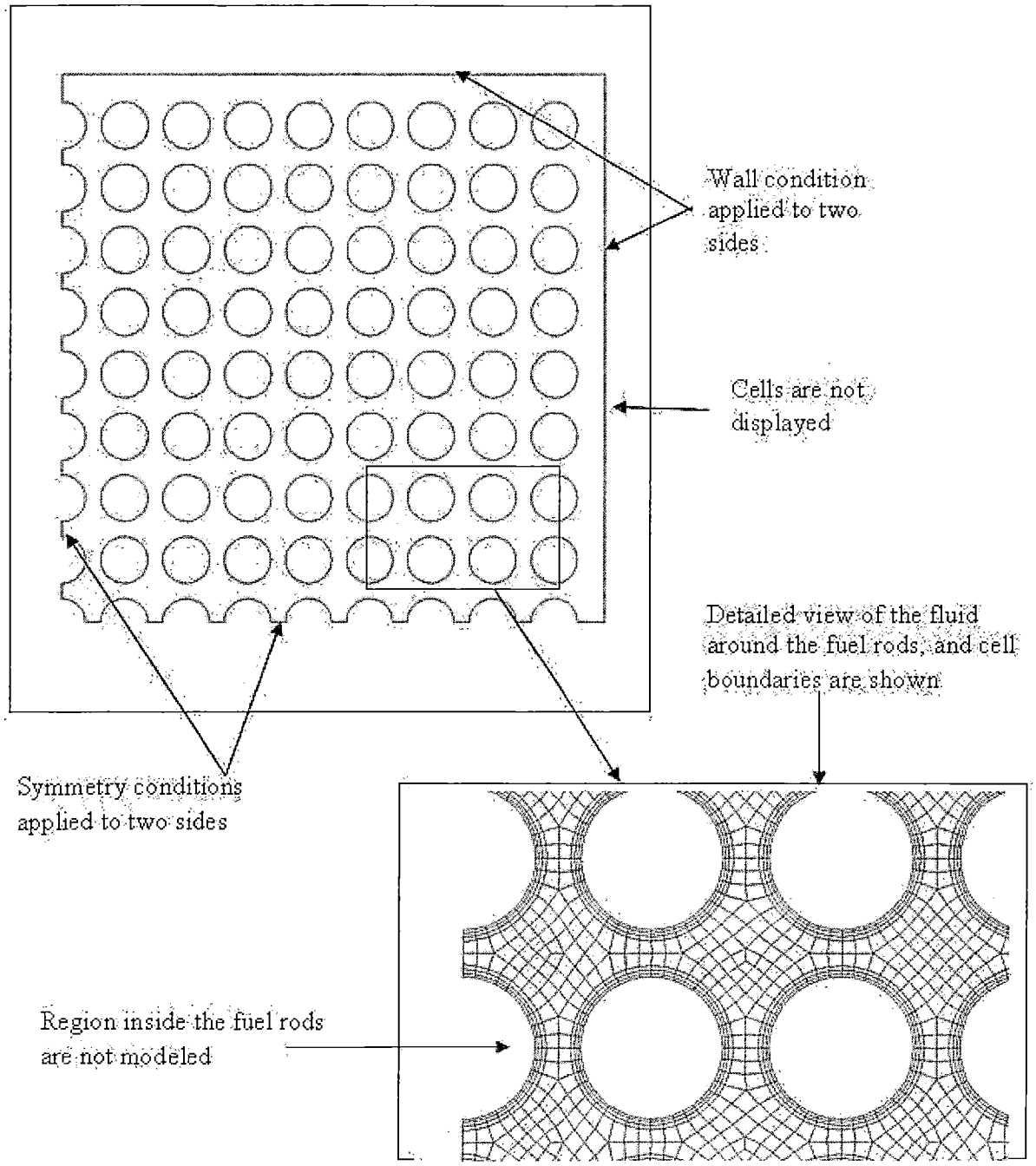
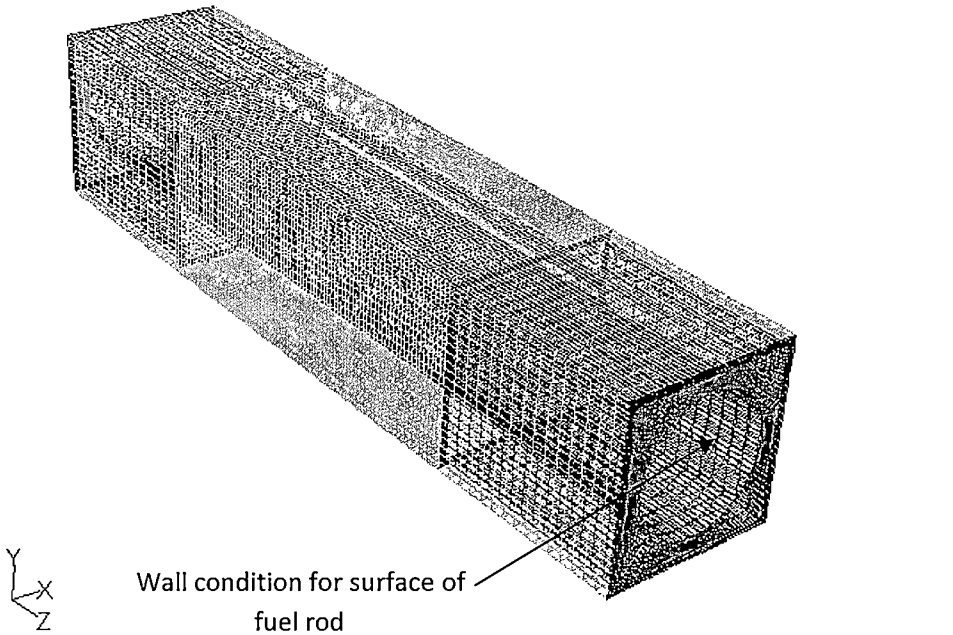


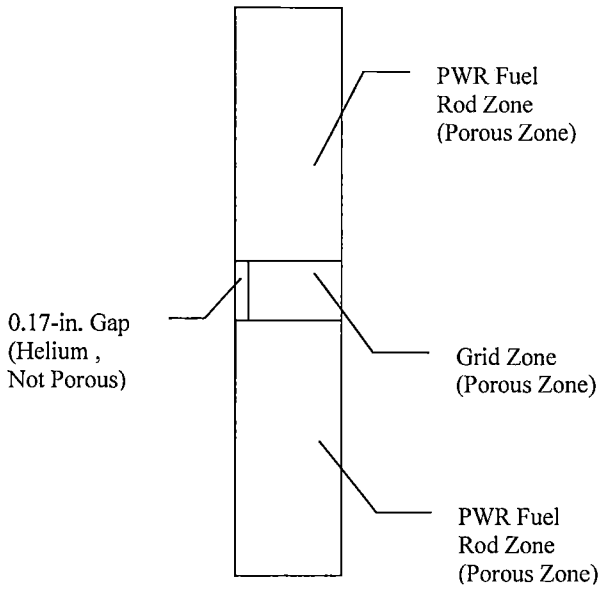
Figure 4.8-7 Three-Dimensional FLUENT Model of a Fuel Assembly Grid



Grid

Jan 10, 2006
FLUENT 6.2 (3d, dp, segregated, lam)

Figure 4.8-8 Three-Dimensional FLUENT Quarter-Symmetry Model for the Flow Around the Grid



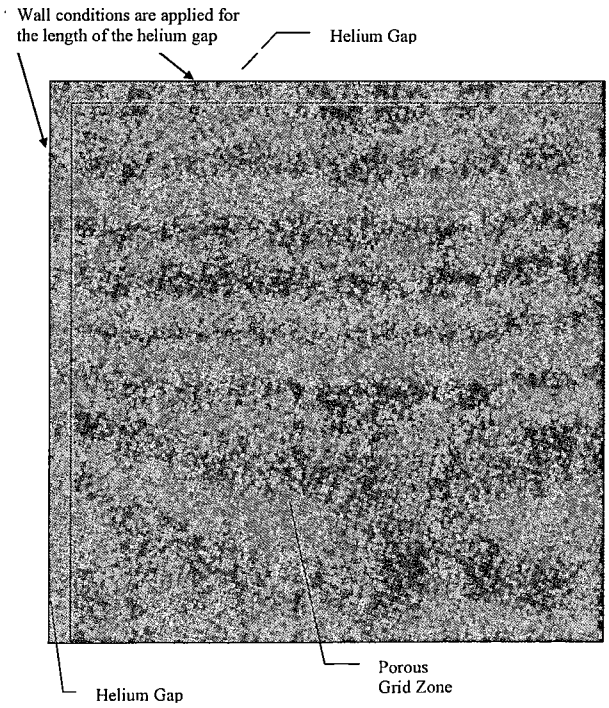
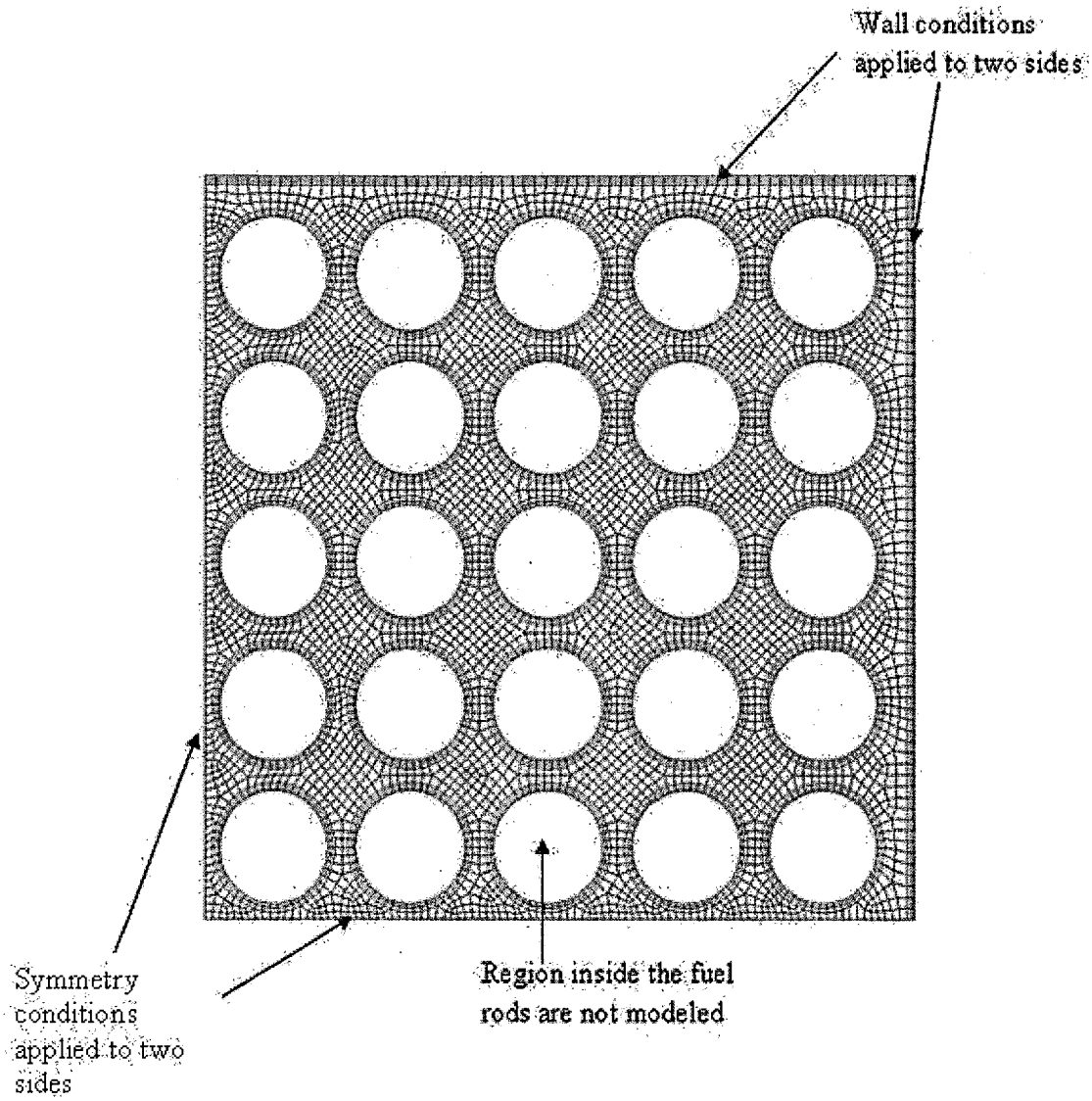


Figure 4.8-9 Cross-Sectional View of the Three-Dimensional FLUENT Model of a 10×10 BWR Fuel Assembly



4.8.3 Benchmark Evaluation of the Two-Dimensional Axisymmetric Methodology for Annular Cooling in the Concrete Cask for MAGNASTOR

In this section, a benchmark evaluation is performed to evaluate the adequacy of the k-ω and the low Reynold's (low Re) k-ε turbulent flow models that can be used in the evaluation of the flow in the annulus between the canister and the concrete cask. A thermal evaluation using two-dimensional modeling methodology is performed for a system for which a thermal test has been conducted. The thermal test is described in EPRI TR-100305 [21]. The results of the thermal evaluation using the two-dimensional methodology performed in this section show that both turbulent flow models provide conservative temperatures for the canister surface and the concrete cask liner. This thermal benchmark evaluation confirms that the use of the k-ω turbulence model, in conjunction with the two-dimensional methodology, is conservative and, therefore, acceptable for use in the thermal evaluation of MAGNASTOR.

4.8.3.1 Introduction

The thermal design of MAGNASTOR rejects heat from the canister surface to the ambient environment via convection and radiation. Ambient air enters the base of the concrete cask, removes heat via convection from the canister surface, as well as from the surface of the concrete liner, and exits the top of the concrete cask through radial outlets. Radiation of heat from the canister surface to the concrete liner also occurs, which allows the heat to then be convected into the annulus region or conducted through the thickness of the concrete cask. The annulus region is axisymmetric, with the exception of the air inlet and the air outlet, thus lending itself to representation by a two-dimensional axisymmetric model. While the air inlet and air outlet are rectangular in shape, the cross-sectional area of the air inlet and air outlet in an axisymmetric model can vary radially to account for the constant cross-sectional area in the actual test article. A single height for the inlets and outlets can be used, provided the modeled height does not represent more cross-sectional area than the actual inlet and outlet. An important consideration for the analysis of the annulus air flow is the identification of the turbulent flow models. Two models are available: k-ω and low Re k-ε turbulent flow models, which are described in the FLUENT documentation [12]. Selection of the turbulent flow model for MAGNASTOR is based on the thermal test data provided in EPRI TR-100305 [21].

4.8.3.2 Purpose

The purpose of this section is to provide a thermal benchmark, which will demonstrate that the k-ε turbulent flow model used in the MAGNASTOR thermal evaluation is conservative.

4.8.3.3 Description of the Thermal Test

In EPRI TR-100305 [21], thermal testing was performed for a vertical concrete cask loaded with a canister containing 17 PWR fuel assemblies with a total heat load of 14.9 kW. The basket contained in the cask during testing was comprised of 17 square slots in which the basket walls were constructed of carbon steel. A series of thermal tests were performed that corresponded to different canister conditions, as well as different air inlet and air outlet conditions. To minimize the uncertainty introduced by other thermal behavior, either inside the canister or outside the canister, the test using the vacuum condition with fully opened vents was employed. This test was conducted inside a large structure, which removed the uncertainty of solar insolance affecting the surface temperatures. Additionally, the method and location in which the inlet temperatures were measured were also documented. Axial profiles of the temperatures for the canister surface, as well as the concrete liner surface, were provided in the results published for the thermal test. The temperature profile provides the basis for the comparison of the performance of the different turbulent flow models.

4.8.3.4 Fluent Model Description

The FLUENT two-dimensional axisymmetric model of the VSC-17 is comprised of the canister and the concrete cask. The definition of the regions and the cells comprising the model is shown in Figure 4.8-10. Since the vacuum condition is being modeled in the canister, the only region to support fluid flow is the air annulus region between the canister and the concrete liner. The edge of the model corresponds to the outer surface of the concrete cask. The model contains the same changes in direction in the air inlet and the air outlet as exist in the concrete cask used in the thermal test. The heights of the air inlet and air outlet for each segment are selected to allow the physical cross-sectional area to bound the area contained in the FLUENT model.

There are two parameters of interest that influence the heat rejection into the annulus region. Since the heat is being radiated from the canister to the inner liner of the concrete cask, the emissivity of the two facing surfaces (the outer surface of the canister and the inner surface of the liner of the concrete cask) can directly influence the heat transfer. In this evaluation, an emissivity value of 0.7 was used for the carbon steel surfaces. More important is the selection of one of the turbulent flow models for the air flow up through the annulus region: a transitional turbulent flow model (k-ω model) or a low Re turbulent flow model (low Re k-ε model). In FLUENT, either turbulent flow model can be selected. Unlike the specification of emissivity as a property of the surface, the use of a particular turbulence model defines certain requirements for the cells adjacent to the wall. The radial size of the cell divisions near the wall is typically compared to a dimensionless quantity defined as y+ [12]. Guidelines contained in Reference 12

recommend using a y+ of near unity for the transitional model (k-ω) and for the low Re k-ε model. This implies that the near wall cell divisions for the models are significantly refined near the wall.

4.8.3.5 Effective Properties for the Basket and Fuel Region

For the regions corresponding to the basket, effective properties are employed in the analysis. The effective thermal properties for the basket region are computed using an ANSYS model shown in Figure 4.8-11. In Reference 21, the description of the basket indicates that a cylindrical shell (connected to the outer basket tubes) forms part of the surface facing the inner surface of the canister. Outside of the axial locations that do not have the cylindrical shell, the outer surface of the outer basket slots faces the inner surface of the canister shell directly. The model shown in Figure 4.8-11 models the cylindrical shell for the full length of the basket. The cylinder shell, where it does exist in the canister used in the thermal test, provides an additional radiation shield that reduces the effectiveness of the radiation heat transfer from the outer basket tubes to the canister shell. This would result in higher basket temperatures in the analyses. In the FLUENT model in Figure 4.8-10, there is a gap between the outer radius of the cylindrical shell and the inner surface of the canister. Between these two surfaces, radiation is simulated using conduction properties that have a cubic temperature dependency.

The basket cross-section model contains the carbon steel basket and the fuel regions, which are modeled with homogeneous orthotropic thermal conductivities. To determine the temperature-dependent effective thermal conductivity of the basket region, a series of temperatures is applied to the boundary of the model (as shown in Figure 4.8-11). Solutions for each boundary condition determine the maximum temperature of the basket and the associated change in temperature from the boundary to the maximum temperature location. The effective thermal conductivities are determined using the same expression employed for MAGNASTOR in Section 4.4.1.2.

4.8.3.6 Boundary Conditions

The outer edges of the model correspond to the outer surface of the concrete cask. Two cases are presented in this section to assess the performance of each turbulent flow model. The boundary conditions employed for each model were identical, with the exception of the selection of the turbulent flow model.

Temperature Specification

The edge of the model includes not only the air inlet and the air outlet, but also the remainder of the concrete cask surface. For the air inlets, the average temperature of the test recorded ambients for the vacuum test for the fully opened inlets (Run No. 6 in [21]) was applied as the

temperature for the air inlet in the model. For the remainder of the concrete cask surface, a temperature of 26°C was used for computation of the heat transfer by natural convection from the side and top of the concrete cask. A film coefficient was also specified for the bottom surface of the model to maximize the heat transfer to the base, thereby reducing the heat flux to the canister surface.

Heat Generation

The total heat load applied to the active fuel region of the model was 14.9 kW, and a user specified function reflected the power profile curve for the fuel in EPRI TR-100305 [21]. The power distribution has a peaking factor of 1.2. The heat generation was assumed to be uniformly distributed over the radial direction from the basket centerline to the outer radius of the porous media region.

Buoyancy

Since the annulus gas was specified as an ideal gas, the only condition required to enact buoyancy as a driving force for the air is to set the gravity acceleration as –9.8 m/sec^2.

An additional parameter that must be specified is the "operating" density at the air inlet. Since the annulus gas is being treated as an ideal gas, the "operating" density was specified to be the density of the gas at the inlet temperature for a site elevation of 1,400 m.

4.8.3.7 Analysis Results

The temperature profiles for the two turbulent flow models for the canister surface and for the concrete cask liner surface are shown in Figure 4.8-12 and Figure 4.8-13, respectively. The results confirm that both turbulent flow models conservatively predict the temperatures on both the canister surface and the concrete liner surface. The temperature profiles for the low Re k-ε model provided a slight improvement over the k-ω turbulent flow model.

4.8.3.8 Application of the Benchmark to the MAGNASTOR Evaluation

The primary purpose of the preparation of this benchmark is to confirm the selection of the turbulent flow model, and for this reason, the vacuum test in EPRI TR-100305 [21] was selected, which minimized the uncertainties of the thermal behavior internal to the canister. The air flow in the annulus is primarily controlled by the height, the radial thickness of the annulus and the heat load. Since the test in EPRI TR-100305 [21] employed actual fuel assemblies, the height of the annulus in the thermal test and in the MAGNASTOR design are sufficiently similar. The thicknesses of the annulus region for the thermal test and for the MAGNASTOR are 3 inches and 3.75 inches, respectively. A metric for buoyancy-driven flows for vertical parallel surfaces is a

modified Rayleigh's number in which the standard Rayleigh number is factored by the ratio (D/L) of the gap thickness (D) and the length (L). Since D/L is actually larger for the MAGNASTOR design, this would indicate that the modified Rayleigh number is larger for MAGNASTOR, resulting in increased convection. Likewise, the design basis heat load for MAGNASTOR is 35.5 kW, as compared to the thermal test using 14.9 kW. Increased heat load would only increase the level of turbulence in the annulus region.

4.8.3.9 Conclusions

In this section, a thermal evaluation has been performed for the thermal test described in EPRI TR-100305 [21]. The analysis results indicate that the two-dimensional axisymmetric modeling methodology using the k-ω turbulent flow model is acceptable to determine a bounding maximum fuel temperature and bounding concrete temperatures. The benchmark also confirms the use of the operating density associated with the ambient temperature for the concrete cask.

Figure 4.8-10 Two-Dimensional Axisymmetric FLUENT Model of the VSC-17

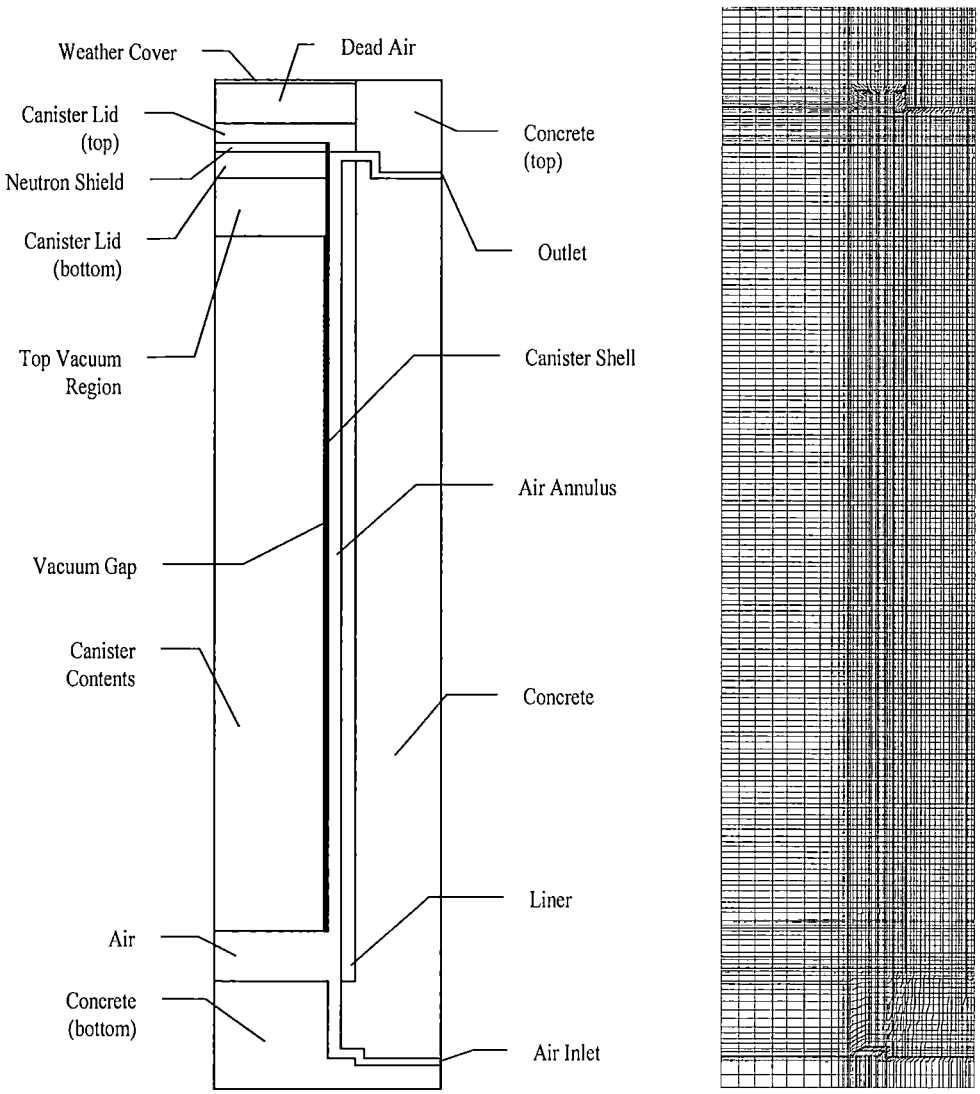


Figure 4.8-11 ANSYS Model for Effective Properties Calculation

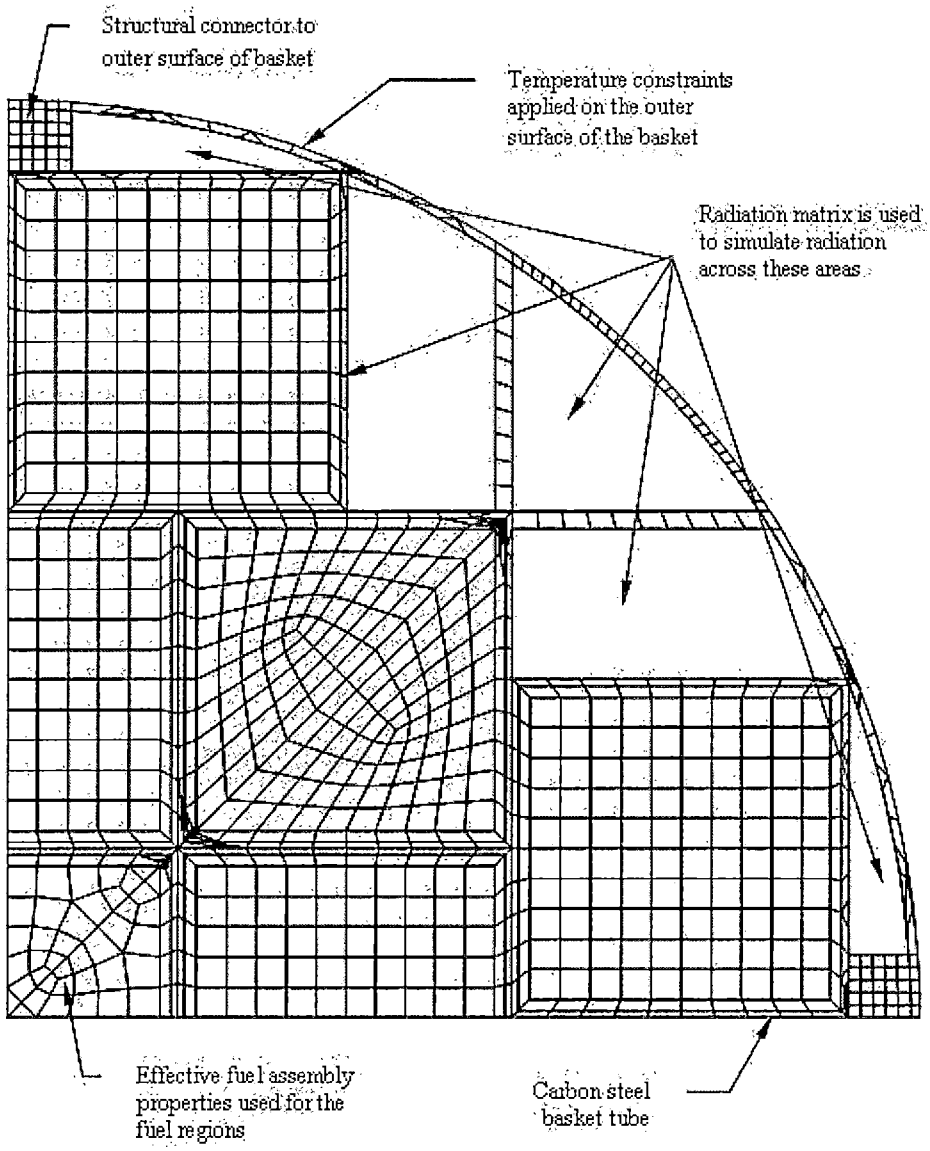


Figure 4.8-12 Temperature Profiles for the Canister Surface

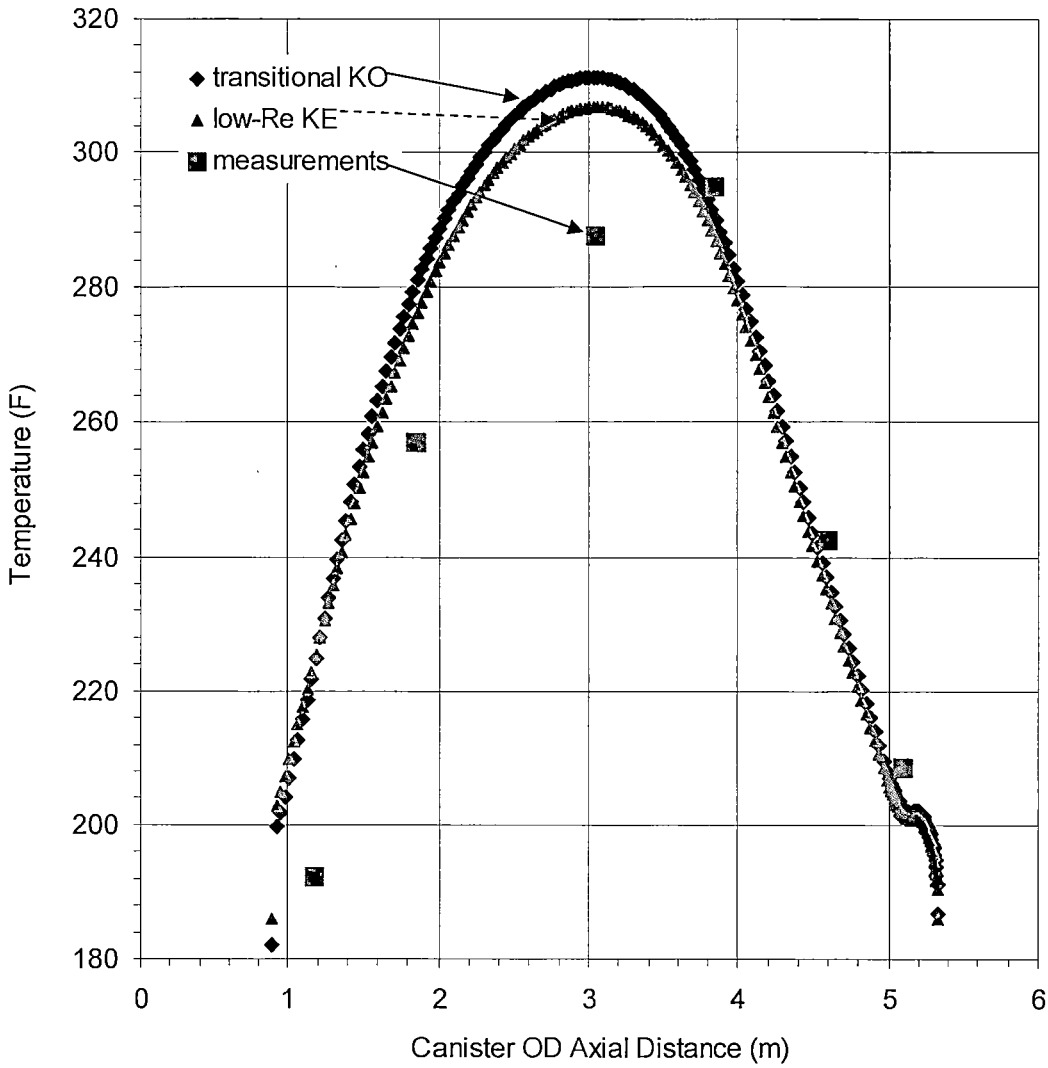
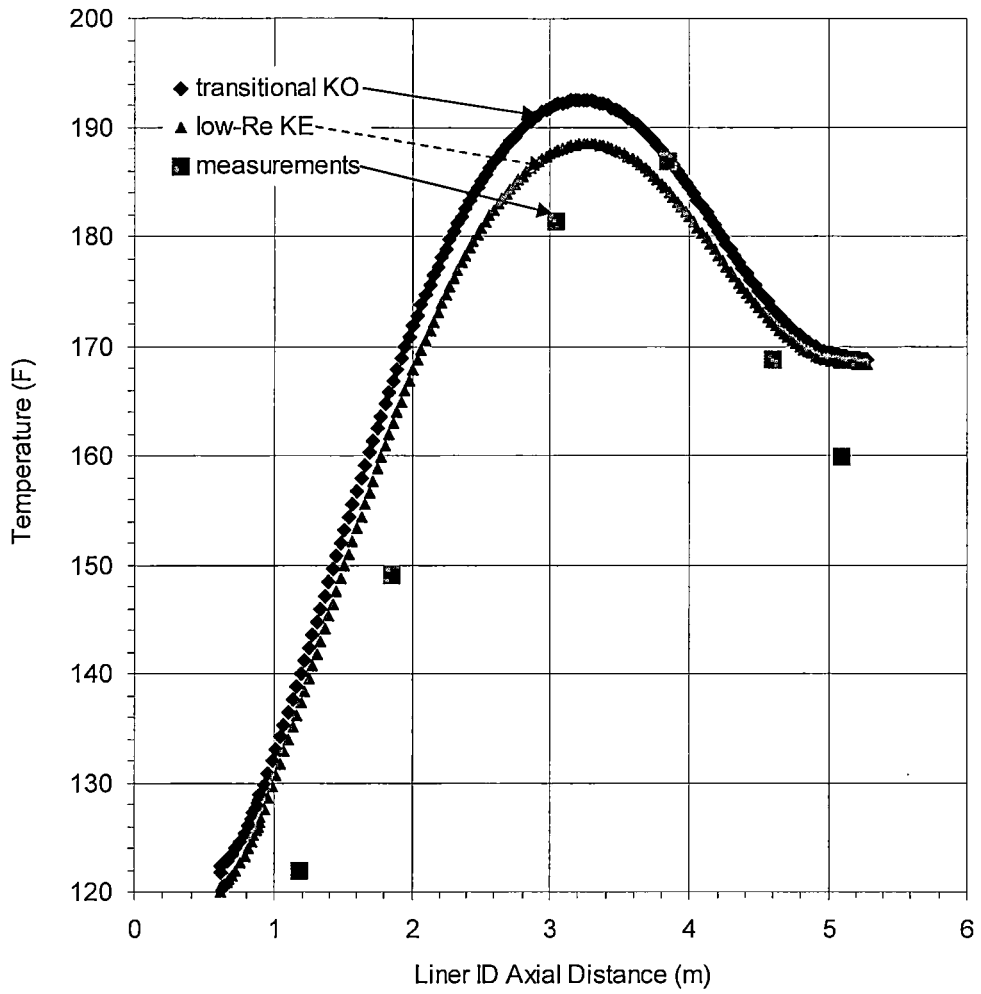


Figure 4.8-13 Temperature Profiles for the Concrete Liner Surface



4.9 Thermal Contingency Events During PWR TSC Preparation and Transfer Operations

This section has been prepared to present the analyses performed to evaluate the postulated thermal contingency events, and operational corrective actions to be taken to resolve these events. These events have been analyzed to ensure that the MAGNASTOR System for PWR spent fuel assemblies can be safely loaded by Licensees. Operational requirements for identification of the contingency events and the actions to be taken to resolve are documented in the MAGNASTOR System Operations Manual, Document No. 71160-P-02, or site-specific Operations Manuals prepared for specific utility users.

4.9.1 Water Phase Contingency Events for PWR Fuel

Water phase contingency events are applicable after closure lid installation through initiation of draining operations. This includes operations such as TSC removal from the spent fuel pool, TSC lid closure welding, and TSC hydrostatic testing. Time and temperature limitations are based on full heat load PWR decay heat (maximum of 35.5 kW) and are bounding of lower decay heat loads.

The following water phase contingency events have been analyzed:

[redacted]

4.9.2 Draining and Vacuum Drying Phase Contingency Events for PWR Fuel

Draining and vacuum drying phase contingency events are applicable from the start of TSC cavity water draining operations through completion of the final helium backfill and completion of Helium Backfill Time in accordance with Technical Specification LCO 3.1.1. Normal operations include continuous ACWS or equivalent cooling, throughout the draining, vacuum drying, and helium backfill phases to maintain TSC temperatures below normal allowable/operational limits. Cooling is confirmed during ACWS by monitoring the transfer cask (MTC) annulus outlet temperature and ensuring it is ≤ 113°F. For reverse ACWS flow, the inlet temperature and flow rate are monitored to ensure they meet the following approved operational limits:

- A maximum inlet water temperature of ≤ 100°F, which requires a minimum inlet flow rate of ≥ 60 GPM
- A minimum inlet flow rate of ≥ 40 GPM, which limits the maximum inlet water temperature to ≤ 70°F

The following draining and vacuum drying phase contingency events have been analyzed:

[redacted]

[redacted]

[redacted]

4.9.3 TSC Transfer Phase Contingencies for PWR Fuel

The TSC Transfer Phase contingency events are applicable during the period from the termination of ACWS cooling following completion of the required Minimum Helium Backfill Time (i.e. cooling time) per LCO 3.1.1 through completion of TSC transfer from the MTC into the VCC. The allowable TSC Transfer Times are as specified in Technical Specification LCO 3.1.1, as applicable to the decay heat load and Minimum Helium Backfill Time (i.e. cooling time) utilized.

[redacted]

[redacted]

[redacted]

4.9.4 Post TSC Transfer Phase Contingency Events for PWR Fuel

The Post-TSC Transfer Phase contingency events are applicable following completion of the TSC transfer to the VCC and relate to the potential for final measurements of TSC exterior surfaces removable surface contamination levels exceeding Technical Specification allowable levels.

[redacted]

Chapter 5
Shielding Evaluation

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5 SHIELDING EVALUATION

Specific dose rate limits for individual casks in a storage array are not established by 10 CFR 72 [1]. Annual dose limit criteria for the ISFSI-controlled area boundary are established by 10 CFR 72.104 and 10 CFR 72.106 for normal operating conditions and for design basis accident conditions, respectively. These regulations require that, for an array of casks in an 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. For a design basis accident, the dose to an individual outside the controlled area boundary must not exceed 5 rem to the whole body. In addition, the occupational dose limits and radiation dose limits established in 10 CFR Part 20 (Subparts C and D) [2] for individual members of the public must be met.

This chapter describes the shielding design and the analysis used to establish bounding radiological dose rates for the safe storage of up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly or damaged fuel, which may be a damaged PWR fuel assembly or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

PWR fuel assemblies may contain nonfuel hardware – i.e., reactor control components (RCCs), burnable poison rod assemblies (BPRAs), guide tube plug devices (GTPDs), neutron sources/neutron source assemblies (NSAs), hafnium absorber assemblies (HFRAs), instrument tube tie components, in-core instrument thimbles, and steel rod inserts (used to displace water from the lower section of guide tubes), and components of these devices, such as individual rods. The analysis shows that for the design basis fuel, the system meets the requirements of 10 CFR 72.104 and 10 CFR 72.106 and complies with the requirements of 10 CFR 20 with regard to annual and occupational doses at the owner-controlled area boundary.

The system is designed with two transfer cask and four concrete cask configurations. Transfer casks are designed with either carbon steel shells for PWR and BWR systems (MTC1) or stainless steel shells for the PWR system (MTC2). Concrete casks are designed in:

- A standard shielding configuration (one piece – CC1 and segmented – CC2) with a 1.75-inch liner thickness (PWR and BWR systems);
- An augmented shielding configuration (CC3) with a 3-inch liner thickness, an increased lid thickness and additional shielding at the air inlets (PWR system);
- And a short, standard shielding configuration cask (CC4) with a 1.75-inch liner thickness and additional shielding at the air inlets (PWR system).

Canisters may be sealed with either an all stainless steel closure lid (PWR and BWR systems) or a composite carbon steel and stainless steel lid assembly (PWR system). BWR evaluations are performed with the all stainless steel closure lid and PWR evaluations are performed with the composite closure lid assembly. The composite lid assembly bounds the all stainless steel lid in shielding evaluations due to the lower density of carbon steel.

Minimum cool times prior to fuel transfer and storage are specified as a function of minimum assembly average fuel enrichment and maximum assembly average burnup (MWd/MTU). To minimize the number of loading tables, PWR and BWR fuel assemblies are grouped by bounding fuel and hardware mass. Key characteristics of each assembly grouping are shown in Section 5.2. Refer to Section 5.8.9 for detailed loading tables meeting the system heat load limits.

Source terms for the various vendor-supplied fuel types are generated using the SCALE 4.4 sequence as discussed in Section 5.2. Three-dimensional MCNP [3] shielding evaluations provide dose rates for transfer and concrete casks at distances up to four meters. NAC-CASC, a modified version of the SKYSHINE-III code [4], calculates site boundary dose rates for either a single cask or cask array. See Section 5.6 for more detail on the shielding codes.

5.1 Cask Shielding Discussion and Dose Results

The TSC is loaded and sealed inside a transfer cask and then moved into a concrete cask for placement on the ISFSI pad. Dose evaluations are performed for the various TSC contents when the TSC is inside the transfer cask or the concrete cask.

With the exception of the offsite dose discussion, the dose results are presented based on bounding heat loads and corresponding source terms based on a 35.5 kW PWR cask heat load and a 35 kW BWR cask heat load. Offsite dose results are produced by similar bounding values of a 40 kW PWR cask heat load and a 38 kW BWR cask heat load. Thermal evaluations restrict BWR payloads to 33 kW. Cool time tables for the thermally restricting payloads are listed in Section 5.8.9. Based on the code validation discussion in Section 5.2, a 5% uncertainty is applied to the heat loads for fuel burnups above 45 GWd/MTU. This results in an extension in minimum allowed cool time for high burnup fuel assemblies. All dose rates calculated at higher cask heat loads are bounding for the reduced heat load. For any fuel type, burnup, initial enrichment, and cool time combination allowed, additional cool time and, therefore, reduced sources are associated with the lower cask heat load. This conclusion applies also to the PWR preferential loading patterns.

A reduced minimum cool time of 2.5 years and four-zone preferential loading pattern (max 1.8 kW/assy heat load) are evaluated in Section 5.9 for undamaged or damaged PWR assembles in the CC4 or MTC2.

Dose rates (detector tallies) in this chapter are calculated using Monte Carlo methods and, therefore, contain a result and statistical uncertainty of the result. The statistical uncertainty is expressed as a percentage and referred to as fractional standard deviation (FSD) or relative uncertainty.

5.1.1 Transfer Cask Shielding Discussion and Dose Results

The transfer cask radial shield is comprised of steel inner and outer shells connected by solid steel top and bottom forgings. The shell encloses a lead gamma shield and a solid borated polymer (NS-4-FR) neutron shield. The TSC shell and the basket internal structure provide additional radial shielding. The transfer operation bottom shielding is provided by the TSC bottom plate and solid steel transfer cask doors. The TSC closure lid provides radiation shielding at the top of the TSC.

The three-dimensional transfer cask shielding analysis provides a complete, nonhomogenized representation of the transfer cask and TSC structure. The model assumes the following TSC/transfer cask configuration for all dose rate evaluations.

- Dry canister cavity
  The majority of the TSC operations, in particular closure lid welding, are performed with the TSC cavity filled with water. Evaluating a dry canister cavity is conservative. Note that the water filling the TSC/transfer cask annulus between the inflatable seals is modeled. Transfer cask dose rates from a wet canister, while containing an increased neutron source due to a higher subcritical multiplication resulting from a higher k_{eff}, are lower than those of the dry system due to the additional radiation shielding provided by the water within and surrounding the source region. PWR and BWR confirmatory calculations comparing dry, wet and partially flooded canister configurations are included in Section 5.8.11.

- 6-in auxiliary weld shield
  Closure lid weld operations are typically performed with an automated weld system that is mounted on a weld platform. The presence of this platform provides significant auxiliary shielding during the TSC closure operation.

- Homogenization of the fuel assembly into five source regions
  While TSC and concrete cask features are discretely modeled, the fuel assembly is homogenized into upper and lower end-fitting (nozzle) regions, upper and lower plenum regions (lower plenum regions are modeled only for B&W fuel assemblies), and an active fuel region. For shielded applications, such as in the heavily shielded spent fuel transfer and concrete casks, homogenizing the fuel region does not introduce a significant bias in the dose results presented.

5.1.1.1 Undamaged Fuel Dose Rates

The carbon steel and stainless steel transfer cask maximum calculated dose rates are shown in Table 5.1.3-1 and Table 5.1.3-4. Payload types producing maximum surface dose rates are listed in Table 5.1.3-3 and Table 5.1.3-6. TSC surface contamination release dose rates are shown in Section 5.6.5. Dose rates are based on a three-dimensional Monte Carlo analysis using surface detectors. Uncertainty in Monte Carlo results is indicated in parentheses. Further detail on the detector geometry is included in Section 5.5. There is no design basis off-normal or accident event that will affect the shielding performance of the transfer cask.

Transfer cask top-, side-, and bottom-surface average dose rates are 254 (1.1 %) mrem/hr, 895 (<1%) mrem/hr, and 3,000 (<1%) mrem/hr, respectively. Access to the bottom of the cask is limited to pool-to-workstation transfer operations and the workstation-to-vertical concrete cask transfer operations. Site ALARA plans should specify limited access to areas below and around the loaded transfer cask during lifting and transfer operations.

5.1.1.2 Damaged PWR Fuel Dose Rates

Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. DFC slots are locations 4, 8, 30 and 34 in Figure 5.8.12-10. To ensure that the worst case configuration is considered, two damaged fuel scenarios are evaluated.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. This scenario is modeled by filling the fuel assembly interstitial volume with UO_2 and increasing the fuel neutron, gamma and n-gamma source consistent with this increase in mass. Dose rate profiles for the 37-assembly undamaged assemblies are compared with profiles for 33 undamaged and 4 damaged assemblies in Section 5.8.12. Based on the self-shielding of the added mass compensating for the increase in source, damaged fuel dose rates for the first scenario are bounded by either the corresponding undamaged fuel dose rates or the second damaged fuel scenario.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. However, no credit is taken for the reduction in the lower end fitting hardware dose rate due to the added UO_2 mass and self-shielding nor for the reduction in fuel mass migrated from the active fuel region. In this case, transfer cask bottom surface dose rates increase due to the addition of damaged fuel. The transfer cask bottom axial dose rate increases 53 mrem/hr, increasing the bottom axial dose rate by approximately 0.9 percent. Radial dose rates for PWR fuel increase, but remain less than the bounding BWR fuel.

Damaged fuel dose rates are computed using the carbon steel transfer cask, as it produces higher dose rates than the stainless steel transfer cask due to the higher density of stainless steel versus carbon steel.

Damaged fuel maximum dose rates in the carbon steel transfer cask are summarized in Table 5.1.3-9.

5.1.2 Concrete Cask Shielding Discussion and Dose Results

The concrete cask is composed of body and lid components. The body contains the air inlets, air outlets, and the cavity for TSC placement. The lid provides environmental closure for the TSC. The radial shield design is comprised of a carbon steel inner liner surrounded by concrete. The concrete contains radial and axial rebar for structural support. As in the transfer cask, the TSC shell provides additional radial shielding. The concrete cask top shielding design is comprised of the TSC lid and concrete cask lid. The concrete cask lid incorporates both concrete and steel plate to provide additional gamma shielding. The bottom shielding is comprised of the stainless steel TSC bottom plate, the pedestal/air inlet structure, and a carbon steel base plate. Radiation streaming paths consist of air inlets located at the bottom and air outlets located above the top of the TSC, and above the annulus between the concrete cask body and the TSC. Air inlets and outlets are radial openings to the concrete cask. The inlets and outlets are axially offset from the source regions to minimize dose and meet ALARA principles.

No auxiliary shielding is considered in the concrete cask shielding evaluation. All components relevant to safety performance are explicitly included in the concrete cask model. Homogenization of materials used in the models is limited to the fuel assembly as described in Section 5.1.1.

5.1.2.1 Undamaged Fuel Dose Rates

Refer to Table 5.1.3-2, Table 5.1.3-5, and Table 5.1.3-7 for a summary of the concrete cask normal condition and accident event maximum calculated dose rates for the standard (CC1/ CC2), augmented shield (CC3), and short, standard (CC4) cask configurations. Listed maximum dose rates include fuel and nonfuel hardware contributions. Payload types producing maximum surface dose rates are listed in Table 5.1.3-3, Table 5.1.3-6, and Table 5.1.3-8. Refer to Section 5.6.5 for TSC surface contamination release dose rates. Dose rates are based on three-dimensional Monte Carlo analysis using surface detectors. Further detail on the detector geometry is included in Section 5.5.

The maximum concrete cask side (cylindrical) average surface dose rate is 58 (<1%) mrem/hour. On the concrete cask top (disk), the average surface dose rate is 104 (2%) mrem/hour. Average dose rates for the standard shielding concrete cask are more than twice as high on the radial surface and approximately 20% higher on the axial surface than the augmented shielding cask configuration for the PWR system (augmented cask shield analysis limited to PWR payloads). The maximum inlet and outlet dose rates are 434 and 59 mrem/hr, respectively. No design basis normal condition or accident event exposes the bottom of the concrete cask.

5.1.2.2 Damaged PWR Fuel Dose Rates

The two damaged fuel scenarios described in Section 5.1.1.2 are also evaluated for the concrete cask.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. Dose rate profiles for the 37- undamaged assemblies are compared with profiles for 33 undamaged and 4 damaged assemblies in Section 5.8.12. Based on the self-shielding of the added mass compensating for the increase in source, damaged fuel dose rates for the first scenario are bounded by either the corresponding undamaged fuel dose rates or the second damaged fuel scenario.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. In this case, concrete cask inlet and radial dose rates increase due to the addition of damaged fuel. The concrete cask inlet dose rate increase is 38 mrem/hr, increasing the inlet dose rate by approximately 9 percent. The maximum concrete cask radial dose rate increases to 82.3 mrem/hr, an increase of approximately 4 percent.

Damaged fuel dose rates are computed using the standard concrete cask (CC1/CC2) or the short, standard concrete cask (CC4), as they produce higher dose rates than the augmented shield concrete cask.

Damaged fuel maximum dose rates in the standard concrete cask are summarized in Table 5.1.3-10.

5.1.3 Offsite Dose Discussion and Results

Contributions from concrete casks to site radiation dose exposure are limited to either radiation emitted from the concrete cask surface or a hypothetical release of surface contamination from the TSC. As documented in Section 5.6.5, there is no significant site dose effect from the expected surface contamination of the system. The TSCs are comprised of a welded shell, bottom plate and lid structure. The vent and drain ports in the lid are covered by redundant welded plates. There is, therefore, no credible leakage from the system, and no significant effluent source can be released from the TSC contents. Details on the TSC confinement boundary are provided in Chapter 7, with leakage test information provided in Section 10.1.3.

Controlled area boundary exposure from the concrete cask surface radiation is evaluated using the NAC-CASC code. (As previously stated, NAC-CASC is a modified version of SKYSHINE-

III.) NAC-CASC calculates the direct dose rate as well as the air scattered contribution of the total dose rate. As the detectors are below the top surface of the cask, only the cylindrical shell (radial) cask surface current contributes a direct component to the total dose rate. NAC-CASC primary enhancements to SKYSHINE-III allow the input of an angular surface current, the input of cylindrical shell (side) and disk (top) geometries, and the accounting of concrete cask self-shielding (i.e., radiation emitted from one cask intersecting another cask in the array—in particular, front/back row interaction in the array). The cylindrical shell and top surfaces are Monte Carlo sampled to generate the surface current input into the code. Each of the sampled locations represents a point source to which the SKYSHINE-III line beam response functions are applicable.

The NAC-CASC (SKYSHINE-III) method assumes that radiation emitted from the source does not interact with the cask/source structure after emission (beyond the additional routines added by NAC to account for self-shielding). This assumption does not represent a significant effect on site dose rates as the calculated surface current is near normal to the surface and any backscatter to the cask from the air surrounding the array would then require a second backscatter from the cask surface to reach a detector location. As detector locations for site exposure are at significant distances from the array (typically 100+ meters), there would not be a significant contribution from radiation having undergone such repeated large angle scatter.

Both a single cask and a 2×10 array of casks are evaluated for site exposure evaluations. Each cask in the array is assigned the maximum dose (surface current) source allowed by the cask loading tables. A combination of the maximum cask side and top dose cases provides for a conservative estimate on the controlled area boundary exposure, since the different fuel types produce the highest cask surface dose components.

The full-year exposure for site boundary (controlled area boundary) results is based on 8,760 hours of exposure.

Table 5.1.3-1 Summary of Carbon Steel Transfer Cask Maximum Dose Rates (35.5 kW PWR and 35 kW BWR)

	Transfer Cask Surface (mrem/hr with relative uncertainty)			1 Meter from Surface (mrem/hr with relative uncertainty)		
Source	Side	Top	Bottom[a]	Side	Top	Bottom
Neutron	1,266 (2.0%)	13 (3.3%)	1,173 (2.7%)	396 (1.6%)	4 (3.7%)	273 (1.8%)
Gamma	238 (1.4%)	663 (1.5%)	4,735 (1.8%)	105 (0.8%)	172 (2.7%)	2,410 (0.7%)
Total	1,504 (1.7%)	676 (1.5%)	5,908 (1.5%)	501 (1.3%)	176 (2.7%)	2,683 (0.7%)

Table 5.1.3-2 Summary of Standard Concrete Cask Maximum Dose Rates (35.5 kW PWR and 35 kW BWR)

		Cask Surface (mrem/hr with relative uncertainty)		1 Meter from Surface (mrem/hr with relative uncertainty)	
Condition	Source	Side[b]	Top	Side[b]	Top
Normal	Neutron	0.9 (2.5%)	5 (11.6%)	0.4 (2.0%)	1 (8.8%)
	Gamma	78.4 (0.4%)	425 (3.2%)	40.1 (0.2%)	109 (3.3%)
	Total	79.3 (0.4%)	430 (3.1%)	40.5 (0.2%)	110 (3.3%)
Design Basis Accident[d]	Neutron	9 (2.5%)	N/A[c]	4 (2.1%)	N/A[c]
	Gamma	546 (6.7%)	N/A[c]	282 (5.1%)	N/A[c]
	Total	555 (6.5%)	N/A[c]	286 (5.0%)	N/A[c]

[a] Includes fuel, thimble plug, and BPRA contribution. A full loading of 9 CEAs will increase bottom dose by 2,527 mrem/hr on contact.

[b] Not including air inlet and outlet streaming paths. Maximum air inlet and outlet dose rates including fuel, BPRA, and thimble plug contributions are 434 (1.4%) and 59 (1.2%) mrem/hr, respectively. At a distance of 1 m from the cask surface, the air inlet and outlet maximum dose rates are 71 (2.6%) and 6.3 (2.4%) mrem/hr, respectively. CEAs may add an additional 32 mrem/hr to the inlet dose. There is no CEA contribution to the outlet dose.

[c] Dose effect is enveloped by the concrete cask side dose. Conservatively calculated for a 40 kW PWR and 38 kW BWR payload.

[d] At the missile impact area.

Table 5.1.3-3 Bounding Payload Type for Each Carbon Steel Transfer and Standard Shield Concrete Cask Surface

Cask	Surface	Insert	Core Type[a]	Max MTU	ID[b]	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)[c]	Initial Enrichment (wt% ^{235}U)
Transfer	Radial	N/A	BWR/2-3 9×9	0.1723	09a	9.6	59	3.1
Transfer	Top	N/A	BWR/4-6 8×8	0.1996	08b	4.3	32.5	2.1
Transfer	Bottom	BPRA	WE 14×14	0.4144	14b	6.0	44	2.5
Concrete	Radial	BPRA	WE 14×14	0.4144	14b	4.1	32.5	2.1
Concrete	Top	N/A	BWR/4-6 8×8	0.1996	08b	4.3	32.5	2.1
Concrete	Air Inlet	BPRA	WE 14×14	0.4144	14b	4.8	37.5	2.3
Concrete	Air Outlet	N/A	BWR/4-6 8×8	0.1996	08b	4.3	32.5	2.1

[a] Refers to general core configuration on which assembly hybrid was based (e.g., Westinghouse 14×14, CE 16×16).
[b] Indicates identifier for fuel characteristics documented in Section 5.2 of the SAR.
[c] Maximum fuel assembly average burnup limited to 60 GWd/MTU with a peak rod average burnup limited to 62.5 GWd/MTU.

Table 5.1.3-4 Summary of Stainless Steel Transfer Cask Maximum Dose Rates (35.5 kW PWR)

Source	Transfer Cask Surface (mrem/hr with relative uncertainty)			1 Meter from Surface (mrem/hr with relative uncertainty)		
	Side	Top	Bottom[a]	Side	Top	Bottom
Neutron	706 (0.8%)	88 (1.6%)	1,056 (6.9%)	244 (0.6%)	22 (1.5%)	255 (3.9%)
Gamma	239 (2.2%)	480 (1.2%)	4,270 (2.8%)	108 (1.4%)	121 (1.8%)	2,213 (1.2%)
Total	945 (0.8%)	568 (1.0%)	5,326 (2.6%)	352 (0.6%)	143 (2.6%)	2,468 (1.1%)

Table 5.1.3-5 Summary of Augmented Shield Concrete Cask Maximum Dose Rates (35.5 kW PWR)

Condition	Source	Cask Surface (mrem/hr with relative uncertainty)		1 Meter from Surface (mrem/hr with relative uncertainty)	
		Side[b]	Top	Side[b]	Top
Normal[c]	Neutron	0.8 (3.8%)	17 (4.5%)	0.4 (2.5%)	2.7 (4.6%)
	Gamma	36.3 (3.2%)	391 (2.9%)	19.3 (2.1%)	65.5 (1.7%)
	Total	37.1 (3.1%)	408 (2.8%)	19.7 (2.0%)	68.2 (1.7%)

[a] Includes fuel, thimble plug, and BPRA contribution. A full loading of 9 CEAs will increase bottom dose by 2,304 mrem/hr on contact.

[b] Not including air inlet and outlet streaming paths. Maximum air inlet and outlet dose rates including fuel, BPRA, and thimble plug contributions are 119 (3.1%) and 26.2 (1.3%) mrem/hr, respectively. At a distance of 1 m from the cask surface, the air inlet and outlet maximum dose rates are 17.1 (6.2%) and 4.2 (2.1%) mrem/hr, respectively. CEAs may add an additional 6.7 mrem/hr to the inlet dose. There is no CEA contribution to the outlet dose.

[c] Accident condition dose rates are bounded by the values in Table 5.1.3-2.

Table 5.1.3-6 Bounding Payload Type for Each Stainless Steel Transfer and Augmented Shield Concrete Cask Surface

Cask	Surface	Insert	Core Type[a]	Max MTU	ID[b]	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)[c]	Initial Enrichment (wt% ^{235}U)
Transfer	Radial	BPRA	WE 14×14	0.4114	14b	12.4	59	3.1
Transfer	Top	TP	WE 14×14	0.4144	14b	6.0	44	2.5
Transfer	Bottom	BPRA	WE 14×14	0.4144	14b	6.0	44	2.5
Concrete	Radial	BPRA	WE 14×14	0.4144	14b	4.1	32.5	2.1
Concrete	Top	TP	WE 14×14	0.4144	14b	4.8	37.5	2.3
Concrete	Air Inlet	BPRA	WE 14×14	0.4144	14b	6.0	44	2.5
Concrete	Air Outlet	TP	WE 14×14	0.4144	14b	6.0	44	2.5

Table 5.1.3-7 Summary of the Short, Standard Concrete Cask (CC4) Maximum Dose Rates (35.5 kW PWR)

		Cask Surface (mrem/hr with relative uncertainty)		1 Meter from Surface (mrem/hr with relative uncertainty)	
Condition	Source	Side[d]	Top	Side[d]	Top
Normal[e]	Neutron	0.6 (8.3%)	12 (7.3%)	0.3 (5.9%)	3 (3.4%)
	Gamma	78.9 (1.4%)	353 (3.8%)	40.3 (0.9%)	86.3 (2.2%)
	Total	79.5 (1.4%)	365 (3.7%)	40.6 (0.9%)	89.3 (2.1%)

[a] Refers to general core configuration on which assembly hybrid was based (e.g., Westinghouse 14×14).
[b] Indicates identifier for fuel characteristics documented in Section 5.2 of the SAR.
[c] Maximum fuel assembly average burnup limited to 60 GWd/MTU.
[d] Not including air inlet and outlet streaming paths. Maximum air inlet and outlet dose rates including fuel, BPRA, and thimble plug contributions are 115 (4.8%) and 42.8 (1.6%) mrem/hr, respectively. At a distance of 1 m from the cask surface, the air inlet and outlet maximum dose rates are 16.5 (9.1%) and 4.4 (3.4%) mrem/hr, respectively. CEAs may add an additional 6.3 mrem/hr to the inlet dose. There is no CEA contribution to the outlet dose.
[e] Accident condition dose rates are bounded by the values in Table 5.1.3-2.

Table 5.1.3-8 Bounding Payload Type for Short, Standard Shield Concrete Cask (CC4) Surface

Cask	Surface	Insert	Core Type[a]	Max MTU	ID[b]	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)[c]	Initial Enrichment (wt% ^{235}U)
Concrete	Radial	BPRA	WE 14×14	0.4144	14b	4.0	32.5	2.5
Concrete	Top	TP	WE 14×14	0.4144	14b	4.8	37.5	2.3
Concrete	Air Inlet	BPRA	WE 14×14	0.4144	14b	6.0	44	2.5
Concrete	Air Outlet	TP	B&W 17×17	0.4681	17b	4.7	32.5	2.1

[a] Refers to general core configuration on which assembly hybrid was based (e.g., Westinghouse 14×14).
[b] Indicates identifier for fuel characteristics documented in Section 5.2 of the SAR.
[c] Maximum fuel assembly average burnup limited to 60 GWd/MTU for PWR fuel.

Table 5.1.3-9 Summary of Transfer Cask Maximum Dose Rates (35.5 kW PWR Damaged Fuel)

	Transfer Cask Surface (mrem/hr with relative uncertainty)		1 Meter from Surface (mrem/hr with relative uncertainty)	
Source	Side	Bottom[a]	Side	Bottom
Undamaged	923 (0.5%)	5,824 (1.6%)	320 (0.3%)	2,638 (0.7%)
BPRA	19 (4.3%)	84 (5.4%)	29 (1.3%)	45 (1.8%)
Damaged Neutron	46 (1.2%)	53 (9.2%)	0.6 (4.3%)	61 (3.6%)
Damaged Gamma	48 (2.0%)	--	0.4 (4.7%)	88 (1.2%)
Total	1,036 (0.5%)	5,961 (1.5%)	350 (0.3%)	2,832 (0.6%)

Table 5.1.3-10 Summary of Concrete Cask Maximum Dose Rates (35.5 kW PWR Damaged Fuel)

	Cask Surface (mrem/hr with relative uncertainty)		1 Meter from Surface (mrem/hr with relative uncertainty)	
Source	Side	Inlet[b]	Side	Inlet
Undamaged	74.9 (7.3%)	425.4 (1.4%)	37.1 (0.3%)	69.7 (2.6%)
BPRA	1.7 (3.5%)	8.7 (3.5%)	3.3 (0.5%)	1.3 (5.7%)
Damaged Neutron	0.4 (0.3%)	4.7 (0.6%)	0.0 (1.4%)	0.7 (1.2%)
Damaged Gamma	5.3 (7.6%)	33.0 (2.7%)	0.1 (4.3%)	6.6 (4.9%)
Total	82.3 (6.6%)	471.8 (1.3%)	40.5 (0.2%)	78.3 (2.4%)

[a] A full loading of 9 CEAs will increase the bottom dose rate by 2,527 mrem/hr on contact.
[b] CEAs may add an additional 32 mrem/hr to the inlet surface dose rate.

5.2 Source Specification

To generate radiation and thermal source terms, the PWR and BWR fuel assembly types are surveyed and grouped by primary characteristics critical to shielding and source term evaluations. Critical criteria are the basic reactor type in which the fuel assembly operated, fuel mass (MTU), and hardware mass. For each assembly group, a hybrid assembly is generated. The hybrid assembly contains the maximum fuel mass and hardware masses of any assembly within the group. This combination leads to a conservative source term in each TSC. The critical characteristics are listed in Table 5.2.3-1 for PWR assemblies and Table 5.2.3-2 for BWR assemblies. Fuel assembly hardware quantities for nonzirconium-based hardware are included in Section 5.8.1. This hardware may contribute significantly to cask surface dose rates as a result of ^{59}Co activation. Refer to Section 5.8.1 for the geometry aspects and hardware quantities of the evaluated PWR and BWR fuel assembly hybrids.

The SAS2H code sequence [5] of the SCALE 4.4 package [6] with the 44-group ENDF/B-V cross-section libraries [7] is used to generate source terms for the shielding analysis. SAS2H includes an XSDRNPM [8] neutronics model of the fuel assembly and the ORIGEN-S code [9] for fuel depletion and source term calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware.

The 44-group library (44GROUPNDF5) is composed primarily of ENDF/B-V cross-sections with ENDF/B-VI data for a limited number of isotopes (e.g., ^{154}Eu and ^{155}Eu). The cross-section set is collapsed using an LWR spectrum. References 31 through 35 contain extensive SAS2H validation for PWR burnups up to 47 GWd/MTU and BWR burnups up to 57 GWd/MTU. As indicated in the reference documentation, the combination of the SCALE 4.4 SAS2H sequence and the 44 GROUPNDF5 cross-section library is applicable to LWR fuel assembly source term generation for high burnup fuel.

Open literature validations of the SCALE SAS2H/44 group library versus experimental data do not extend to the system allowable assembly average burnup of 60 GWd/MTU for PWR systems and 60 GWd/MTU for the BWR system. Studies performed in NUREG/CR-6701 (Appendix A and Appendix B) [36] indicate no analysis trends in system sensitivity for LWR SAS2H/44GROUPNDF5 evaluations up to a burnup of 75 GWd/MTU.

NUREG/CR-7012 contains the summary of various NUREGs that document publicly available (and in the case of MARIU, commercially protected) comparisons of experimental to code-generated isotope compositions based on the TRITON sequence of SCALE. Burnups included in the NUREG are very high burnups and cover a range of 8 to 79 GWd/MTU. The NUREG compares isotopes relevant to burnup credit, radiation protection and heat generation, and waste

management. The comparison relies on the TRITON with NITWAL rather than the newer CENTRM sequence. Beyond the transport solution, which used NEWT in TRITON for a 2-D solution rather than XSDRNPM in SAS2H for a 1-D solution, the NUREG and MAGNASTOR analysis methods are very similar and are not expected to show divergent results in the analysis trend versus burnup. The conclusion in NUREG/CR-7012 is that there is no code bias trend of the depletion-generated isotopics and sources versus burnup level. In particular, there is no significant trend for very high burnup fuels. While absolute differences between SAS2H and TRITON are expected due to neutron transport method differences, trending is not expected for SAS2H. This conclusion is confirmed by reevaluating cases from NUREG/CR-6968, NUREG/CR-6969 and NUREG/CR-7013 are evaluated using SAS2H. SAS2H modeled cases go up to 70 GWd/MTU. Similarly to the NUREG TRITON cases, the SAS2H result differences from experimental data are closer related to uncertainties within the experimental data (e.g., isotope measurement, depletion model inputs) and the uniqueness of the geometry or material composition (e.g., Gd poisoned fuel rods) than to burnup levels. There was no significant trending of the SAS2H results as a function of fuel burnup. As such, the SAS2H/44GROUPNDF5 sequence is applicable to the high burnup fuel evaluated.

Source terms are generated on an assembly average burnup basis using SAS2H and are adjusted to reflect the burnup profile as discussed in Section 5.3 and Section 5.4.

Due to the limited experimental PWR and BWR data available for the SAS2H sequence as applied to high burnup (> 45 GWd/MTU) fuel assemblies, a 5% decrement in heat load is applied at the high burnup fuel levels. The heat load decrement implies an extension in minimum cool time required for high burnup fuel and provides additional margin to account for any uncertainties in the source generation method. Note that this reduction will also reduce neutron and gamma source terms below those previously discussed in Section 5.1.

Site boundary evaluations are based on 40 kW (PWR) and 38 kW (BWR), rather than the 35.5 kW (PWR) and 33 kW (BWR) allowed payloads, providing significant margin in site exposures. The 5% margin high burnup fuel allowed levels are equivalent to 33.72 kW (PWR) and 31.35 kW (BWR) and provides further margin to the calculated site boundary exposures.

The hardware activation is calculated by light element transmutation using the in-core neutron flux spectrum produced by the SAS2H neutronics model. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios determined from empirical data [11]. Refer to Section 5.8.1 for the in-core reactor primary system properties required for burnup calculations for the PWR and BWR systems. Refer to Section 5.8.8.1 for sample PWR and BWR SAS2H input files.

Rather than determining a single cool time, assembly average burnup, and initial enrichment combination acceptable for all payloads, source terms are produced in the following range.

- Assembly average burnup from 10,000 MWd/MTU to 60,000 MWd/MTU
- Assembly average initial enrichment 1.3 wt% ^{235}U to 4.9 wt% ^{235}U
- Cool time from 4 years to 90 years (nonfuel hardware is evaluated at cool times down to two years)

5.2.1 Gamma Source

The gamma source term of the spent nuclear fuel assembly is composed of a fuel gamma source, fission product and actinide sources, and a light element activation source primarily associated with fuel hardware. Spectra are initially produced in the default 18-group energy spectrum of ORIGEN-S at reactor shutdown. The source is then decayed and rebinned into the 22-energy group gamma structure shown in Table 5.2.3-3. The 22-group structure shown is the default MCBEND [12] structure and provides improved binning at the ^{60}Co energy lines. Source generation and rebin are accomplished in the same computer run using the SCALE 4.4 stacked input file structure.

The light element gamma spectra contain contributions primarily from ^{60}Co due to the activation of stainless steel or inconel hardware components. Hardware activation is based on an assembly average nonzirconium alloy structural material ^{59}Co level of 0.8 g/kg. Minor dose contributions result from the hardware ^{59}Ni and ^{58}Fe activation and activation of the zirconium alloy clad impurities. The nonzirconium alloy hardware gamma spectral distribution is determined by the irradiation of 1 kg of material (modeled as stainless steel) in the in-core flux spectrum produced by the SAS2H neutronics calculation. Activated fuel assembly hardware source term magnitudes are determined by multiplying the source strength from the 1 kg SAS2H run by the total mass of nonzirconium in the active fuel, plenum, and end-fitting regions and then multiplying this result by a regional flux activation ratio. This regional flux ratio accounts for the effects of both magnitude and spectrum variation on hardware activation. The following list provides the flux ratios for the various source regions.

Region	Generic PWR	CE16×16 PWR	B&W PWR	Generic BWR
Upper-End Fitting	0.10	0.05	0.10	0.10
Upper Plenum	0.20	0.20	0.20	0.20
Fuel	1.00	1.00	1.00	1.00
Lower Plenum	N/A	N/A	0.20	N/A
Lower-End Fitting	0.20	0.20	0.10	0.15

Additional gamma source is produced by nonfuel hardware included in the PWR system evaluation. Included nonfuel hardware components are reactor control element assemblies (e.g., CEAs and RCCAs), burnable poison rod assemblies (e.g., BPRAs and wet annular burnable absorbers [WABAs]), thimble plugs (also referred to as guide tube plugs or flow mixers), reconstituted fuel assemblies with activated stainless steel fuel replacement rods, and HFRAs. Table 5.2.3-4 contains the activated nonfuel hardware mass by core type for BPRAs, thimble plugs, stainless steel rods, and HFRAs. Combustion Engineering (CE) cores employ integral absorber rods that replace some fuel rods. Assuming all lattice locations are filled with fuel rods bounds the in-lattice absorber rods. Refer to Sections 5.8.5, 5.8.6, and 5.8.13 for more information on the nonfuel components.

Source term calculations are based on a maximum three-cycle exposure for BPRAs and a multicycle exposure equivalent to 180 GWd/MTU burnup for thimble plugs and reactor control elements (e.g., guide tube plugs and nozzle region hardware). Actual BPRA exposure may be in more than three cycles, but is conservatively modeled by the three-cycle approach (i.e., no down time between additional cycles is included in the model). Exposure of the stainless steel fuel replacement rods is limited to 32.5 GWd/MTU, as the rods were inserted after at least one cycle of assembly depletion has occurred. The steel rods are designed to replace fuel rods that were removed for examination or due to failure. To limit the effects of steel activation on cask dose rates, reconstituted fuel assemblies with activated stainless steel fuel replacement rods may be loaded in any basket location, provided the number of replacement rods is limited to five per assembly and one assembly per case. Unirradiated (i.e., no in-core use) replacement rods are not limited in quantity per assembly or assemblies per cask.

HFRAs may be loaded in the basket at a maximum exposure of 4.0 GWd/MTU per HFRA at a minimum cool time of 16 years.

Activation of the nonfuel hardware is treated identical to that of the fuel assembly hardware, including the use of flux factors to account for the location of the activated material in relation to the full (100%) in-core flux employed in the SAS2H depletion calculations.

5.2.2 Neutron Source

Light water reactor spent fuel neutron sources result from actinide spontaneous fission and from (α,n) reactions. The isotopes ^{242}Cm and ^{244}Cm characteristically produce all but a few percent of the spontaneous fission neutrons and (α,n) source. The next largest contribution is from (α,n) reactions in ^{238}Pu. The neutron spectra for each emission type are included in the ORIGEN-S nuclear data libraries of the SCALE 4.4 code package. Similar to the gamma spectrum, the

neutron energy spectrum is decayed and rebinned into the MCBEND [12] default neutron structure using ORIGEN-S. The MCBEND neutron spectrum is listed in Table 5.2.3-5.

The MCBEND neutron energy spectrum is employed for consistency with the MCBEND gamma spectrum chosen for its enhanced grouping around the ^{60}Co energy lines. All shielding evaluations are performed with MCNP.

Neutron shielding evaluations for fissile material must account for subcritical multiplication (neutron production) inside the system being evaluated. This subcritical multiplication is taken into account by a scale factor applied to the dose results. While MCNP contains the option to directly account for the subcritical neutron multiplication, the homogenization of the fuel assembly and application of the weight window acceleration method could result in inefficient and possibly erroneous results. Code biasing is set to optimize the speed at which cask surface dose rates are obtained. Thermal energy neutrons within the fuel region are not likely to escape the shielded storage system and tend to be biased out of the evaluation. However, the thermal neutrons account for a significant portion of the subcritical multiplication. Removing the thermal neutrons from the system by biasing for cask surface dose, therefore, has the potential to bias the subcritical neutron multiplication. To account for subcritical multiplication, the neutron source rates are scaled by a subcritical multiplication factor based on the system multiplication factor, k_{eff}:

$$\text{Scale Factor} = \frac{1}{1 - k_{eff}}$$

For dry cask conditions, the system k_{eff} is taken as 0.4, with a resulting scale factor of 1.67. While the fresh fuel dry cask system reactivity is calculated slightly over 0.4 in Chapter 6, 0.4 bounds TSCs loaded with spent fuel.

Primary and secondary source/neutron source assemblies (NSAs) have a neutron source magnitude similar to that of an irradiated fuel assembly (i.e., 1×10^8 to 1×10^9 n/sec). Neutron sources may be loaded in one of the center nine basket locations. The number of neutron sources/NSAs is limited to one per assembly and one per basket. Further detail is provided in Section 5.8.13.1. Hardware portions of NSAs may also contribute gamma source. Applying thimble plug and/or BPRA restrictions on ^{60}Co content via burnup/cool time or curie limits, as appropriate, (see Section 5.8.13) ensures that the NSA non-neutron source hardware is bounded.

5.2.3 Bounding Gamma and Neutron Spectrum

The shielding evaluations are performed using a response function approach (see Sections 5.6 and 5.8.2). Allowable cool time, initial enrichment, and maximum assembly average burnup are

provided for a range of fuel assembly designs. Fuel assembly source spectra for the cases (fuel type, initial enrichment, burnup and cool time) producing the maximum radial transfer and storage cask dose rates are shown in Table 5.2.3-6 for the gamma source and in Table 5.2.3-7 for the neutron source. Maximum radial storage cask dose rates were obtained from PWR fuel, while maximum transfer cask dose rates were calculated for BWR fuel. Therefore, in Table 5.2.3-6 and Table 5.2.3-7 PWR data is presented for the storage cask, while BWR data is shown for the transfer cask. Fuel gamma sources in the tables are expressed on a per-assembly basis, while the hardware (nonzirconium alloy) source is expressed on a per-kilogram basis.

Table 5.2.3-1 Key PWR Fuel Assembly Characteristics

Fuel Type	CE	WE	WE	B&W	CE	WE	B&W
Label	14a	14b	15a	15b	16a	17a	17b
Array	14x14	14x14	15x15	15x15	16x16	17x17	17x17
Nominal Number of Fuel Rods	176	179	204	208	236	264	264
Fuel Mass [MTU]	0.4115	0.4144	0.4671	0.4807	0.4463	0.4671	0.4681

Table 5.2.3-2 Key BWR Fuel Assembly Characteristics

Fuel Type	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/4-6
Label	07a	07b	08a	08b	09a	09b	10a
Array	7x7	7x7	8x8	8x8	9x9	9x9	10x10
Number of Fuel Rods	49	49	63	64	79	79	92
Fuel Mass (MTU)	0.1985	0.2037	0.1855	0.1996	0.1723	0.1979	0.1946

Table 5.2.3-3 22-Group Gamma Energy Spectrum

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.200E+01	1.400E+01	1.300E+01
2	1.000E+01	1.200E+01	1.100E+01
3	8.000E+00	1.000E+01	9.000E+00
4	6.500E+00	8.000E+00	7.250E+00
5	5.000E+00	6.500E+00	5.750E+00
6	4.000E+00	5.000E+00	4.500E+00
7	3.000E+00	4.000E+00	3.500E+00
8	2.500E+00	3.000E+00	2.750E+00
9	2.000E+00	2.500E+00	2.250E+00
10	1.660E+00	2.000E+00	1.830E+00
11	1.440E+00	1.660E+00	1.550E+00
12	1.220E+00	1.440E+00	1.330E+00
13	1.000E+00	1.220E+00	1.110E+00
14	8.000E-01	1.000E+00	9.000E-01
15	6.000E-01	8.000E-01	7.000E-01
16	4.000E-01	6.000E-01	5.000E-01
17	3.000E-01	4.000E-01	3.500E-01
18	2.000E-01	3.000E-01	2.500E-01
19	1.000E-01	2.000E-01	1.500E-01
20	5.000E-02	1.000E-01	7.500E-02
21	2.000E-02	5.000E-02	3.500E-02
22	1.000E-02	2.000E-02	1.500E-02

Table 5.2.3-4 Bounding Regional Nonfuel Hardware Masses

Assembly	Component	Regional Masses [kg]		
		Upper Nozzle	Upper Plenum	Active Fuel
Westinghouse 14×14	Thimble Plug SS	2.12	2.18	0
	BPRA SS	2.41	2.07	9.22
Westinghouse 15×15	Thimble Plug SS	2.19	2.72	0
	BPRA SS	2.47	2.18	11.39
	HFRA Hafnium	--	--	70.45
	Reconstituted Assembly SS	--	--	13.90
Westinghouse 17×17	Thimble Plug SS	2.73	3.16	0
	BPRA SS	3.04	2.85	10.995
B&W 15×15	Thimble Plug SS	3.641	3.41	0
	BPRA SS	3.602	0	0
B&W 17×17	Thimble Plug SS	3.641	3.41	0
	BPRA SS	3.602	0	0

Table 5.2.3-5 28-Group Neutron Energy Spectrum

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.360E+01	1.460E+01	1.410E+01
2	1.250E+01	1.360E+01	1.305E+01
3	1.125E+01	1.250E+01	1.188E+01
4	1.000E+01	1.125E+01	1.063E+01
5	8.250E+00	1.000E+01	9.125E+00
6	7.000E+00	8.250E+00	7.625E+00
7	6.070E+00	7.000E+00	6.535E+00
8	4.720E+00	6.070E+00	5.395E+00
9	3.680E+00	4.720E+00	4.200E+00
10	2.870E+00	3.680E+00	3.275E+00
11	1.740E+00	2.870E+00	2.305E+00
12	6.400E-01	1.740E+00	1.190E+00
13	3.900E-01	6.400E-01	5.150E-01
14	1.100E-01	3.900E-01	2.500E-01
15	6.740E-02	1.100E-01	8.870E-02
16	2.480E-02	6.740E-02	4.610E-02
17	9.120E-03	2.480E-02	1.696E-02
18	2.950E-03	9.120E-03	6.035E-03
19	9.610E-04	2.950E-03	1.956E-03
20	3.540E-04	9.610E-04	6.575E-04
21	1.660E-04	3.540E-04	2.600E-04
22	4.810E-05	1.660E-04	1.071E-04
23	1.600E-05	4.810E-05	3.205E-05
24	4.000E-06	1.600E-05	1.000E-05
25	1.500E-06	4.000E-06	2.750E-06
26	5.500E-07	1.500E-06	1.025E-06
27	7.090E-08	5.500E-07	3.105E-07
28	1.000E-11	7.090E-08	3.546E-08

Table 5.2.3-6 Gamma Source Spectrum – Maximum Radial Dose Rate Configuration

Cask	Storage		Transfer	
Fuel Type	PWR		BWR	
Burnup[a]	32,500 MWd/MTU		59,000 MWd/MTU	
Cool Time	4.1 yrs		9.6 yrs	
Initial Enrichment	2.1 wt%		3.1 wt%	
Group	[γ/sec/assy]	[γ/sec/kg]	[γ/sec/assy]	[γ/sec/kg]
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	7.4804E+03	0.0000E+00	1.1750E+04	0.0000E+00
3	1.4468E+05	0.0000E+00	2.2725E+05	0.0000E+00
4	6.8141E+05	0.0000E+00	1.0703E+06	0.0000E+00
5	3.4736E+06	0.0000E+00	5.4555E+06	0.0000E+00
6	8.6551E+06	0.0000E+00	1.3593E+07	0.0000E+00
7	1.6921E+10	1.7267E-15	2.0472E+08	5.2053E-15
8	1.3579E+11	6.8687E+04	1.4196E+09	4.6465E+04
9	4.1272E+12	4.4297E+07	1.8591E+10	2.9966E+07
10	1.7127E+12	9.8431E+03	5.1315E+10	2.0805E-05
11	5.6468E+12	1.1778E+01	8.2650E+11	7.9652E+00
12	4.6708E+13	4.1963E+12	1.2763E+13	2.8387E+12
13	4.5444E+13	4.4232E+12	7.0545E+12	2.9922E+12
14	2.9488E+14	9.5781E+10	4.1222E+13	1.0028E+09
15	1.9045E+15	7.8101E+06	8.3149E+14	5.2829E+06
16	7.5264E+14	2.3127E+07	8.0768E+13	1.5212E+07
17	7.0043E+13	3.5580E+08	1.4734E+13	2.4069E+08
18	9.5410E+13	2.7118E+08	2.2731E+13	1.8345E+08
19	3.3810E+14	5.4614E+09	7.7551E+13	3.6945E+09
20	4.0250E+14	2.2637E+10	1.0662E+14	1.5314E+10
21	8.7664E+14	6.4740E+10	2.6099E+14	4.3935E+10
22	6.2752E+14	7.6843E+10	1.9082E+14	5.2571E+10
Total	5.4660E+15	8.8857E+12	1.6476E+15	5.9479E+12

[a] Assembly average

Table 5.2.3-7 Neutron Source Spectrum – Maximum Radial Dose Rate Configuration

Cask	Storage	Transfer
Fuel Type	PWR	BWR
Burnup[a]	32,500 MWd/MTU	59,000 MWd/MTU
Cool Time	4.1 yrs	9.6 yrs
Initial Enrichment	2.1 wt%	3.1 wt%
Group	[n/sec/assy]	[n/sec/assy]
1	0.000E+00	0.000E+00
2	1.658E+04	2.615E+04
3	6.910E+04	1.090E+05
4	2.295E+05	3.620E+05
5	7.200E+05	1.135E+06
6	1.933E+06	3.049E+06
7	3.337E+06	5.262E+06
8	1.117E+07	1.761E+07
9	1.895E+07	2.982E+07
10	2.555E+07	3.998E+07
11	6.074E+07	9.508E+07
12	9.496E+07	1.495E+08
13	2.474E+07	3.901E+07
14	8.584E+06	1.353E+07
15	2.044E+02	2.452E+02
16	0.000E+00	0.000E+00
17	0.000E+00	0.000E+00
18	0.000E+00	0.000E+00
19	0.000E+00	0.000E+00
20	0.000E+00	0.000E+00
21	0.000E+00	0.000E+00
22	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00
24	0.000E+00	0.000E+00
25	0.000E+00	0.000E+00
26	0.000E+00	0.000E+00
27	0.000E+00	0.000E+00
28	0.000E+00	0.000E+00
Total	2.510E+08	3.945E+08

[a] Assembly average

5.3 Axial Burnup Profile

The axial burnup profile changes as fuel burnup progresses from initial in-core loading (0 GWd/MTU) to the maximum burnup requested (60 GWd/MTU). For PWR fuel assemblies, maximum burnup peaking occurs in the range of 10 to 15 GWd/MTU with a peak of approximately 1.25. The burnup profile peak then decreases as burnup increases to the 30 GWd/MTU range, after which the peak remains relatively constant. For BWR fuel assemblies, similar peaking occurs early during depletion with a bottom peak near 1.35 in the range of 10-20 GWd/MTU. The BWR peak burnup ratio then decreases to the 1.22 peak specified in the following paragraph. Dose calculations on both transfer and storage systems summarized in Section 5.1 demonstrate that, at a fixed burnup profile, fuel assemblies burned in excess of 30 GWd/MTU produce maximum dose rates. For a fixed burnup profile, Figure 5.3.1-3 (storage cask) and Figure 5.3.1-4 (transfer cask) illustrate the dose rate increase as a function of burnup that offsets any potential increase in burnup peak at lower burnup levels.

Figure 5.3.1-5 contains YAEC compiled PWR burnup profiles at 5 GWd/MTU increments showing low burnup fuel having a higher peak. Peaking is less than 10% higher for the low burnup material, which is a smaller increase than the dose decreases plotted in Figure 5.3.1-3 and Figure 5.3.1-4 for the lower burnup fuels. The following discussion, therefore, describes the burnup profile for fuel burned in excess of 30 GWd/MTU. The 30 GWd/MTU derived profile is applied in the shielding evaluations summarized in Sections 5.1 and 5.6 and detailed in Section 5.8.

Fuel burned in excess of 30 GWd/MTU produces the maximum dose rates as shown in Section 5.6. For PWR fuel, an enveloping axial burnup profile with a 1.08 uniform peaking factor is justified on the basis of calculated PWR data from Seabrook Station and Maine Yankee and from measured Turkey Point gamma data [13,14,15,16,17]. This normalized enveloping shape is shown in Figure 5.3.1-1. A uniform burnup peaking factor of 1.08 is applied between 15% and 85% of core height. Above and below these elevations, the relative burnup/decay heat decreases linearly to 0.547 at the top and bottom of the active fuel region.

For BWR fuel, an enveloping burnup profile with a 1.22 maximum peaking factor can be justified on the basis of calculated BWR burnup profile data from eight cycles of Washington Public Power (WPP) BWR/4-6 data [18]. This normalized enveloping shape is shown in Figure 5.3.1-2. Uniform peaking factors of 1.22 and 1.18 are applied from 15% to 55% and from 55% to 80% of core height, respectively. Above and below these elevations, the burnup profile decreases linearly to 0.043 at the top and bottom of the active fuel region. This profile bounds the burnup peaks listed in Vermont Yankee and Takoi-2 BWR nuclear power station burnup

curves, demonstrating that the detailed information from WPP represents typical BWR operational data and may be used as the generic licensing basis.

PWR and BWR fuel assemblies may contain axial unenriched end regions (blankets). In particular, BWR/4-6 type reactor assemblies are typically designed with 6-inch unenriched axial blankets at the top and bottom of the fuel region. The BWR dataset employed in the calculation of the bounding burnup profile includes axial end-blankets and is, therefore, directly applicable to the MAGNASTOR® contents. PWR information that constructed the PWR curve did not contain blanketed fuel. To demonstrate acceptability of the PWR profile to blanketed fuel, NAC compared the profile in Figure 5.3.1-1 to the YAEC-1937 [13] profile for assemblies in the range of 30 to 35 GWd/MTU. The YAEC profile includes both blanketed and non-blanketed fuel assemblies. As seen in Figure 5.3.1-5, the profiles match well, demonstrating acceptability of the chosen profile across the range of PWR fuel assembly types.

The use of axial blankets in the fuel assembly has the potential for affecting overall source magnitudes, as sources vary as a function of enrichment at a fixed burnup (thus leading to higher sources at lower enrichment). Axial blankets may also shift the burnup profile and indirectly modify source magnitudes. End blanket effects on source magnitudes, in particular unenriched blankets, are discussed in Section 5.8.10 and demonstrated to be not significant to system performance.

The PWR and BWR profiles applied in the shielding evaluations are designed to produce bounding dose rates when used in conjunction with the evaluation methods and inputs described in this chapter. Individual sites may utilize unique axial enrichment loadings, or have nonstandard operating conditions (e.g., a PWR running with substantial control rod insertion for a significant portion of the assembly operating history) that could produce significant variations in burnup profile. Other references for burnup profiles may contain higher peak burnup profiles, such as the 1.108 peak profile in NUREG/CR-6801 for >30 GWd MWd/MTU fuel. NUREG/CR-6801 contains burnup profiles for criticality burnup credit analysis. Minor changes in profile, such as the difference between MAGNASTOR design basis and NUREG/CR-6801, are not expected to impact the concrete storage system significantly, as dose rate are gamma dominated (fuel gamma source is proportional to burnup). Fuel mid-plane dose rate on the transfer cask may see a statistically significant increase with a higher peaked profile as the neutron source, which is a significant contributor to cask side dose, increases to the fourth power of burnup. As this location is not typically occupied during system operations, it is not expected that the neutron source increase will impact ALARA planning. Regardless of the previous argument, burnup profile shape should be considered during ALARA and site boundary planning by the system licensee, as it may affect system dose rate profiles.

Figure 5.3.1-1 Enveloping Axial Burnup Profile for PWR Fuel

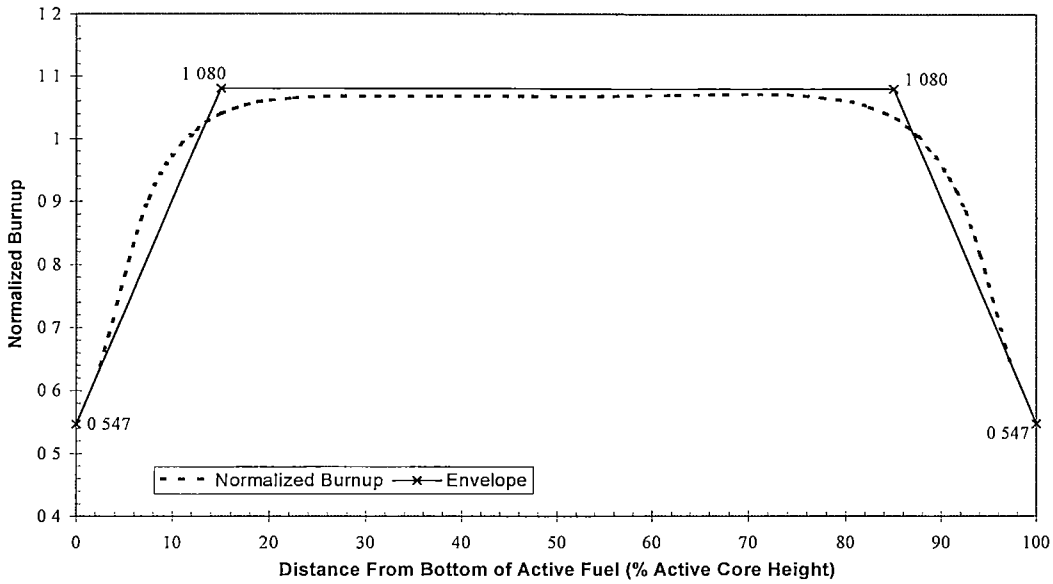


Figure 5.3.1-2 Enveloping Axial Burnup Profile for BWR Fuel

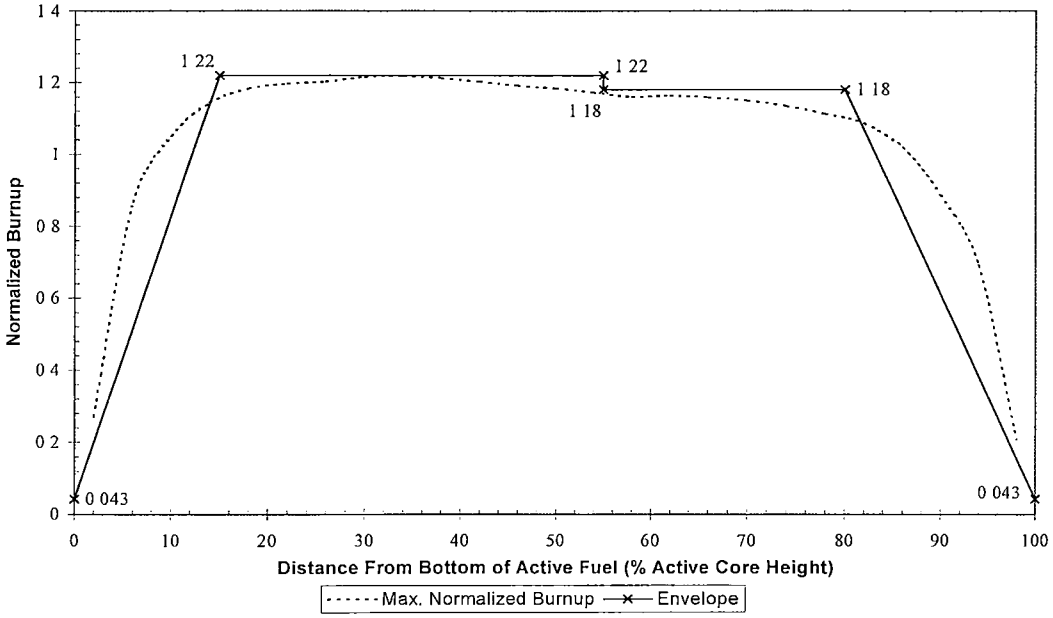


Figure 5.3.1-3 Average and Midplane Storage Cask Dose Rates as a Function of Burnup (Fixed Heat Load – 4-Year Minimum Cool Time)

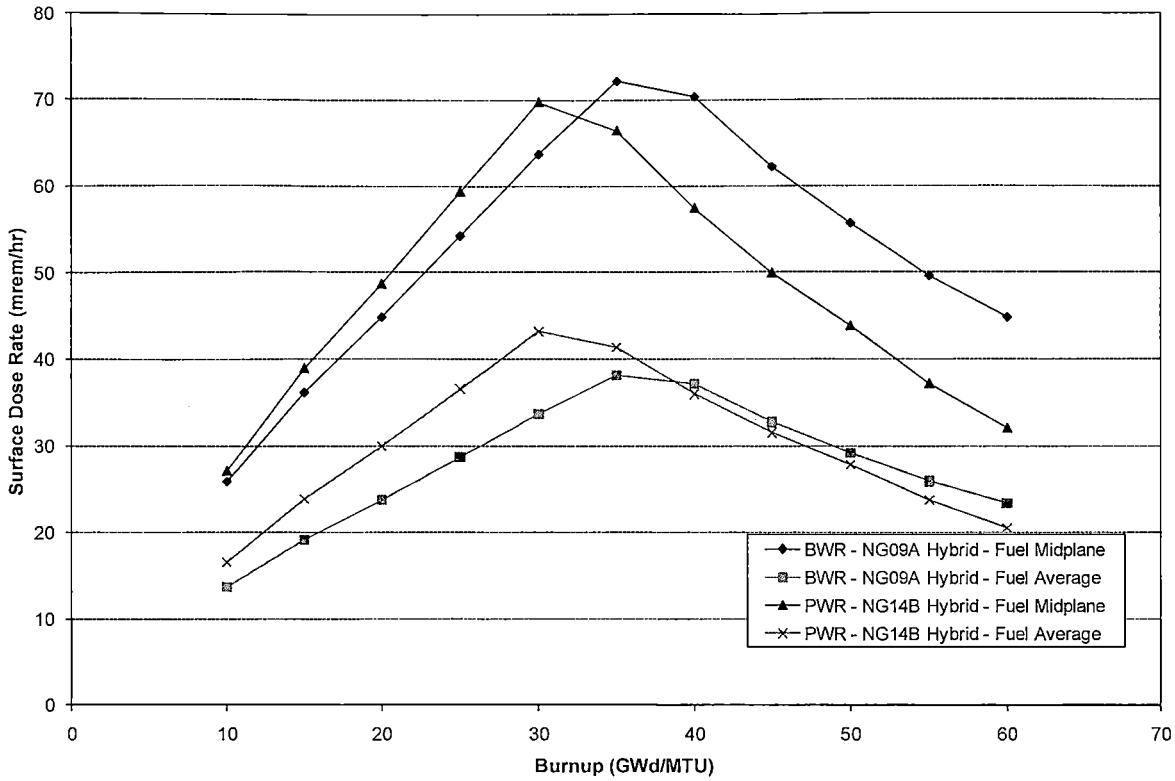


Figure 5.3.1-4 Average and Midplane Transfer Cask Dose Rates as a Function of Burnup (Fixed Heat Load – 4-Year Minimum Cool Time)

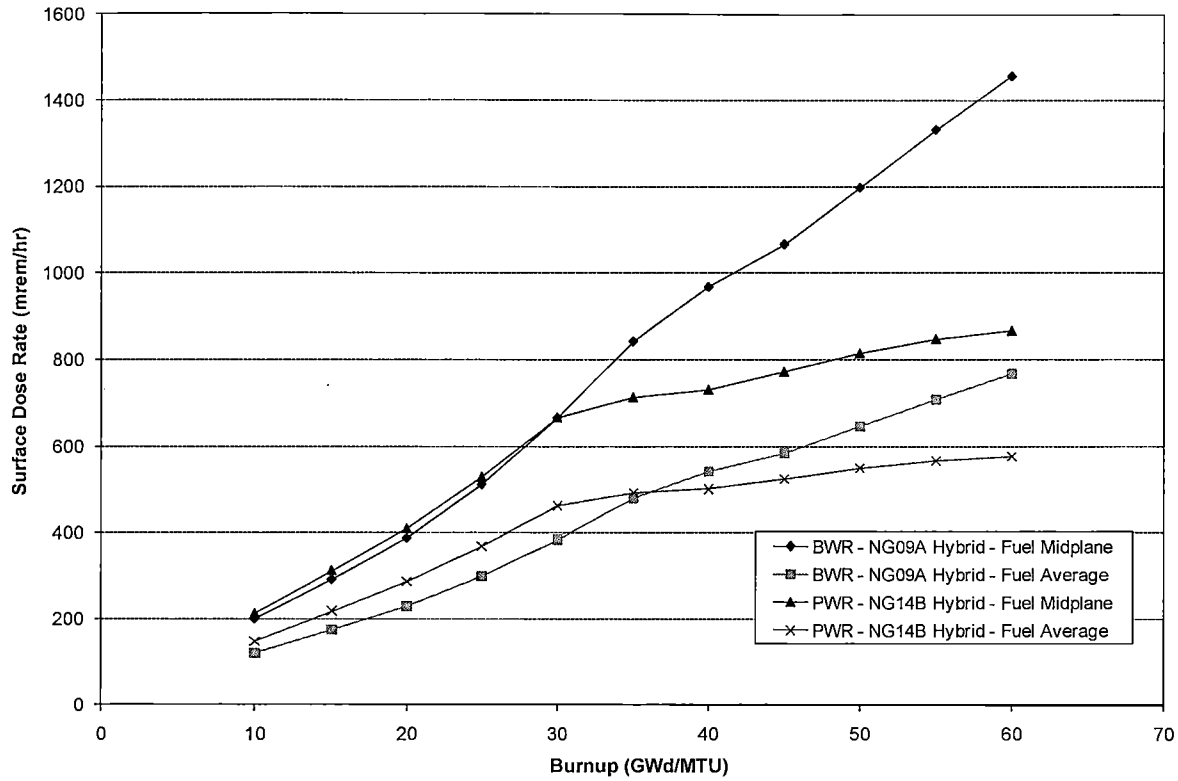
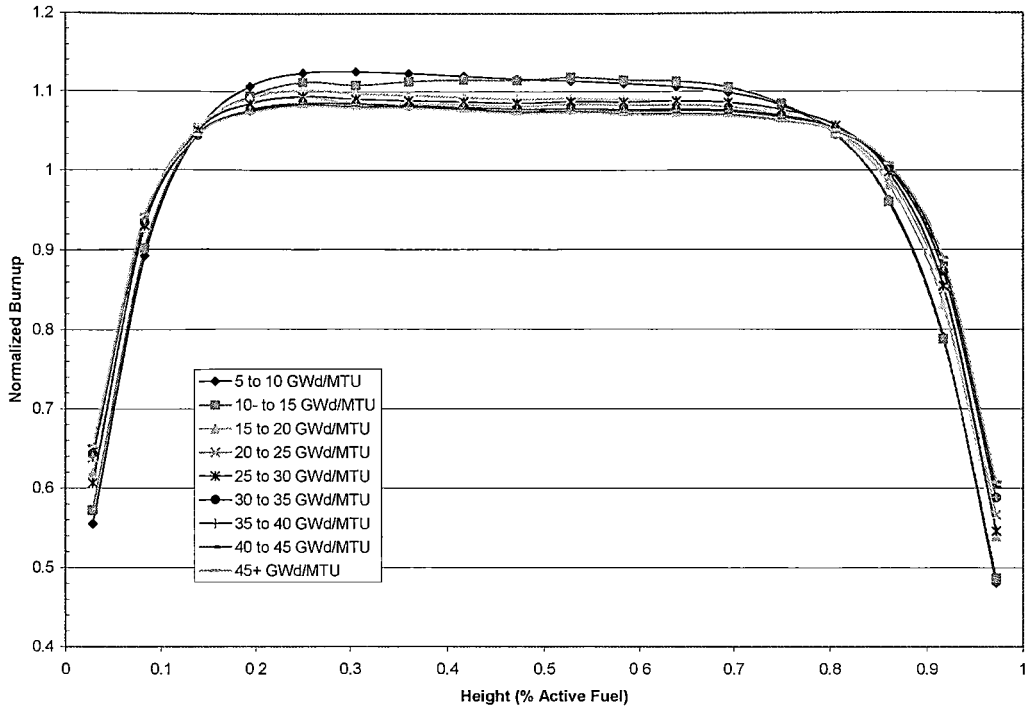


Figure 5.3.1-5 Normalized Burnup Profiles from YAEC-1937 (Grouped in 5 GWd/MTU Bins)



5.4 Axial Source Profile

5.4.1 Neutron and Gamma Source Rates Related to Burnup

Neutron and gamma source rates are related to burnup by $S \sim aB^b$, where "S" is the source rate for a particular radiation type, "B" is the burnup at a given axial elevation, and the "b" factor is set by curve fitting of SAS2H produced source magnitudes. Based on the SAS2H results, the "b" factor is 1.0 for gamma (photons) and 4.22 for neutrons. The variable "a", while included in the source magnitude to burnup correlation, is not required in the analysis as the variable drops out of the equation when establishing source ratios and determining the variable "b".

$$S = aB^b$$

Given two burnups, B_1 and B_2 and a Source Strength S_1, solve for S_2

$$S_1 = aB_1^{\ b} \text{ and } S_2 = aB_2^{\ b}$$

yields

$$a = \frac{S_2}{B_2^{\ b}} \text{ substituting } \frac{S_1}{B_1^{\ b}} = \frac{S_2}{B_2^{\ b}} \text{ solving for } S_2 \rightarrow S_2 = \frac{B_2^{\ b}}{B_1^{\ b}} \times S_1$$

As the "b" factor is unity (1.0) for gamma and greater than 1 for neutron, the axially integrated source of an assembly is, therefore, equal to that of the assembly at average burnup for gamma but not for neutrons. The fuel neutron and fuel gamma source rate profiles for the PWR and BWR fuel are shown in Figure 5.4.1-1 and Figure 5.4.1-2, respectively.

Two scaling quantities are of interest. First, since SAS2H analyses are conducted at the average assembly burnup, a scale factor is required to relate the assembly average sou/rce rate to the source rate at the average burnup:

$$r = \frac{\overline{S}}{S(\overline{B})} = \frac{\frac{a}{H}\int B^b dz}{a\overline{B}^b}$$ (Note: variable "a" drops out of the equation)

where H is the height of the fuel region. With the burnup profile normalized to one, this becomes

$$r = \frac{1}{H}\int B^b dz$$

The integral is evaluated numerically using the trapezoid rule, and the resulting scale factors are shown in Table 5.4.1-1 for PWR fuel and Table 5.4.1-2 for BWR fuel. The second scaling parameter is the ratio of the peak to average source rate.

$$s = \frac{S(B_{max})}{\overline{S}}$$

This parameter is also shown in Table 5.4.1-1 (PWR) as 1.127 and Table 5.4.1-2 (BWR) as 1.585.

The dose response function method multiplies the SAS2H-generated assembly source at average burnup by the corresponding dose response (mrem/hr/particle). The MCNP dose response runs, therefore, must include a tally multiplier (TM) to adjust for the complete basket source. The tally multiplier is based on the number of fuel assemblies in the basket and, for neutron cases, the subcritical neutron multiplication adjustment and the correction for source at average burnup to integrated source (e.g., PWR neutron source TM=69.5=37*1.127*1.667).

Figure 5.4.1-1 PWR Photon and Neutron Axial Source Profiles

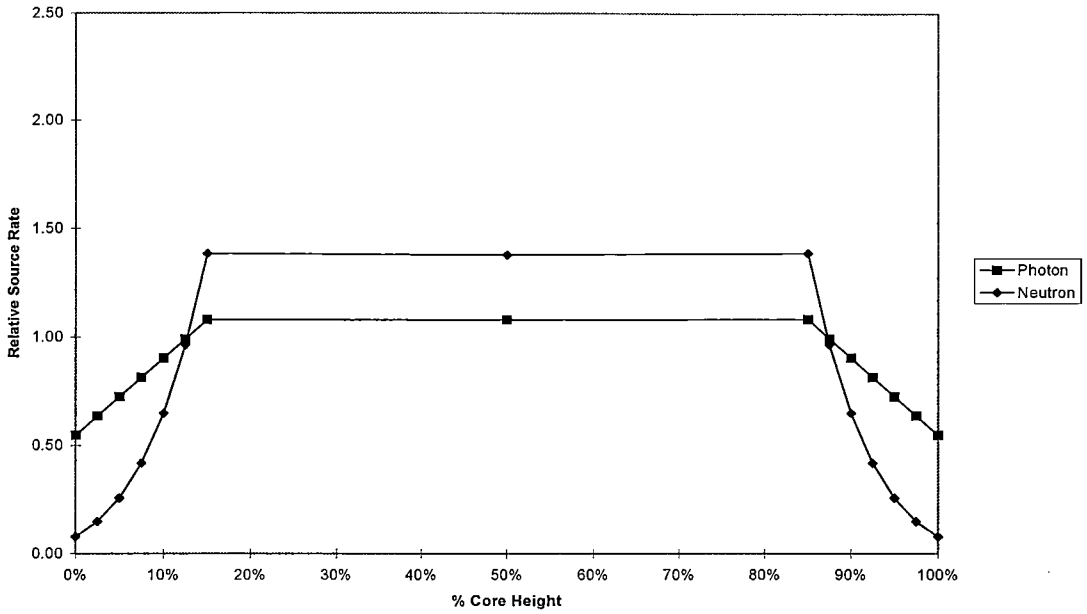


Figure 5.4.1-2 BWR Photon and Neutron Axial Source Profiles

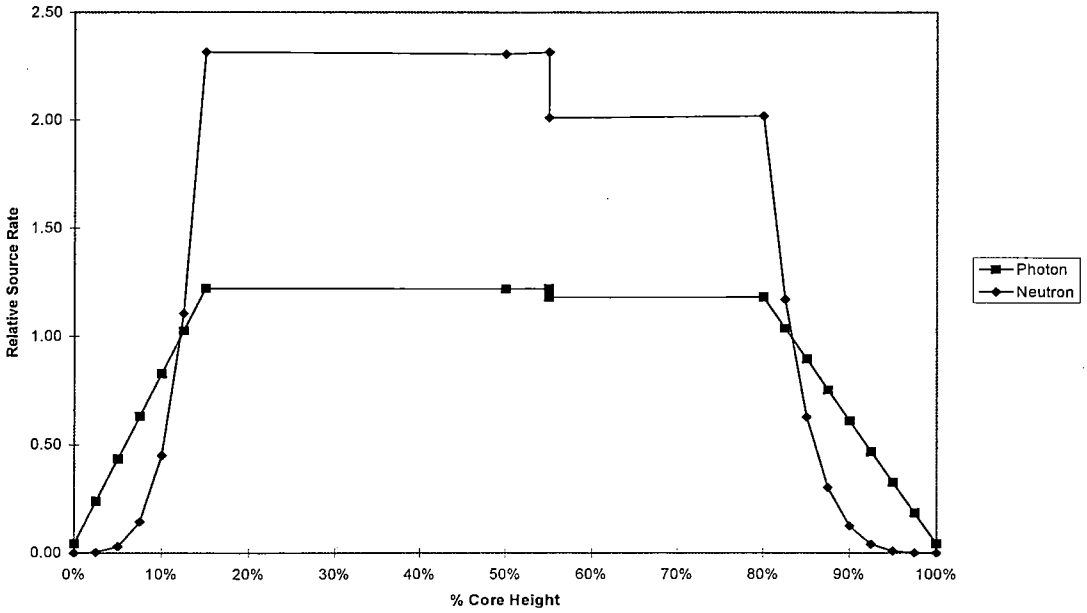


Table 5.4.1-1 PWR Source Profile Integration

% Core Height	Burnup Profile	Photon Source	Neutron Source	Photon Interval	Neutron Interval	Photon Weight	Neutron Weight
0.00%	0.5470	0.5470	7.84E-02				
2.50%	0.6358	0.6358	1.48E-01	5.91E-01	1.13E-01	1.48E-02	2.83E-03
5.00%	0.7247	0.7247	2.57E-01	6.80E-01	2.02E-01	1.70E-02	5.06E-03
7.50%	0.8135	0.8135	4.19E-01	7.69E-01	3.38E-01	1.92E-02	8.44E-03
10.00%	0.9023	0.9023	6.48E-01	8.58E-01	5.33E-01	2.14E-02	1.33E-02
12.50%	0.9912	0.9912	9.63E-01	9.47E-01	8.06E-01	2.37E-02	2.01E-02
15.00%	1.0800	1.0800	1.38E+00	1.04E+00	1.17E+00	2.59E-02	2.93E-02
85.00%	1.0800	1.0800	1.38E+00	1.08E+00	1.38E+00	7.56E-01	9.69E-01
87.50%	0.9912	0.9912	9.63E-01	1.04E+00	1.17E+00	2.59E-02	2.93E-02
90.00%	0.9023	0.9023	6.48E-01	9.47E-01	8.06E-01	2.37E-02	2.01E-02
92.50%	0.8135	0.8135	4.19E-01	8.58E-01	5.33E-01	2.14E-02	1.33E-02
95.00%	0.7247	0.7247	2.57E-01	7.69E-01	3.38E-01	1.92E-02	8.44E-03
97.50%	0.6358	0.6358	1.48E-01	6.80E-01	2.02E-01	1.70E-02	5.06E-03
100.00%	0.5470	0.5470	7.84E-02	5.91E-01	1.13E-01	1.48E-02	2.83E-03
Average						1.000	1.127

Table 5.4.1-2 BWR Source Profile Integration

% Core Height	Burnup Profile	Photon Source	Neutron Source	Photon Interval	Neutron Interval	Burnup Weight	Neutron Weight
0.00%	4.30E-02	4.30E-02	1.71E-06				
2.50%	2.39E-01	2.39E-01	2.39E-03	1.41E-01	1.20E-03	3.53E-03	2.99E-05
5.00%	4.35E-01	4.35E-01	2.99E-02	3.37E-01	1.61E-02	8.43E-03	4.04E-04
7.50%	6.32E-01	6.32E-01	1.44E-01	5.33E-01	8.68E-02	1.33E-02	2.17E-03
10.00%	8.28E-01	8.28E-01	4.50E-01	7.30E-01	2.97E-01	1.82E-02	7.42E-03
12.50%	1.02E+00	1.02E+00	1.10E+00	9.26E-01	7.77E-01	2.31E-02	1.94E-02
15.00%	1.22E+00	1.22E+00	2.31E+00	1.12E+00	1.71E+00	2.80E-02	4.27E-02
55.00%	1.22E+00	1.22E+00	2.31E+00	1.22E+00	2.31E+00	4.88E-01	9.26E-01
55.00%	1.18E+00	1.18E+00	2.02E+00	1.20E+00	2.17E+00	0.00E+00	0.00E+00
80.00%	1.18E+00	1.18E+00	2.02E+00	1.18E+00	2.02E+00	2.95E-01	5.04E-01
82.50%	1.04E+00	1.04E+00	1.17E+00	1.11E+00	1.59E+00	2.77E-02	3.98E-02
85.00%	8.96E-01	8.96E-01	6.28E-01	9.67E-01	8.99E-01	2.42E-02	2.25E-02
87.50%	7.54E-01	7.54E-01	3.03E-01	8.25E-01	4.66E-01	2.06E-02	1.16E-02
90.00%	6.11E-01	6.11E-01	1.25E-01	6.83E-01	2.14E-01	1.71E-02	5.36E-03
92.50%	4.69E-01	4.69E-01	4.11E-02	5.40E-01	8.33E-02	1.35E-02	2.08E-03
95.00%	3.27E-01	3.27E-01	8.97E-03	3.98E-01	2.50E-02	9.96E-03	6.26E-04
97.50%	1.85E-01	1.85E-01	8.10E-04	2.56E-01	4.89E-03	6.40E-03	1.22E-04
100.00%	4.30E-02	4.30E-02	1.71E-06	1.14E-01	4.06E-04	2.85E-03	1.02E-05
Average						1.000	1.585

5.5 Model Specification

The transfer and concrete casks are evaluated using the MCNP three-dimensional Monte Carlo code. In the MCNP fuel assembly model, the fuel and hardware source regions are homogenized within a volume defined by the fuel assembly width and height. This volume is subdivided axially into active fuel, upper and lower plenum, and upper and lower end fitting source regions. Within these axial volumes, the material masses of the fuel assembly are homogenized. In all models, the cask and TSC shield thicknesses and axial extents are explicitly represented, including streaming paths. Surface detectors are used to estimate the dose profiles at the cask surface and at distances of 1ft, 1m, 2m, and 4m from the cask surface. The MCNP code employs an automated biasing technique for the Monte Carlo calculation based on weight window adjustments in mesh cells. Radial biasing is performed to estimate dose rates at the transfer cask radial surface and concrete cask radial surface, including air inlets and outlets. Axial biasing is used for cask top and bottom surface rates. Angular biasing components are used to capture azimuthal variations in bulk shielding properties. Primary examples of azimuthal variations within bulk shields are the concrete cask air inlets and outlets and the vent/drain port location in the TSC closure lid.

The geometric description of an MCNP model is based on the combinatorial geometry system embedded in the code. In this system, surfaces and bodies, such as cylinders and rectangular parallelepipeds, and their logical intersections and unions, are used to describe the extent of material zones.

NAC-CASC, a modified version of SKYSHINE-III, uses the MCNP generated cask surface current to estimate site boundary exposures. NAC-CASC allows for self-shielding of casks and permits input of an angular surface current emission spectrum. In the NAC-CASC evaluations, the concrete casks are modeled as "black body" cylinders. Given the concrete cask thickness, radiation emitted from one cask and impacting an adjacent cask will not significantly impact site boundary dose rates. To verify the acceptability of this assumption, a radial neutron and gamma source MCNP analysis was performed on a 2×10 cask array with the front row assigned either an importance of 1 (same as back row casks) or assigned an importance of 0 (terminating the particle tracking). Results of this analysis are shown in Figure 5.5.5-7 for the short array axis (facing the x direction 2 cask side of the array in Figure 5.5.5-6) and Figure 5.5.5-8 for the long array axis (facing the y direction 10 cask side of the array in Figure 5.5.5-6). While significantly affecting the radial dose contribution from the "shielded" back row of casks along the y-axis, the "black body" assumption does not significantly affect total dose rates in this direction, as the majority of dose is contributed by the front row of casks (i.e., casks facing the detector). Including the axial contribution in the comparison, which is not affected by the "black body" assumption, would further decrease the relative effect of the "black body" assumption. The

energy and angular spectrum of radiation emitted from the cask surface are retained when transitioning from the MCNP to the NAC-CASC model.

5.5.1 Description of Radial and Axial Shielding Configurations

The three-dimensional shielding analysis allows detailed modeling of the source and shield regions, including streaming paths. Cask and TSC details include the axial extent of the radiation shields. This section includes system sketches, discussion of the general TSC shell (including closure lid and bottom plate) and features, and detailed information on the transfer cask and concrete cask shield configurations. Content dependent TSC, basket and fuel specific model details are included in Sections 5.8.3 and 5.8.4.

5.5.1.1 MCNP Canister Model

Key TSC shielding features are listed in Table 5.5.5-1. The TSC closure lid, shell, and bottom plate are explicitly modeled. Port covers are modeled as open in transfer cask evaluations and closed in concrete cask evaluations. The TSC elevations with respect to the cask shields are illustrated in the cask shield configuration descriptions.

5.5.1.2 MCNP Concrete Cask Model

The three-dimensional model of the concrete cask contains the following features:

- heat transfer annulus with standoffs
- bottom weldment, including pedestal, bottom plate, and air inlet structure
- radial concrete cask body with rebar
- concrete lid
- concrete pad below base plate

Detailed model parameters used in creating the three-dimensional model are taken directly from the relevant drawings. Key shielding features are listed in Table 5.5.5-2. Elevations associated with the concrete cask three-dimensional model are established with respect to the bottom plate of the TSC for the global model. Sketches of the three-dimensional concrete cask model are shown in Figure 5.5.5-1 and Figure 5.5.5-2 for the standard shield cask configuration, Figure 5.5.5-9 and Figure 5.5.5-10 for the augmented shield configuration, and Figure 5.5.5-11 for the short, standard shield cask configuration (CC4).

The standard shield concrete cask design is specified as 1) a standard assembly, one-piece version, with optional embedded lift anchors, and 2) an alternate, segmented assembly with two covered lift anchor cavities. The modeled geometry reflects a conservative combination of both models, with two uncovered lift anchor cavities added to the standard assembly geometry as

shown in Figure 5.5.5-3. The augmented shield concrete cask and CC4 is designed in a one-piece version.

5.5.1.3 MCNP Transfer Cask Model

The transfer cask is evaluated in detail for the welding, draining, and drying operations. As with the concrete cask models, all basket areas, with the exception of the fuel assembly, are discretely modeled. Six inches of auxiliary shielding are included in the transfer cask evaluation, as is the water in the TSC/transfer cask annulus between the upper and lower inflatable seals. A foreign material exclusion bar is modeled over the TSC to transfer cask annulus. Key transfer cask shield features are listed in Table 5.5.5-3. Figure 5.5.5-4 provides a model sketch of the carbon steel transfer cask with TSC. The stainless steel transfer cask is identical in configuration to the carbon steel cask shown with the exception of the carbon steel component replacement by stainless steel and a reduced overall height of 191 inches.

5.5.2 MCNP Detector Mesh Definition

MCNP surface detectors are used to calculate dose rates at various distances from the casks. The surface tallies are subdivided using the FS tally segmentation card. A graphical illustration of the detector overlay on a cask is shown in Figure 5.5.5-5. Depicted are 1ft, 1m, 2m, and 4m detector surfaces on the concrete cask. For clarity, the cask surface detector and azimuthal (angular) divisions are not shown. Typical detector grids for the transfer and concrete cask analysis are shown in Table 5.5.5-4 to Table 5.5.5-6. The dose maps produced by this method completely enclose the accessible cask surfaces and capture all locations necessary for the evaluation of occupational exposures.

5.5.3 NAC-CASC Model

The site boundary evaluation relies on single cask and 2×10 cask array models. An illustration of the 2×10 cask array is shown in Figure 5.5.5-6. The nominal cask pitch for the array is 15 feet. A conservative 16-ft pitch is evaluated to minimize cask self-shielding.

In each of the models, the concrete cask is represented as a cylindrical body onto which detailed surface radiation currents are applied. Cask surface currents are extracted from the 3-D MCNP shielding evaluation of each payload/configuration. The MCNP evaluation also provides the angular distribution of the cask surface current for sampling in the NAC-CASC skyshine code. The cask surface currents are based on the fuel type, assembly average burnup, initial enrichment, and cool time combination that produce the maximum cask radial and axial surface dose rates. In the PWR system, the source also accounts for the addition of nonfuel hardware.

Separating the TSC contents evaluation of the cask body from the site air transport exposure evaluation minimizes analysis complexity. All cask gamma source components, including the n-γ production in the cask, are combined into a single gamma source for the skyshine analysis. The model includes a representation of the cask pad, soil surrounding the pad, and an air envelope (air density applied is 0.001225 g/cm^3, which is the density of dry air at 20°C). The air envelope provides both an n-γ source as well as radiation scatter. Air density of 0.001225 g/cm^3 applied in the analysis formed the basis for the development of the line beam response functions used in the NAC-CASC (SKYSHINE-III) code. Variations in the air density are permitted within the code input deck but were not utilized in the dose rate evaluations. Variations in site conditions, including expected atmospheric conditions, should be addressed per Appendix A (Chapter 13) Section 5.5 "Radiation Protection Program" evaluations. Detectors are spaced along the rectangular outline of the ISFSI to a maximum extent of 2,000 ft (610 m) from the center of the array or single cask. NAC-CASC detectors are located at an elevation of 3 ft relative to the bottom of the cask. To obtain a sufficiently detailed dose rate map, dose rate results were evaluated at intervals of 5 ft from 85 ft to 100 ft and at 25-ft intervals from 100 ft to 2000 ft. A detector grid spacing of less than 10 meters is sufficient to provide the generic information necessary to determine system array or single cask effects on site boundary dose. The dose rate data plotted in Section 5.8.3-5 for PWR and BWR systems demonstrates a smooth drop off of dose rate (or yearly dose) that could be fit with a larger detector spacing than that employed in this evaluation.

An ISFSI containing a significant number of casks may be surrounded by a berm or wall structure to reduce offsite doses. The model generated here, conservatively, does not consider any other shielding components with the exception of the other casks on the pad.

5.5.4 Offsite Particulate and Gas Release

The TSC is welded closed using controlled welding processes to ensure that the TSC is in a configuration where no credible leakage of the TSC's radionuclide contents can occur. Since the TSC was submerged in the spent fuel pool for loading, a limited amount of surface contamination may be released from the TSC.

A calculation is made to determine dose rate as a function of distance based on residual contamination limits of β-γ and α activity, released from the TSC surface, using the plume dispersion method of Regulatory Guides 1.109 [19] and 1.145 [20].

The χ/Q factor is determined according to the formula from Reg. Guide 1.145.

$$\frac{\chi}{Q} = \frac{1}{U_{10} \cdot \pi \cdot \Sigma_y \cdot \sigma_z}$$

$$\frac{\chi}{Q} = 8.29\text{ E-03 [sec/m}^3\text{] at 100 meters}$$

The releasable activity is determined using:

$$Q[Ci] = \frac{(C)(A)(N)}{(2.22E+12)(100)}$$

where:

2.22E+12 = the conversion from curies (Ci) to disintegrations per minute [dpm]
C=the contamination limits
Q = the activity released [Ci]
A= the surface area of the TSC
N = the number of TSCs from which contamination is released

Reg. Guide 1.109 defines the annual dose due to submersion and inhalation. These equations are solved for the amount of activity released in a year, Q [Ci].

Submersion: $D_{submersion} = Q \cdot \frac{\chi}{Q} \cdot DCF_S$

Inhalation: $D_{inhalation} = Q \cdot \frac{\chi}{Q} \cdot BR \cdot DCF_I$

where:

D = dose [rem]
DCF_S=submersion dose conversion factor [rem-m^3/Ci-yr]
DCF_I=inhalation dose conversion factor [rem/Ci]
BR = amount of air breathed annually [8000 m^3]

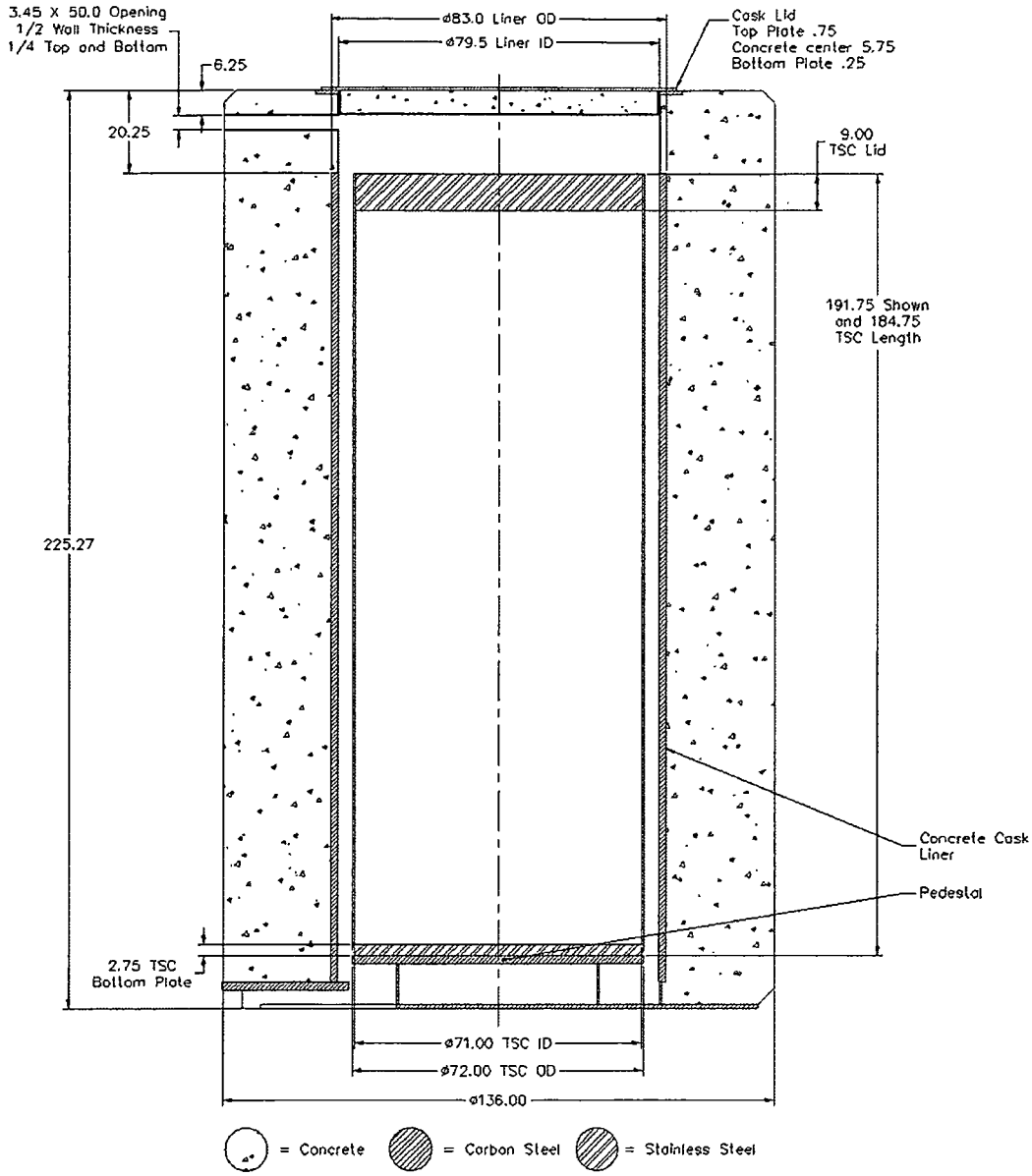
Refer to Section 5.6.5 for the results of this evaluation.

5.5.5 Shield Regional Densities

Material densities for the fuel, basket, TSC, and cask components modeled are listed in this section. Basket, TSC, and cask components are explicitly modeled. Density and material compositions for structural components are primarily obtained from the standard composition library included with SCALE 4.4 [10]. Exceptions to this rule are the density and composition of the neutron shielding material (NS-4-FR), the composition of the neutron absorber sheets in the basket, and the density of concrete for the concrete cask. The NS-4-FR composition is based on the material specification after curing. The neutron absorber sheet composition is based on an

aluminum-boron carbide mixture containing ^{10}B at a fixed areal density. The required ^{10}B areal density is dependent on the system evaluated. Cask systems are evaluated under dry TSC cavity conditions. Therefore, the absorber sheets do not affect system dose rates significantly. Concrete density is set to the minimum permitted. Basket, TSC, and cask material densities and compositions are shown in Table 5.5.5-7. Fuel region densities are calculated quantities dependent on the hardware and fuel masses in the assembly. A sample homogenized fuel assembly material description is shown in Table 5.5.5-8.

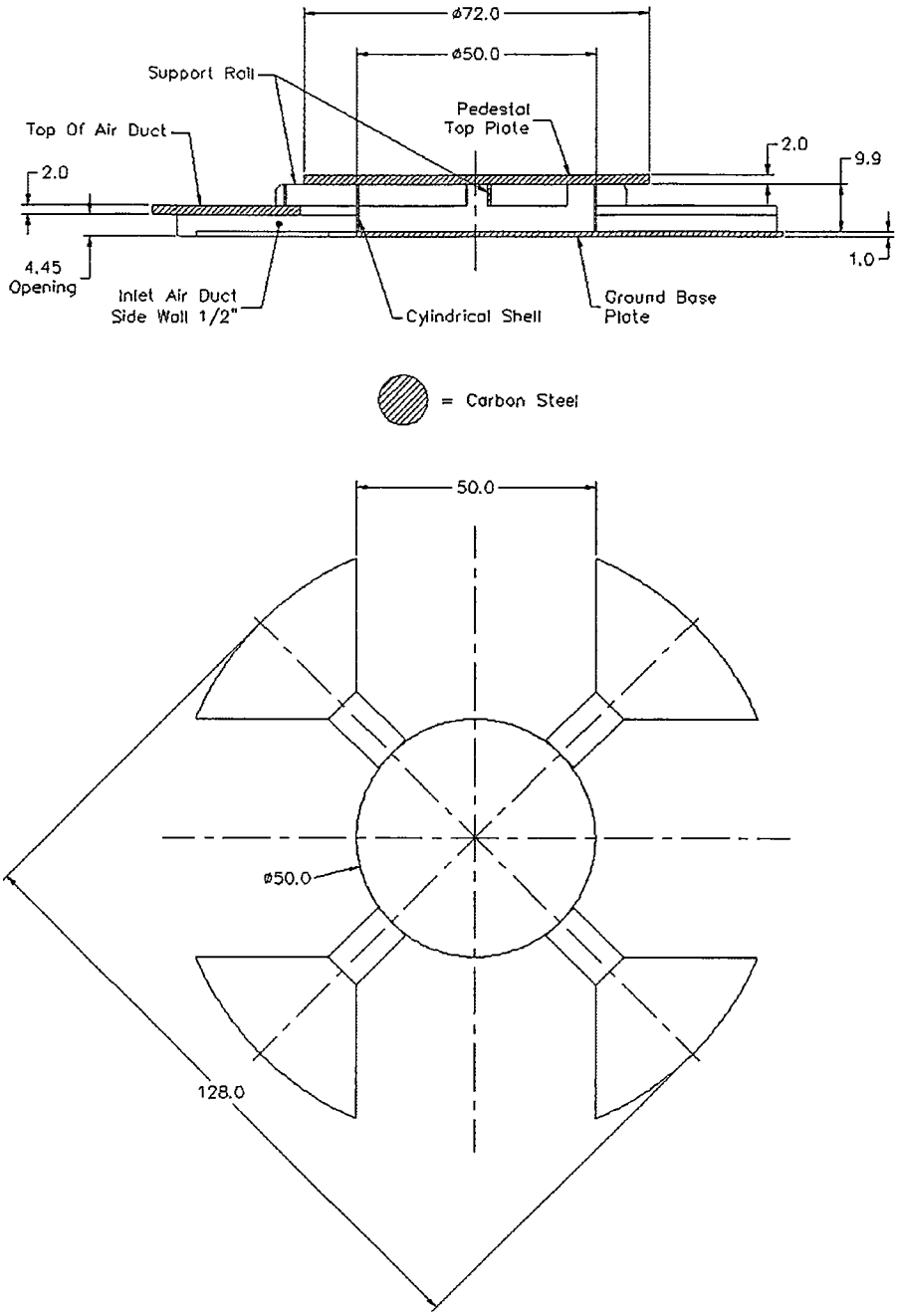
Figure 5.5.5-1 Concrete Cask Model – Primary Shield Dimensions[a]



Dimensions in inches.

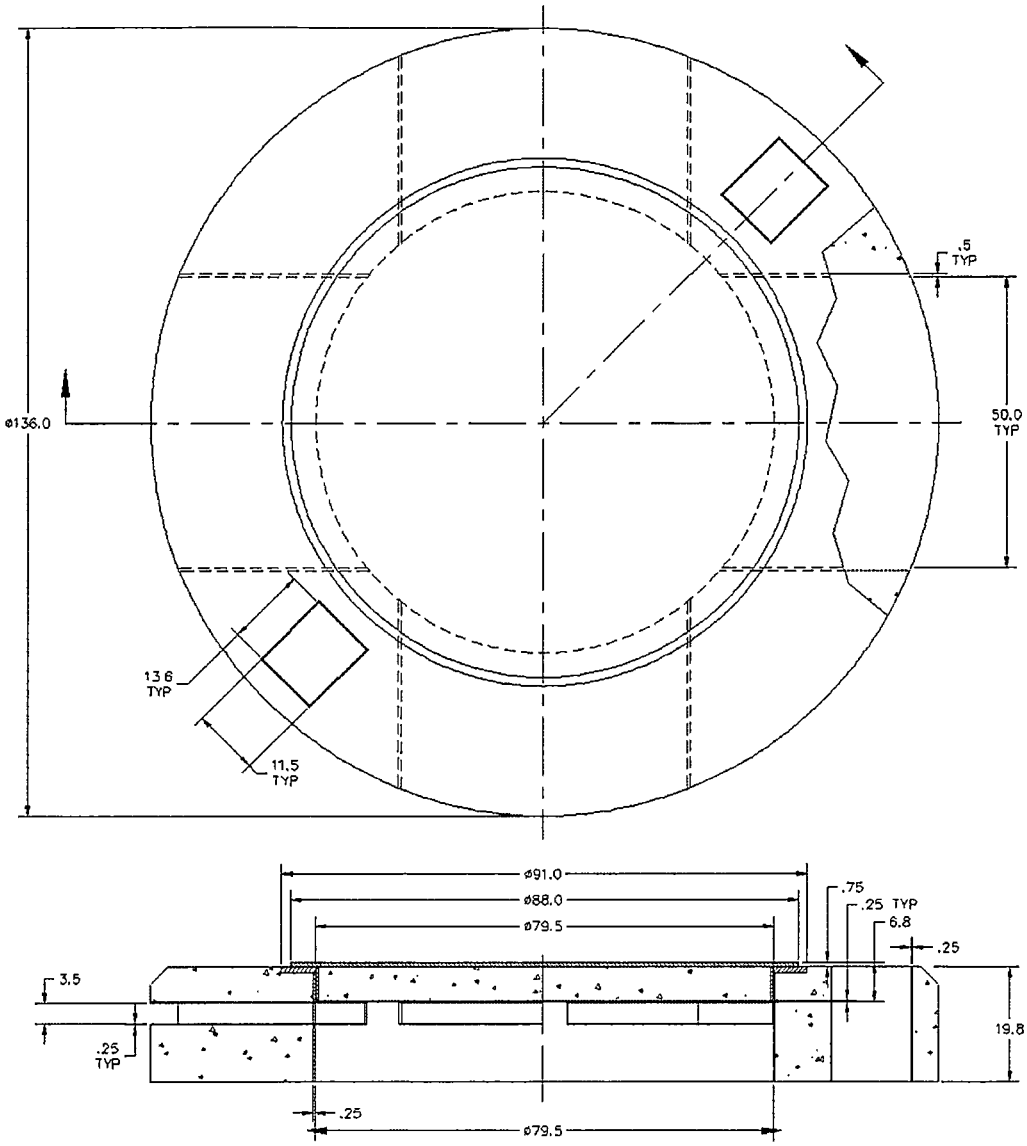
[a] Shown with stainless steel closure lid used in BWR evaluations. PWR evaluations use the composite carbon/stainless steel closure lid assembly.

Figure 5.5.5-2 Standard Shield Concrete Cask Model – Bottom Weldment



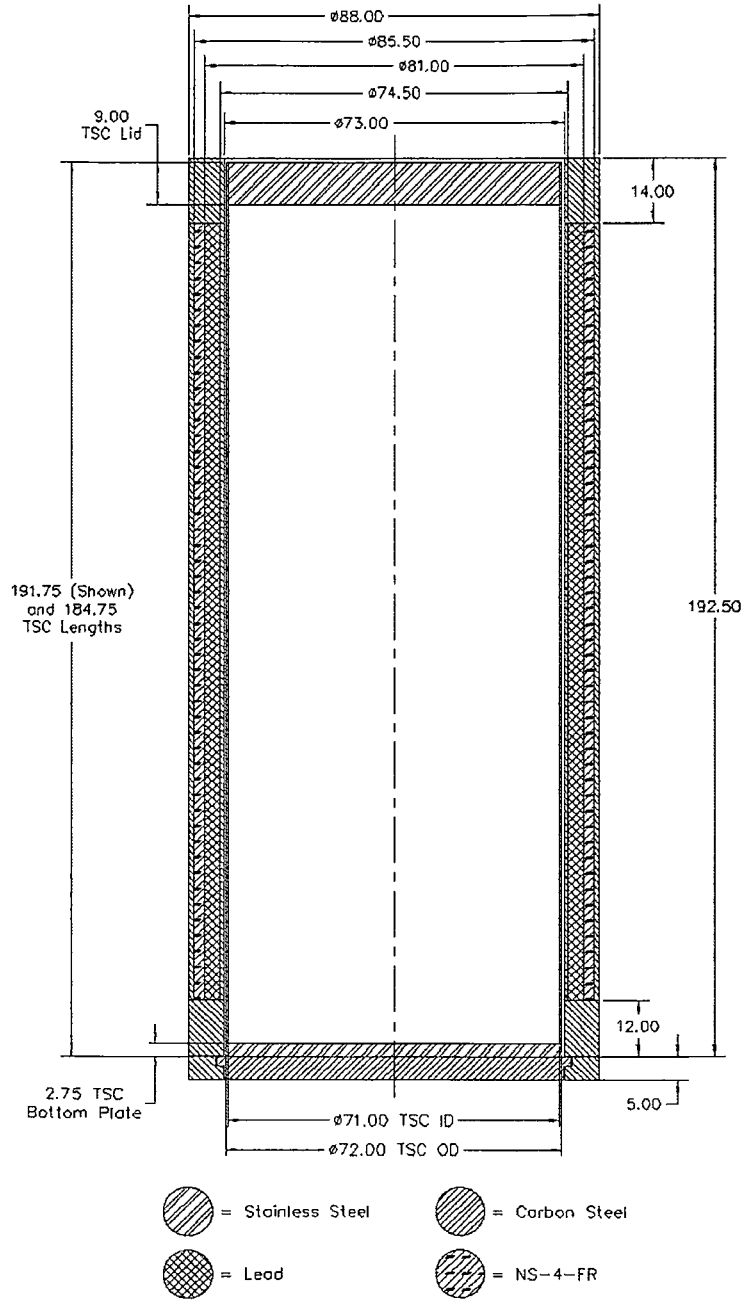
Dimensions in inches.

Figure 5.5.5-3 Standard Shield Concrete Cask Model – Top Section



Dimensions in inches.

Figure 5.5.5-4 Carbon Steel Transfer Cask/TSC Model[a]



Dimensions in inches.

[a] Shown with stainless steel closure lid used in BWR evaluations. PWR evaluations use the composite carbon/stainless steel closure lid assembly.

Figure 5.5.5-5 MCNP Detector Grid Locations for Concrete Cask

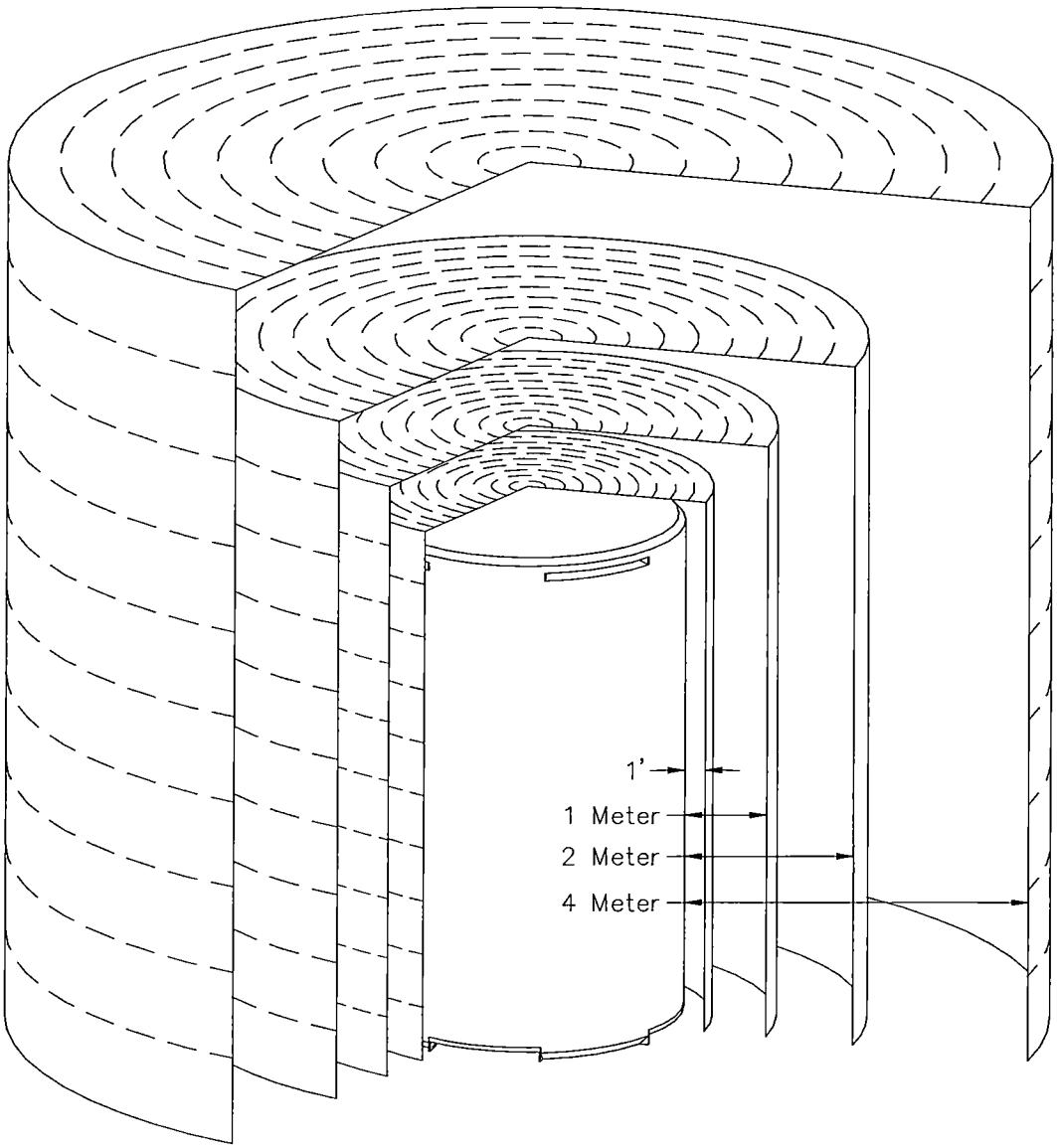
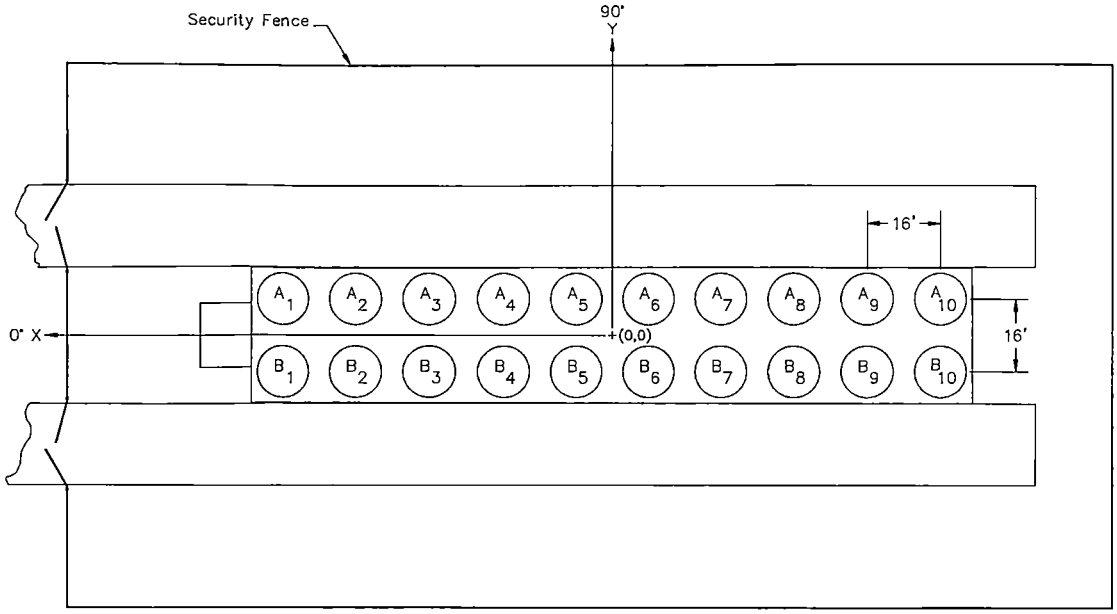


Figure 5.5.5-6 NAC-CASC Model Cask Array



Note: A cask pitch of 16 ft is conservative when considering cask array self-shielding.

Figure 5.5.5-7 NAC-CASC "Black Body" Assumption Test Along Short (X-Axis) Side of Array

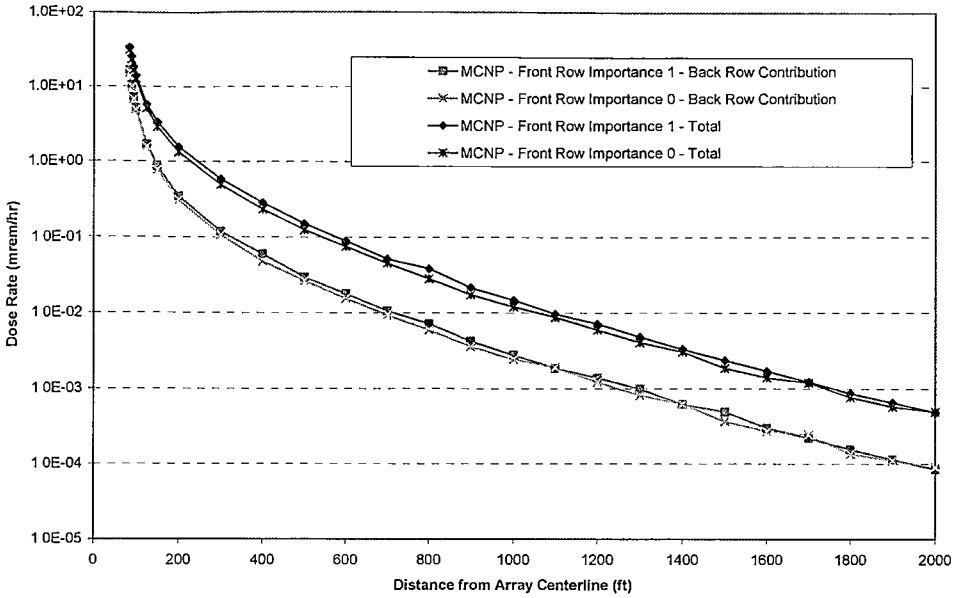


Figure 5.5.5-8 NAC-CASC "Black Body" Assumption Test Along Long (Y-Axis) Side of Array

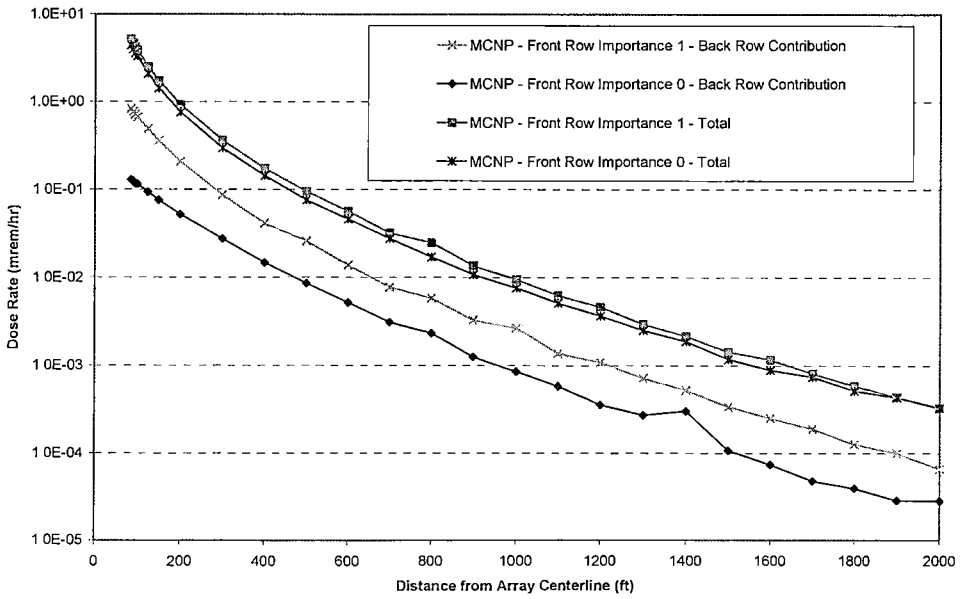
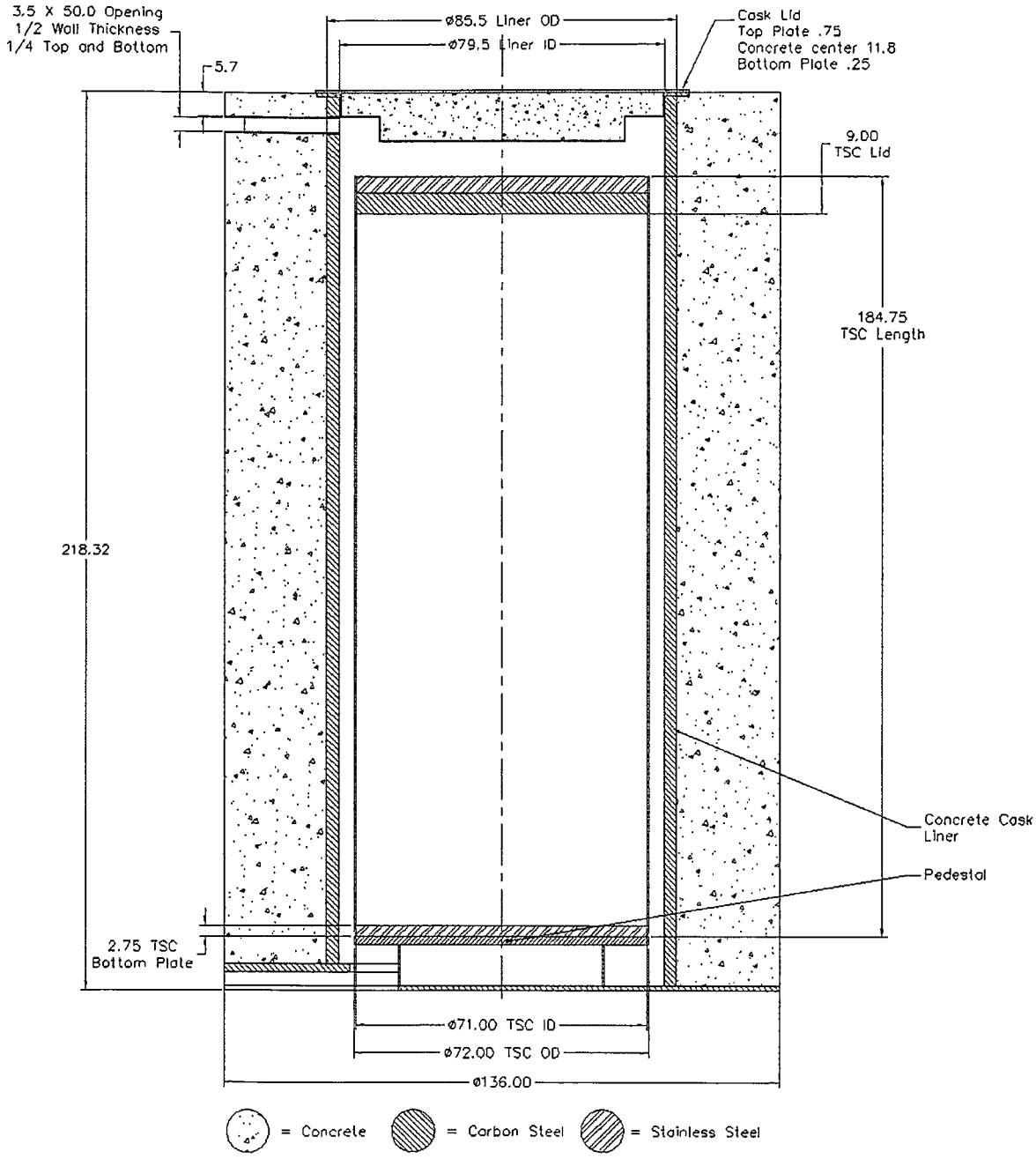


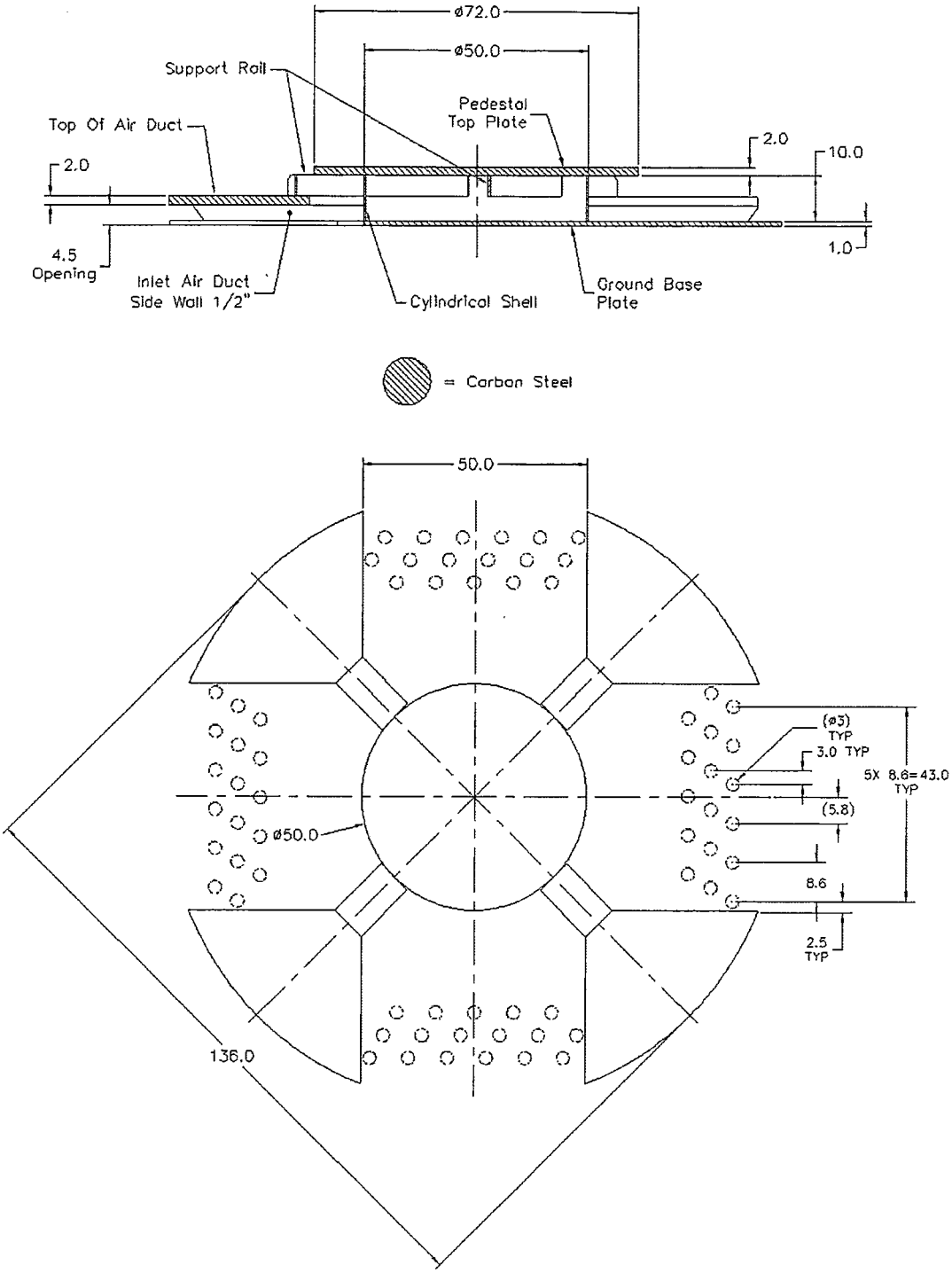
Figure 5.5.5-9 Augmented Shield Concrete Cask Model – Primary Shield Dimensions



Dimensions in inches.

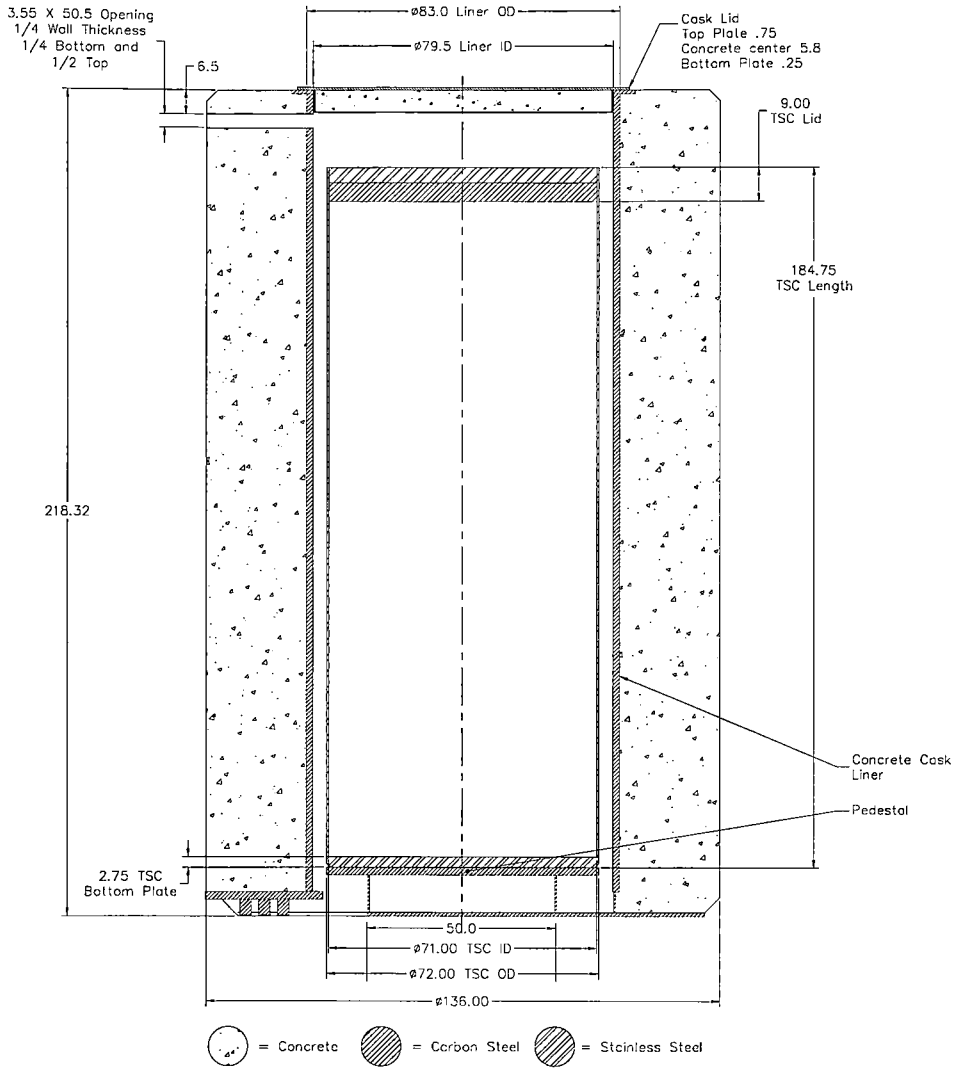
Note: Cask sketch includes composite carbon/stainless steel TSC lid assembly.

Figure 5.5.5-10 Augmented Shield Concrete Cask Model – Bottom Weldment



Dimensions in inches.

Figure 5.5.5-11 CC4 Model – Primary Shield Dimensions



Dimensions in inches.

Note: Cask sketch includes composite carbon/stainless steel TSC lid assembly.

Table 5.5.5-1 Key TSC Shielding Features

Feature	Material	Stainless Lid Dimension	Composite Lid Assy Dimension
TSC Shell	Stainless Steel	0.5-in. thick, 72-in. OD	
TSC Bottom Plate	Stainless Steel	2.75-in. thick	
TSC Closure Lid	Stainless Steel	9-in. thick	N/A
TSC Closure Lid Lower	Carbon Steel	N/A	5
TSC Closure Lid Upper	Stainless Steel	N/A	4
TSC Vent and Drain Port	--	2.12-in. diameter	

Table 5.5.5-2 Key Concrete Cask Shielding Features

Feature	Material	Standard Shield Dimension	Augmented Shield Dimension	CC4 Dimension
Inner Shell	Carbon Steel	1.75-in. thick, 83-in. OD	3.0-in. thick, 85.5-in. OD	1.75-in. thick, 83-in. OD
Cask Body Radial Shell	Concrete	26.5-in. thick (calculated), 136-in. OD	25.25-in. thick (calculated), 136-in. OD	26.5-in. thick (calculated), 136-in. OD
Lid Concrete	Concrete	5.75-in. thick	11.8-in. thick	5.80-in. thick
Lid Steel	Carbon Steel	1.0-in. total thickness		
Pedestal Plate	Carbon Steel	2-in. thick, 72-in. OD		
Cask Bottom Plate	Carbon Steel	1-in. thick		
Air Inlet	--	4.45-in. void height		
Air Outlet	--	3.5-in. void height	3.55-in. void height	3.55-in. void height

Table 5.5.5-3 Key Transfer Cask Shielding Features

Feature	Material[a]	Dimension
Inner Shell	Carbon / Stainless Steel	0.75-in. thick, 74.5-in. OD
Outer Shell	Carbon / Stainless Steel	1.25-in. thick, 88-in. OD[b]
Top Weldment	Carbon / Stainless Steel	14-in. height
Bottom Weldment	Carbon / Stainless Steel	12-in. height
Gamma Shield	Lead	3.2-in. thick
Neutron Shield	NS-4-FR	2.2-in. thick (calculated)[c]
Door	Carbon / Stainless Steel	5-in. thick
FME Bar	Carbon Steel	0.75-in. thick

[a] Dependent on cask configuration, components are either stainless steel or carbon steel.
[b] Modeled at 87.9-in. for BWR evaluations.
[c] Modeled at 2.2-in. for BWR evaluations.

Table 5.5.5-4 Typical Radial Surface Detector Division

Transfer Cask			Concrete Cask		
Location	Axial Div	Azimuthal Div	Location	Axial Div	Azimuthal Div
Surface	15	1	Surface	12	1
1ft	15	1	1ft	12	1
1m	20	1	1m	15	1
2m	20	1	2m	20	1
4m	20	1	4m	20	1

Table 5.5.5-5 Typical Top Surface Detector Division

Location	Radial Div	Azimuthal Div	Location	Radial Div	Azimuthal Div
Surface	12	1	Surface	10	1
1ft	12	1	1ft	10	1
1m	12	1	1m	10	1
2m	12	1	2m	10	1
4m	12	1	4m	10	1
Port Surface[a]	1	64	Air Outlet[b]	1	20

Table 5.5.5-6 Typical Air Inlet and Outlet Detector Division

Location	Axial Div[c]	Azimuthal Div
Surface	1	20
1ft	1	20
1m	1	20

[a] Radial restricted to radial location of vent and drain ports.
[b] Radial restricted to area above air outlets.
[c] Elevation restricted to air inlet and outlet height.

Table 5.5.5-7 Fuel Basket, TSC, and Transfer and Concrete Cask Material Description

Material	Density [g/cm³]	Nuclide / Element	Density [atom/barn-cm]
Carbon and Low-Alloy Steel	7.8212	CARBON	3.9250E-03
		IRON	8.3494E-02
Stainless Steel	7.94	CHROMIUM	1.7472E-02
		MANGANESE	1.7407E-03
		IRON	5.9505E-02
		NICKEL	7.7392E-03
Lead	11.344	LEAD	3.2967E-02
NS-4-FR	1.6316	HYDROGEN	5.8508E-02
		BORON-10	9.1385E-05
		BORON-11	3.3665E-04
		CARBON	2.2600E-02
		NITROGEN	1.3904E-03
		OXYGEN	2.6107E-02
		ALUMINUM	7.8003E-03
Concrete	2.3234	HYDROGEN	1.3883E-02
		OXYGEN	4.6537E-02
		SODIUM	1.7649E-03
		ALUMINUM	1.7631E-03
		SILICON	1.6789E-02
		CALCIUM	1.5361E-03
		IRON	3.5075E-04
Neutron Absorber (PWR)	2.6336	ALUMINUM	3.8828E-02
		BORON-10	7.5719E-03
		BORON-11	3.1393E-02
		CARBON	9.7414E-03
Water	0.9982	HYDROGEN	6.6752E-02
		OXYGEN	3.3376E-02
Lid Concrete (PWR only)	2.2432	HYDROGEN	1.3404E-02
		OXYGEN	4.4931E-02
		SODIUM	1.7040E-03
		ALUMINUM	1.7022E-03
		SILICON	1.6209E-02
		CALCIUM	1.4831E-03
		IRON	3.3864E-04

Table 5.5.5-8 Sample Fuel Region Homogenized Material Description (17a PWR Assembly)

Material	Density [g/cm³]	Nuclide / Element	Density [atom/barn-cm]
Lower End-Fitting	1.8782	CHROMIUM	4.1330E-03
		MANGANESE	4.1176E-04
		IRON	1.4076E-02
		NICKEL	1.8307E-03
Lower Plenum	2.6798	CHROMIUM	3.1037E-05
		TIN	2.0391E-04
		IRON	3.6121E-05
		NITROGEN	5.7622E-05
		ZIRCONIUM	1.7376E-02
Active Fuel	3.8195	URANIUM-235	3.5714E-04
		URANIUM-238	6.6998E-03
		ZIRCONIUM	4.2594E-03
		CHROMIUM	7.6082E-06
		TIN	4.9986E-05
		NITROGEN	1.4125E-05
		OXYGEN	1.4110E-02
		IRON	8.8542E-06
Upper Plenum	0.7412	CHROMIUM	1.1716E-03
		TIN	1.5971E-05
		MANGANESE	1.1647E-04
		IRON	3.9846E-03
		NITROGEN	4.5132E-06
		NICKEL	5.1787E-04
		ZIRCONIUM	1.3610E-03
Upper End-Fitting	1.8385	CHROMIUM	4.0457E-03
		MANGANESE	4.0305E-04
		IRON	1.3778E-02
		NICKEL	1.7920E-03

5.6 Shielding Evaluation

This section evaluates the shielding design of the concrete and transfer casks. The calculation methods, computer codes used, and bounding results are described. Dose rate profiles are reported as a function of distance from the sides and top of the concrete cask and from the sides, top, and bottom of the transfer cask.

5.6.1 Calculation Methods

5.6.1.1 MCNP Calculation Method

The shielding evaluations of the transfer and concrete cask are performed with MCNP5 [3]. Source terms include fuel neutron, fuel gamma, and gamma contributions from activated hardware. As described in Section 5.2, these evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms.

The MCNP shielding models described in Section 5.5 are used with the source terms described in Section 5.2 to estimate the dose rate profiles at the cask surface and at distances of 1ft, 1m, 2m, and 4m. The method of solution is continuous energy Monte Carlo, with a Monte Carlo based weight window generator to accelerate code convergence. Radial or axial biasing is performed, depending on the desired dose location. Azimuthal components are included in the weight window mesh to account for the angular variations in the bulk shielding properties of the concrete cask at the inlets and outlets and at the TSC lid ports (transfer evaluation only).

Significant validation literature is available for MCNP, as it is an industry standard tool for spent fuel cask evaluations. Available literature covers a range of shielding penetration problems ranging from slab geometry to spent fuel cask geometries [21,22,23,24,25]. Confirmatory calculations against other validated shielding codes (SCALE [6] and MCBEND [12]) on NAC casks have further validated the use of MCNP for shielding evaluations.

MCNP calculations are performed using a response function approach for each source type present in each source region. There are eight source types: encompassing fuel neutron, fuel gamma, fuel n-gamma (secondary gammas arising from neutron interaction in the shield), fuel region hardware, upper and lower plenum, and upper and lower end-fitting gamma sources.

In the response function method, each of the assemblies, and source regions within an assembly, is analyzed with a unit source in each relevant energy group. These sources are analyzed in a finite number of energy groups with a unit source in each group. The scalar product of source term and response function allows for the creation of large arrays of dose rate results, whether

they are for a single detector, or the maximum or average over a detector surface. Further detail on the response function approach to generating dose rates is included in Section 5.8.2.

5.6.1.2 Site Boundary Dose (NAC-CASC) Calculation Method

Exposure at the controlled area boundary of the ISFSI is limited to 25 mrem/year in accordance with 10 CFR 72.104(a). The NAC version of the SKYSHINE-III code, referred to as NAC-CASC, is used to evaluate the placement of the controlled area boundary for a single cask and a 2×10 array of casks. Given the source geometry, spectra and desired detector locations, NAC-CASC calculates dose rates using a combination of precalculated transmission and reflection data and the Monte Carlo technique to integrate over the source direction and energy variables.

NAC staff modified the FORTRAN source coding of the SKYSHINE-III code to add explicit cask body source and cask array input features, allow the reading and sampling of angular surface current files for cask radial and top surfaces, and correct for self-shielding of casks in the array. Minor output changes were made to collect results in a more compact format than the SKYSHINE default. Code benchmarks were repeated after each modification.

Subroutines were modified to allow the entering and sampling of a cylindrical surface for the cask side wall, and disk source for the cask lid. Sampling on the surfaces is based on user defined source dimensions (i.e., in the MAGNASTOR analysis, the surfaces over which the current was tallied by MCNP). This code modification provides a significant increase in input flexibility versus the typical SKYSHINE input of point sources.

Code modifications also allow for the input of current files from Monte Carlo cask evaluations (such as MCNP and MCBEND tally files) containing the angular distribution of the source. Options exist in the revised coding to use a default angular distribution for the cask surface source, but for the MAGNASTOR evaluation an explicit concrete cask surface profile was used.

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

The performance of the NAC-CASC code is validated by modeling a set of Kansas State University ^{60}Co skyshine experiments and by modeling two Kansas State University neutron

computational benchmarks. The code compared well with these benchmarks for both neutron and gamma doses versus distance.

5.6.2 Flux-to-Dose Rate Conversion Factors

The ANSI/ANS 6.1.1-1977 [26] flux-to-dose rate conversion factors are used in all cask shielding evaluations. Neutron and gamma dose conversion factors are listed in Table 5.6.5-1 and Table 5.6.5-2, respectively.

5.6.3 Cask Dose Rate and Exposure Results

This section provides bounding dose profiles for the concrete and transfer cask based on the source terms presented in Section 5.2. 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, upper and lower fuel rod plenum hardware, and activated nonfuel material in the active fuel region. The three-dimensional model dose rates include the effects of axial profiles.

5.6.3.1 Concrete Cask Dose Rates

Maximum concrete cask radial and top axial normal condition dose rates at the cask surface and distances of 1ft, 1 m and 2 m are shown in Figure 5.6.5-1 and Figure 5.6.5-2. In the axial profile plots, each datum represents the circumferentially averaged dose rate at the corresponding elevation. Figure 5.6.5-3 and Figure 5.6.5-4 contain an azimuthal breakdown of the bounding (standard shield) air outlet and inlet dose rate cases. Refer to Sections 5.8.3.4 and 5.8.4.4 for further detail, such as content and cask configuration specific dose rates, and a breakdown in dose by source region.

Concrete cask top dose rates peak at 430 mrem/hr, with the gamma dose accounting for 99% of the total. Gamma radiation exiting the concrete cask top surface has a minimal impact on site-boundary exposure.

The missile impact scenario represents the only accident condition significantly impacting the system shielding performance. The conservative removal of 6 inches of concrete from the entire cask body radial surface results in a maximum 1-m dose of 286 mrem/hr. This is extremely conservative, as the missile impact is limited to an 8-in diameter projectile and the 1-m dose would not be significantly affected by a localized reduction in the concrete cask shield. Missile impact dose rates are conservatively calculated based on PWR and BWR heat loads of 40 and 38 kW, respectively.

5.6.3.2 Transfer Cask Dose Rates

Bounding transfer cask dose rates as a function of distance from the cask are shown in Figure 5.6.5-5, Figure 5.6.5-6 and Figure 5.6.5-7. Dose peaks occur on the radial cask surface near the top and bottom weldment locations where activated end-fitting contributions control dose rate. Over the fuel region, the dose shape follows the burnup shape. On the top axial cask surface, dose rates rise in the cask to the TSC annulus area where significant radiation streaming occurs.

5.6.4 NAC-CASC Dose Evaluation

Bounding site boundary dose rates from direct radiation for the limiting contents, as a function of distance from the single concrete cask and the 2×10 concrete cask array, are plotted in Figure 5.6.5-8. Distances are taken along the axis perpendicular to the 10-cask side of the array. The limiting contents are the PWR TSC, as documented in Section 5.8.3.5. Site boundary evaluations are presented in Sections 5.8.3.4.3 and 5.8.3.5, respectively. The CC4 is not evaluated, as there are no radial shield differences from the CC1, and radial dose is the primary dose contributor for the site boundary (greater than 80%). The negligible differences would be bounded by the 40 kW PWR payload evaluation.

5.6.5 Surface Contamination Release

Offsite release exposures from particulate contamination are evaluated at a conservative distance of 100 meters and a residual contamination limit of 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α.

The selected dose conversion factors are based on using the highest conversion factor for each radiologically significant group of nuclides expected on the TSC surface. ^{60}Co conversion factors are applied to β-γ activity and ^{241}Am factors are applied to the α activity. Dose conversion factors are taken from EPA Federal Guidance Report No. 11 [27], Table 2.1 and Federal Guidance Report No. 12 [28], Table III.1. Both Class Y (oxide) and W compound dose conversion factors were extracted. Class Y (oxide) conversion factors are bounding for the β-γ cobalt release. Only class W conversion factors are available for the ^{241}Am release. The dose conversion factors employed are:

Dose Type	Unit	(^{60}Co)	(^{241}Am)
Submersion – Skin	[rem-m³/Ci-yr]	1.69E+07	--
Inhalation – Lung	[rem/Ci]	1.28E+06	6.81E+07
Inhalation – Whole Body	[rem/Ci]	2.19E+05	4.44E+08
Inhalation – Bone	[rem/Ci]	--	8.03E+09

The inventory available for release is calculated assuming that 100% of the surface area of each TSC is covered with the contamination levels listed, and applies a conservative release fraction of 1% using the methodology presented in Section 1.2.1 of NUREG-1400 [29]. The resulting inventory available for release is conservative, as the release fractions presented in 10 CFR 30.72 are a factor of 10 lower for ^{241}Am (0.001) and ^{60}Co (0.001).

Employing the submersion and inhalation equations from Reg. Guide 1.109, doses are calculated over a range of distances from 100 to 1,000 meters. A dose summary for a distance of 100 m is shown in Table 5.6.5-3. Surface contamination at 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α does not represent a significant exposure contribution at the site boundary.

Figure 5.6.5-1 Bounding Concrete Cask Side Dose Rate Profile (CC4 – PWR 35.5 kW)

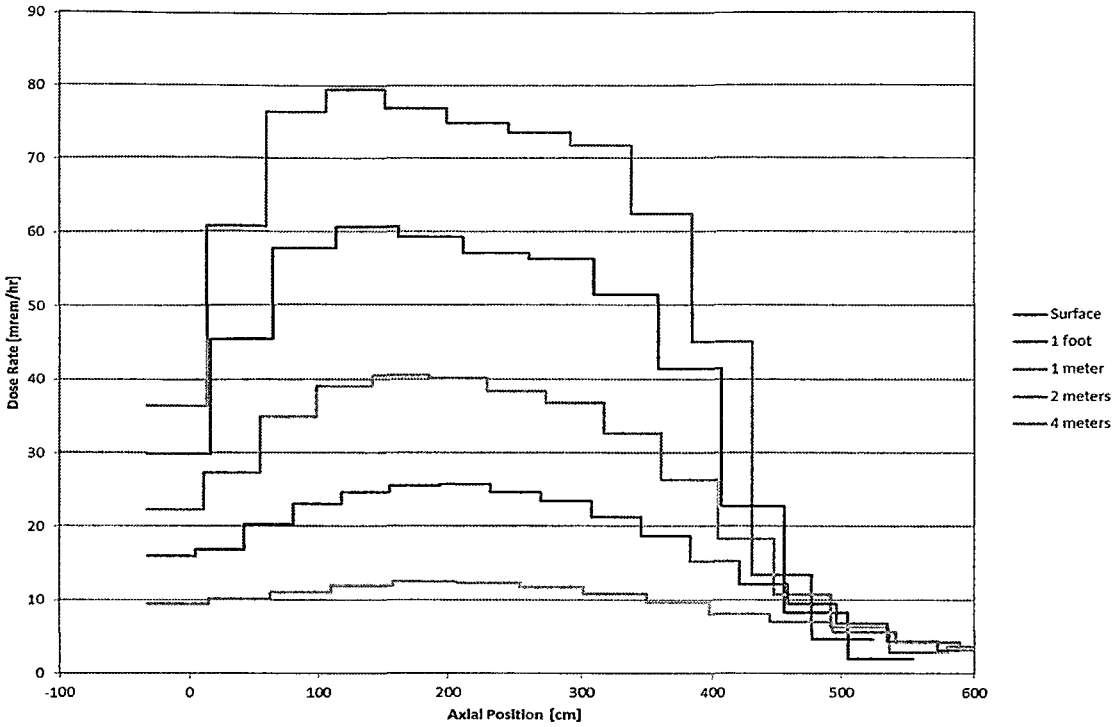


Figure 5.6.5-2 Bounding Concrete Cask Top Dose Rate Profile (Standard Shield Concrete Cask – BWR 35 kW)

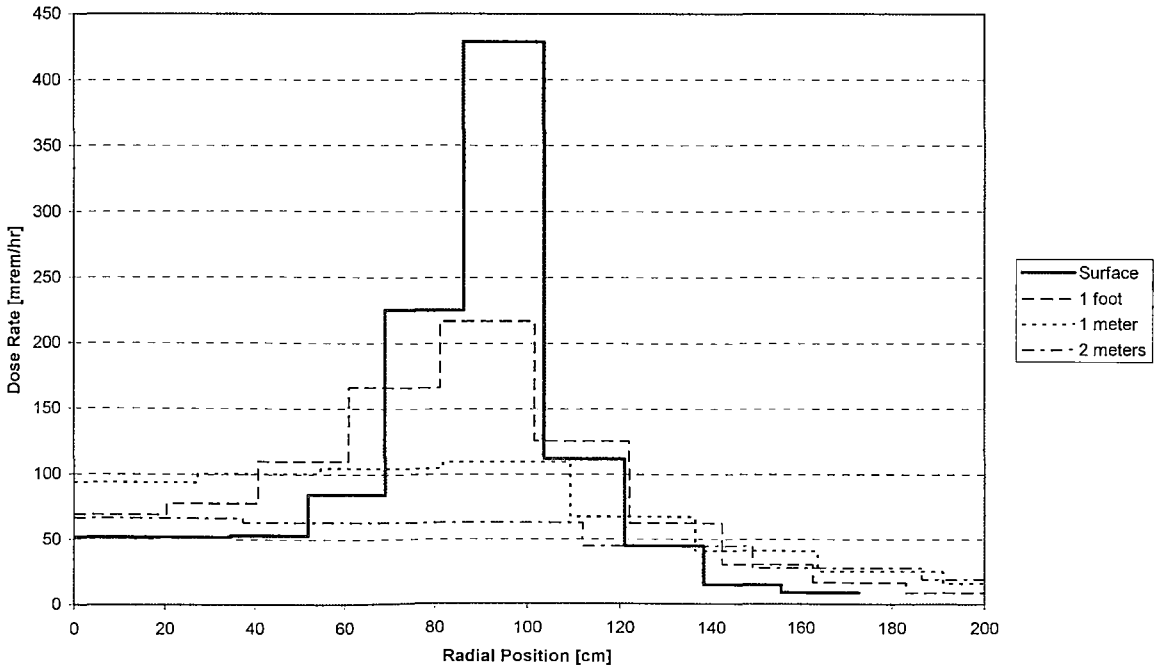


Figure 5.6.5-3 Bounding Concrete Cask Air Outlet Elevation Surface Dose Rate Profile (Standard Shield Concrete Cask – BWR 35 kW)

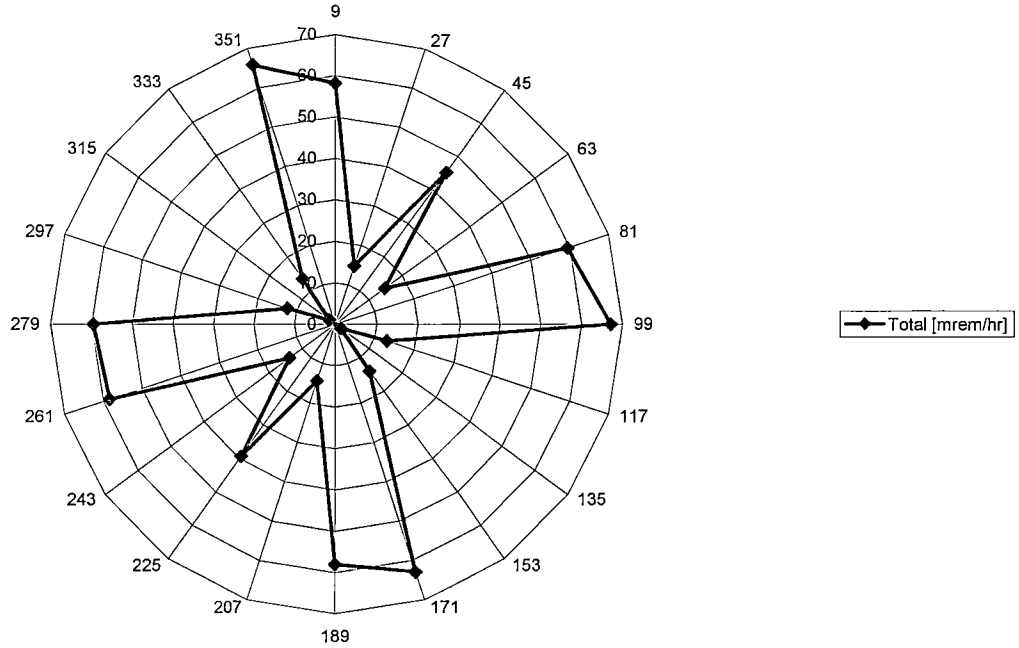


Figure 5.6.5-4 Bounding Concrete Cask Bottom Air Inlet Elevation Dose Rate Profile (Standard Shield Concrete Cask – PWR 35.5 kW)

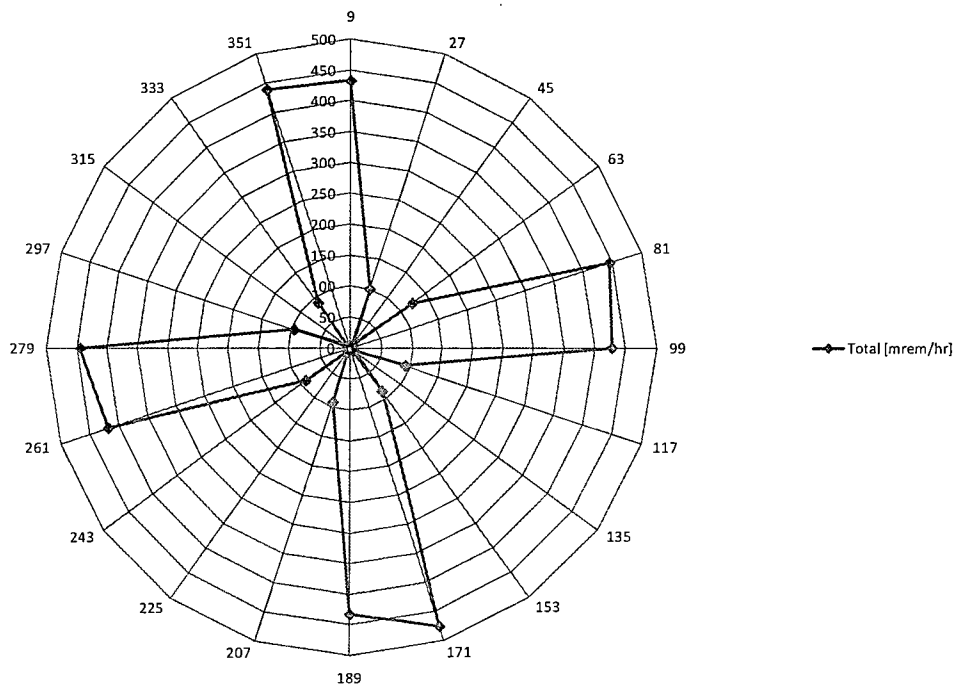


Figure 5.6.5-5 Bounding Transfer Cask Side Dose Rate Profile (Carbon Steel Transfer Cask – BWR 35 kW)

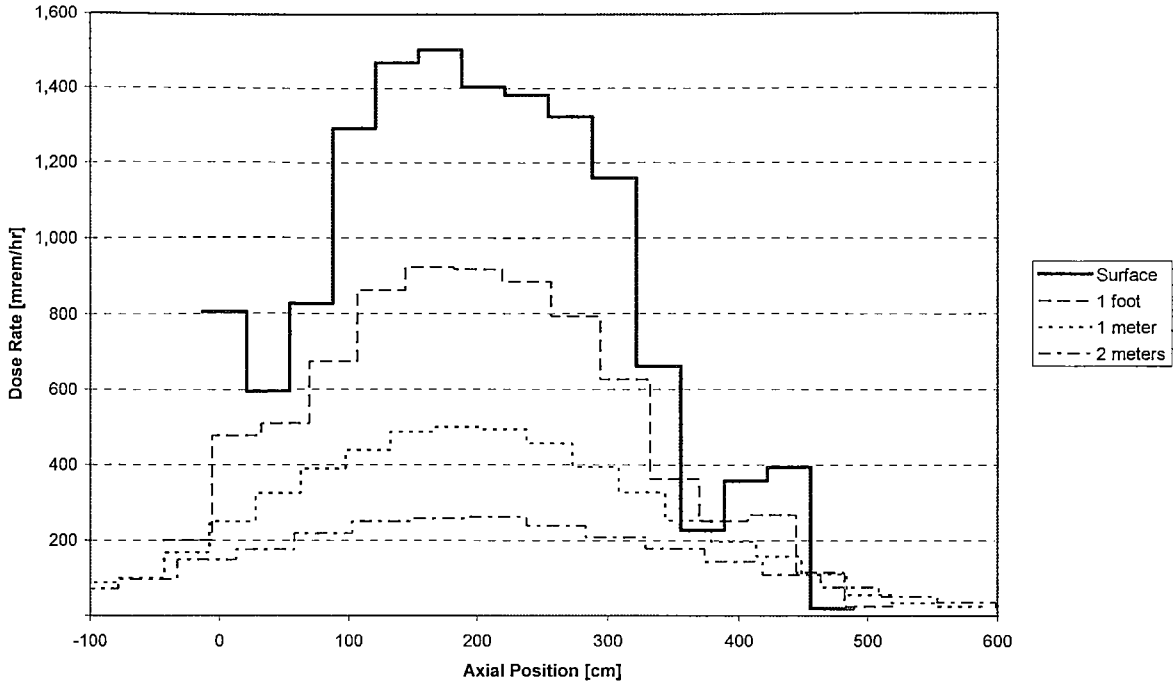


Figure 5.6.5-6 Bounding Transfer Cask Top Dose Rate Profile (Carbon Steel Transfer Cask – BWR 35 kW)

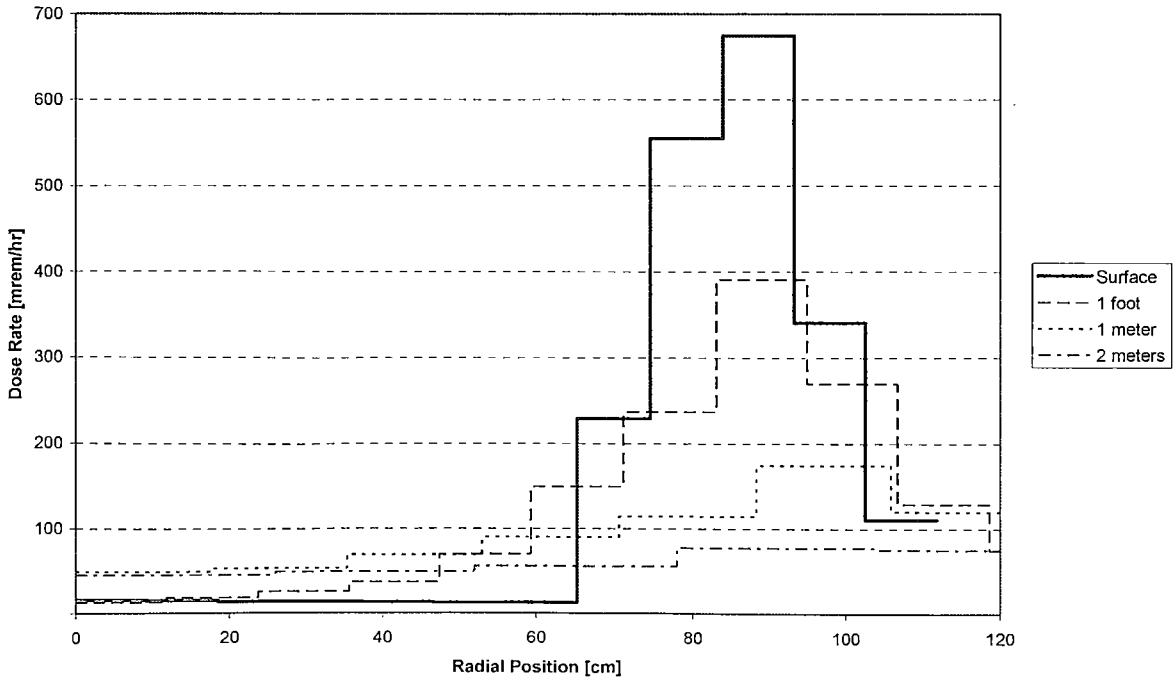


Figure 5.6.5-7 Bounding Transfer Cask Bottom Dose Rate Profile (Carbon Steel Transfer Cask – PWR 35.5 kW)

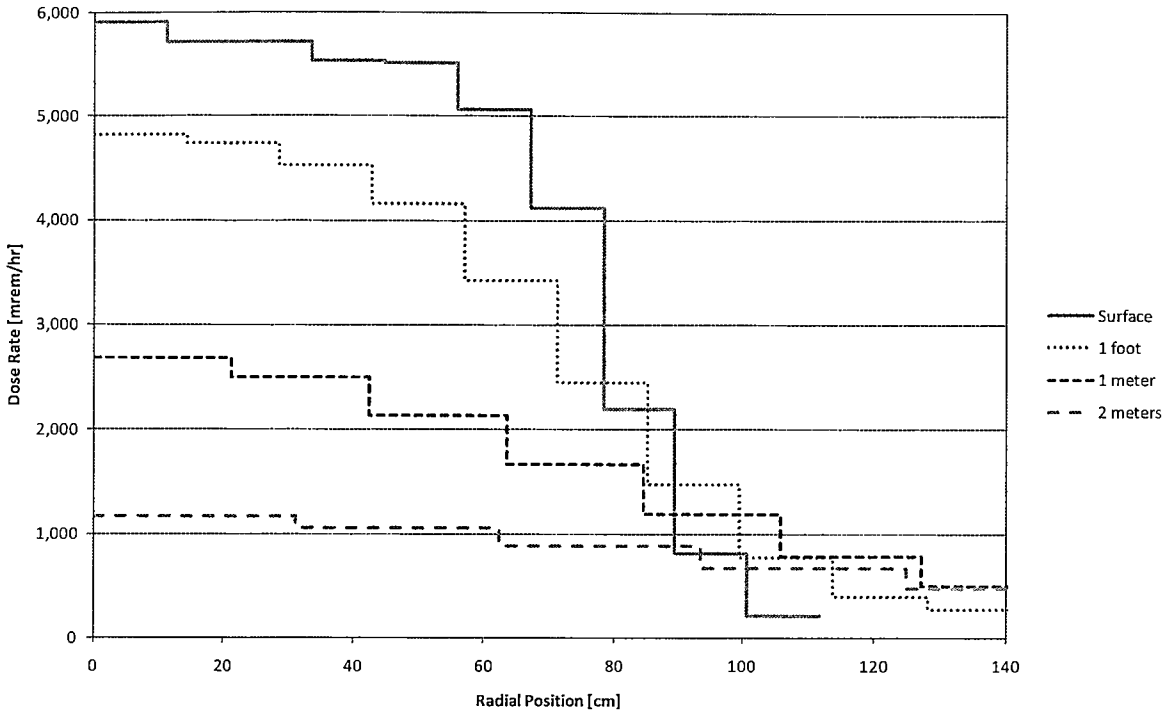


Figure 5.6.5-8 Bounding Site Boundary Dose Rates vs. Distance

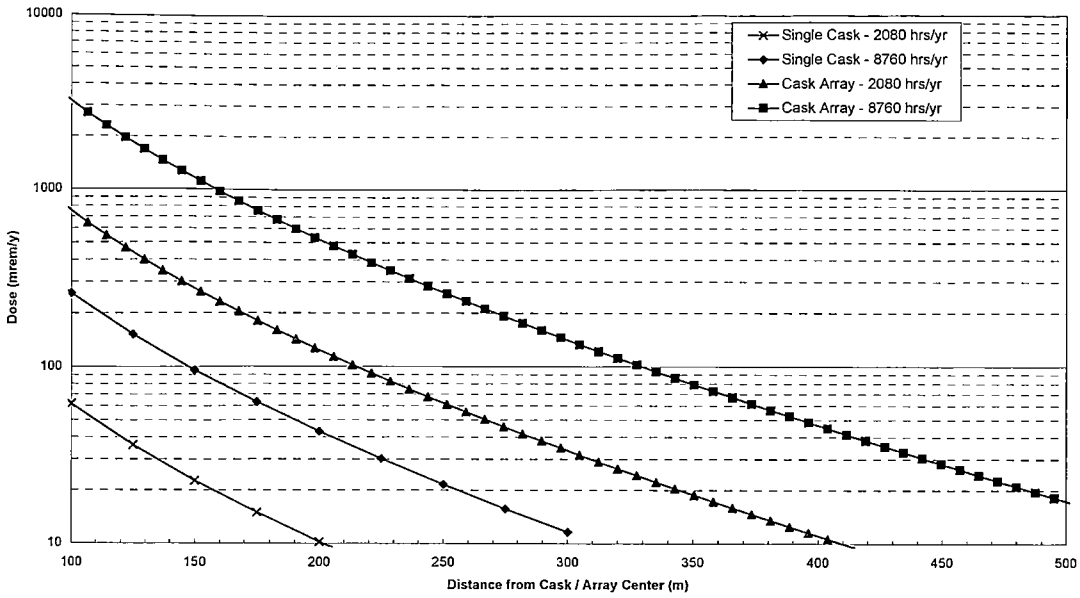


Table 5.6.5-1 ANSI Standard Neutron Flux-To-Dose Rate Factors

Energy (MeV)	(rem/hr)/(n/cm²/sec)
2.5E-08	3.67E-06
1.0E-07	3.67E-06
1.0E-06	4.46E-06
1.0E-05	4.54E-06
1.0E-04	4.18E-06
1.0E-03	3.76E-06
1.0E-02	3.56E-06
1.0E-01	2.17E-05
5.0E-01	9.26E-05
1.0	1.32E-04
2.5	1.25E-04
5.0	1.56E-04
7.0	1.47E-04
10.0	1.47E-04
14.0	2.08E-04
20.0	2.27E-04

Table 5.6.5-2 ANSI Standard Gamma Flux-To-Dose Rate Factors

Energy (MeV)	(rem/hr)/(γ/cm²/sec)	Energy (MeV)	(rem/hr)/(γ/cm²/sec)
0.01	3.96E-06	1.4	2.51E-06
0.03	5.82E-07	1.8	2.99E-06
0.05	2.90E-07	2.2	3.42E-06
0.07	2.58E-07	2.6	3.82E-06
0.1	2.83E-07	2.8	4.01E-06
0.15	3.79E-07	3.25	4.41E-06
0.2	5.01E-07	3.75	4.83E-06
0.25	6.31E-07	4.25	5.23E-06
0.3	7.59E-07	4.75	5.60E-06
0.35	8.78E-07	5	5.80E-06
0.4	9.85E-07	5.25	6.01E-06
0.45	1.08E-06	5.75	6.37E-06
0.5	1.17E-06	6.25	6.74E-06
0.55	1.27E-06	6.75	7.11E-06
0.6	1.36E-06	7.5	7.66E-06
0.65	1.44E-06	9	8.77E-06
0.7	1.52E-06	11	1.03E-05
0.8	1.68E-06	13	1.18E-05
1	1.98E-06	15	1.33E-05

Table 5.6.5-3 Dose Summary at 100 meters from TSC Surface Contamination Release

Source	Organ / Whole Body	Exposure (mrem)
β-γ	Skin Dose (β-γ)	1.33E-06
	Lung Dose (β-γ)	8.03E-04
	Whole Body Dose (β-γ)	1.38E-04
α	Bone Surface Dose (α)	5.05E-02
	Lung Dose (α)	7.52E-03
	Whole Body Dose (α)	2.79E-03
Total	Skin Dose (β-γ)	1.33E-06
	Bone Surface Dose (α)	5.05E-02
	Whole Body Dose (α + β-γ)	2.93E-03
	Lung Dose (α + β-γ)	8.32E-03

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5.8 Shielding Evaluation Detail

This section contains evaluation detail not found in the preceding sections.

5.8.1 Contents Description

Three-dimensional models of the loaded TSC within the transfer or concrete cask require the relative elevations of the various source regions, hardware masses, and in-core condition to describe source and shielding models. The elevation of each of the assembly regions also defines the volume into which the fuel assembly is homogenized.

5.8.1.1 PWR Fuel Assembly Definitions

As described in Section 5.2, PWR fuel assemblies were surveyed to construct hybrids containing maximum fuel and hardware masses. Source regions in the model are defined as the fuel neutron and gamma source originating in the active fuel region, the active fuel region hardware source (typically from activated steel or inconel grids or springs), upper and lower plenum spring sources (with lower springs being limited to B&W core fuel assemblies), and upper and lower end fittings. Grouping assemblies by these characteristics results in similar elevations for the end fitting and plenum regions for assemblies in each group. Elevations selected for the shielding analysis are those of the maximum fuel mass assembly in each group. Merging maximum hardware masses for any assembly in the group into the basic structure of the maximum fuel mass assembly produces a bounding assembly hybrid. Geometry data for the fuel assembly hybrids are listed in Table 5.8.1-1 and nonzirconium alloy-based fuel assembly hardware masses are listed in Table 5.8.1-2.

In addition to the assembly configuration, source term generation requires in-core conditions as input into SAS2H. Inputs provided are temperatures and densities of the moderator, assembly power level, and number of days at power. The number of days at power is calculated based on the desired assembly average burnup and assembly power level. In-core characteristics are core type-dependent and vary for each of the assembly hybrids evaluated. A set of sample PWR in-core parameters, in this case for the 17a assembly type, is presented in Table 5.8.1-3. The corresponding sample SAS2H input is shown in Section 5.8.8, Figure 5.8.8-1.

5.8.1.2 BWR Fuel Assembly Definitions

BWR assemblies are grouped similarly to the PWR assemblies, with groupings driven by BWR reactor type and lattice configuration. BWR fuel assembly hybrid geometry data are listed in Table 5.8.1-4 and nonzirconium alloy-based fuel assembly hardware masses are listed in Table 5.8.1-5.

Sample in-core assembly characteristics required for source term generation are listed in Table 5.8.1-6. The 09b assembly hybrid is chosen for the sample analysis. The corresponding SAS2H input file is shown in Section 5.8.8, Figure 5.8.8-2.

Table 5.8.1-1 PWR Hybrid Fuel Assembly Geometry Data

Core	CE	WE	WE	B&W	CE	WE	B&W
Label	14a	14b	15a	15b	16a	17a	17b
Array	14x14	14x14	15x15	15x15	16x16	17x17	17x17
Nominal Number of Fuel Rods	176	179	204	208	236	264	264
Fuel Loading [MTU]	0.4115	0.4144	0.4671	0.4807	0.4463	0.4671	0.4681
Fuel Assembly Height [in]	157.238	161.100	160.100	165.625	178.300	159.800	165.719
Fuel Assembly Width [in]	8.030	7.763	8.449	8.536	8.250	8.426	8.536
Fuel Rod Height [in]	146.488	152.360	152.756	153.125	161.318	151.630	152.688
Top End-Cap Height [in]	0.685	0.685	0.685	0.685	0.500	0.685	0.685
Bottom End-Cap Height [in]	0.685	0.685	0.685	0.685	0.891	0.685	0.685
Max Active Length [in]	136.7	145.2	144.0	144.0	150.0	144.0	143.0
Lower Plenum Region Height [in]	0.000	0.000	0.000	4.563	0.000	0.000	4.844
Upper Plenum Region Height [in]	8.418	5.790	7.386	3.193	9.927	6.260	3.474
Lower End-Fitting Height [in]	3.312	3.188	2.738	2.000	3.812	2.700	2.000
Upper End-Fitting Height [in]	5.763	3.500	3.480	8.875	11.047	3.670	9.406
Gap Fuel Rod to Top Nozzle [in]	1.475	2.052	1.126	1.625	2.123	1.800	1.625
Rod Diameter [in]	0.440	0.422	0.422	0.430	0.382	0.374	0.379

Table 5.8.1-2 PWR Hybrid Fuel Assembly Nonzirconium Alloy-Based Hardware Mass

Core	CE	WE	WE	B&W	CE	WE	B&W
Label	14a	14b	15a	15b	16a	17a	17b
Lower Nozzle Hardware (kg)	6.080	7.893	5.680	9.610	7.300	5.900	6.870
Lower Plenum Hardware (kg)	0.000	0.000	0.000	1.980	0.000	0.000	1.560
Fuel Hardware (kg)	7.417	5.370	9.300	4.900	1.360	5.440	4.270
Upper Plenum Hardware (kg)	8.750	6.634	5.698	3.020	10.700	5.406	2.860
Upper Nozzle Hardware (kg)	11.550	9.888	11.840	10.760	16.800	7.850	18.130

Table 5.8.1-3 PWR Sample In-Core Characteristics

Variable	Value
Fuel Temperature	900 K
Clad Temperature	620 K
Coolant Temperature	580 K
Coolant Density	0.725 g/cm^3
Coolant Average Boron Content	550 ppm
Assembly Power	17.670 MW

Table 5.8.1-4 BWR Hybrid Fuel Assembly Geometry Data

Core	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/4-6
Label	07a	07b	08a	08b	09a	09b	10a
Array	7x7	7x7	8x8	8x8	9x9	9x9	10x10
Nominal Number of Fuel Rods	49	49	63	64	79	79	92
Fuel Mass (MTU)	0.1985	0.2037	0.1855	0.1996	0.1723	0.1979	0.1946
Fuel Assembly Height [in]	171.125	176.200	171.125	176.200	171.290	176.161	176.200
Fuel Assembly Width [in]	5.518	5.518	5.518	5.518	5.251	5.518	5.518
Lower Nozzle Height [in]	6.760	6.760	6.760	6.760	6.940	6.760	6.760
Upper Nozzle Height [in]	7.500	7.500	7.500	7.500	7.500	7.500	7.500
Fuel Rod Height [in]	156.025	161.060	156.025	160.551	155.520	160.551	160.551
Top End-Cap Height [in]	0.160	0.435	0.440	0.346	0.345	0.346	0.346
Bottom End-Cap Height [in]	0.625	0.625	0.625	0.625	0.355	0.625	0.625
Active Length [in]	144.0	146.0	144.0	150.0	145.24	150.0	150.0
Upper Plenum Region Height [in]	11.240	14.000	10.960	9.580	9.580	9.580	9.580
Gap Fuel Rod to Top Nozzle [in]	0.840	0.880	0.840	1.389	1.330	1.350	1.389
Rod Diameter [in]	0.570	0.563	0.493	0.484	0.424	0.441	0.404

Table 5.8.1-5 BWR Hybrid Fuel Assembly Nonzirconium Alloy-Based Hardware Quantities

Core	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/4-6
Label	07a	07b	08a	08b	09a	09b	10a
Lower Nozzle Hardware (kg)	4.700	4.700	4.700	4.700	4.530	4.740	4.740
Fuel Hardware (kg)	2.030	0.320	0.330	0.330	0.245	0.246	0.120
Upper Plenum Hardware (kg)	2.830	1.848	2.858	2.812	1.684	1.706	2.132
Upper Nozzle Hardware (kg)	3.520	2.080	2.080	2.080	2.000	2.080	2.080

Table 5.8.1-6 BWR Sample In-Core Characteristics

Variable	Value
Fuel Temperature	840 K
Clad Temperature	620 K
Coolant Density in Lattice	0.446 g/cm^3
Coolant Temperature in Lattice	562 K
Coolant Density Outside Channel	0.743 g/cm^3
Coolant Temperature Outside Channel	553 K
Assembly Power	4.5 MW

5.8.2 Response Function Method

In general, the response method for dose rates is based on the decomposition of the respective quantity into a weighted sum over energy. A dose rate response function, $R_{tpg}(\vec{r})$, gives the response at a point $\vec{r}$ to source particles arising from energy group g from a fuel assembly placed in basket position p. In practice, the spatial parameter, $\vec{r}$, is represented as discrete subsurface detectors on the cask surface. In addition, responses for detector average and maximum values may also be represented using this notation. In the case of a dose rate response, the response $R_{tpg}(\vec{r})$ is a scalar quantity.

For a given TSC loading, the total response to radiation of type t with source spectrum f_{tp} is given by:

$$C_t(\vec{r}) = \sum_p \sum_{g'} R_{tpg'}(\vec{r}) f_{tpg'} w_{tp}$$

where:

$C_t(\vec{r})$ is the dose rate response to radiation of type t at location $\vec{r}$.
$R_{tpg'}(\vec{r})$ is the response to radiation of type t with energy g' emanating from basket position p at location $\vec{r}$.
$f_{tpg'}$ is the source strength for radiation of type t in group g' emanating from basket position p.
w_{tp} is a weight factor applied to radiation of type t in basket position p and is used to scale hardware source spectra that are provided on a per unit mass basis by the effective mass of activated material present in the source region.

The source type t refers to fuel gamma (Fg), fuel neutron (Fn), fuel n-gamma (Ng), fuel hardware (Hw), upper plenum (Up), upper fitting (Uf), lower plenum (Lp), or lower fitting (Lf) source regions.

Response functions for the transfer and storage cask (generated using MCNP) solve the particle transport equations at each relevant spectrum line using Monte Carlo techniques. The results of the individual spectrum lines are then statistically summed. As the basket is loaded uniformly (or in a three-region pattern for the PWR preferential loading pattern), the dose rate response can be calculated for a source located in multiple fuel assembly locations using Monte Carlo sampling within MCNP. For the uniform loading, the basket position variable is, therefore, not required within the summation. Note that the term is still accounted for directly within the

MCNP run. For the three-region preferential loading scenario, the summation is limited to the dose rate response contribution of the three zones.

Source terms are generated in a 28-group neutron and 22-group gamma structure. Dose rate responses are adequately modeled by evaluating only a subset of the source spectrum energy groups. In the fuel neutron case, no fuel neutron source spectra have nonzero values outside energy groups 2 through 15; and groups 2, 3 and 15 do not contribute significantly to the result. The fuel gamma response is accurately calculated by considering energy groups 7 through 15. Energy lines relevant to the analysis of activated zirconium, steel, and inconel hardware are limited to groups 12 and 13. The remaining energy lines either contain no significant source magnitudes or are too low in energy to penetrate the cask shields.

A comparison of the results of the direct calculation (i.e., a calculation based on use of the complete gamma, neutron or hardware gamma source spectrum in an MCNP run) and dose response method (summation of dose calculation at each energy group) is documented to validate the response method, including the reduction in energy lines evaluated. Response validations are based on the maximum dose concrete cask configurations. For the PWR system, this implies the use of the standard concrete cask and the stainless/carbon steel lid assembly TSC.

Graphical comparisons of the two solution methods are generated for PWR and BWR storage systems at three burnup/enrichment combinations. The combinations evaluated are low burnup/low enrichment of 30 GWd/MTU and 2.5 wt % ^{235}U, medium burnup/medium enrichment of 45 GWd/MTU and 4.0 wt % ^{235}U, and a high burnup/high enrichment of 60 GWd/MTU and 5 wt % ^{235}U. All cases are at system minimum cool times (based on 35.5 kW PWR cases and 35 kW BWR cases). Also included as graphical comparisons are a sample storage cask top and transfer cask top and radial cases. Only single runs are included for these surfaces as the method description, sample response tables, and the extensive radial concrete cask cases provide sufficient documentation on the accuracy of the method. The comparison plots are included in Figure 5.8.2-1 through Figure 5.8.2-9.

Direct calculation and dose response method results are also compared for the radial surface of the concrete cask using the 17a hybrid at 40 GWd/MTU assembly average burnup, 3.7 wt % ^{235}U initial enrichment, and 5-year cool time. The cumulative results are plotted in Figure 5.8.2-12. A tabular comparison is presented in Table *5.8.2-1*, along with a "% Diff" column that shows the percentage difference between the results of the direct solution of the problem and those of the dose response method solution. Sample response functions used in the generation of Figure 5.8.2-12 are included in Table

5.8.2-2 through Table 5.8.2-4. The tables demonstrate the implementation of the dose summation function, while simultaneously justifying the reduction in the number of energy lines by example. Energy lines used in the dose assessment are shown in italics and represent 99+% of the total dose. Energy lines with no (0) source magnitude are not included in the tables.

The response function method allows the MCNP weight window (acceleration) map to be optimized for a particular source energy, producing an increased number of particles scoring per source particle. The response function also allows for a significant reduction in the number of MCNP shielding runs, thereby increasing the number of particles per MCNP run (based on fixed computer resources). For example, a single PWR fuel type has approximately 20,000 source runs associated with it, requiring the same number of MCNP runs to determine a complete dose rate set. The same dose rate set for fuel gamma and neutron cases may be generated using approximately 20 MCNP runs (one per relevant neutron and gamma energy line) using the response function.

The applicability of the response function method to determine dose rates at the range of burnups requested (up to 60 GWd/MTU assembly average) is based on the ability to apply fresh fuel material composition based dose rate responses to spent fuel. A single dose response may be generated for all burnups of a particular assembly type, as dose rates have historically been calculated using a fresh fuel material composition (see Table 5.5.5-8). To confirm the accuracy of this assumption, radial dose rates are calculated for a sample high burnup (60 GWd/MTU) fuel assembly in the transfer and storage cask and compared to the fresh fuel results. Radial dose profiles for fresh and spent fuel isotopics are shown in Figure 5.8.2-10 and Figure 5.8.2-11 and demonstrate the acceptability of the fresh fuel assumption (i.e., there is no significant dose change associated with the fresh fuel model).

Figure 5.8.2-1 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – PWR Low Burnup/Low Enrichment

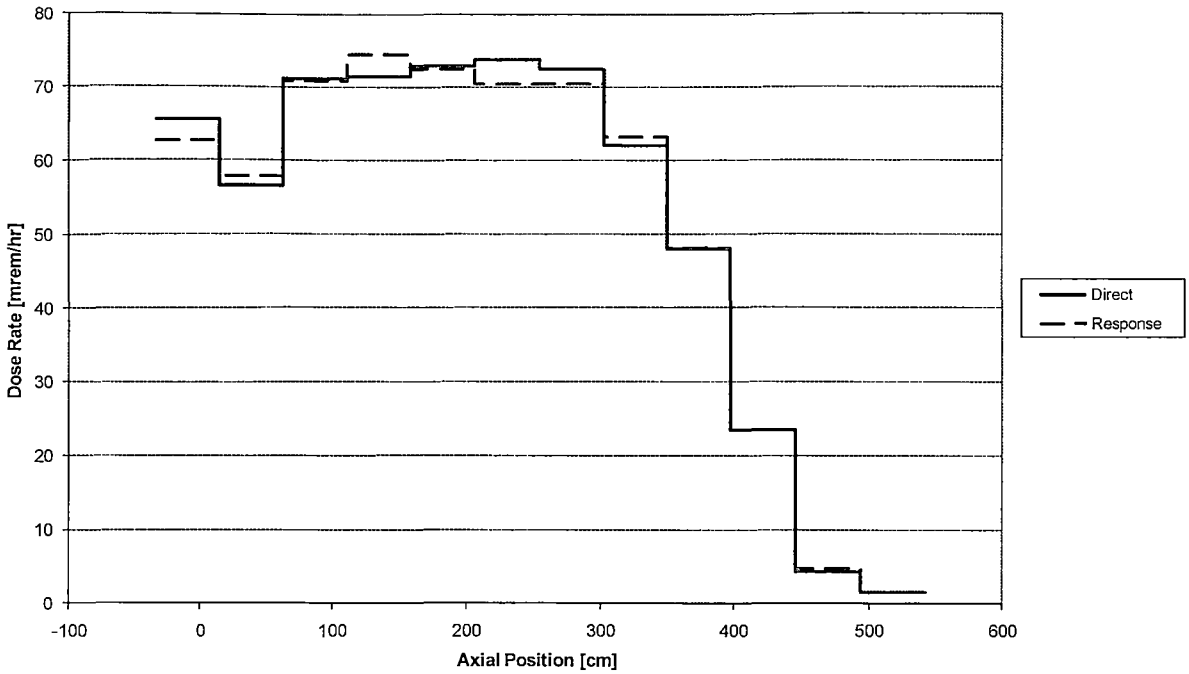

Figure 5.8.2-2 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – PWR Medium Burnup/Medium Enrichment

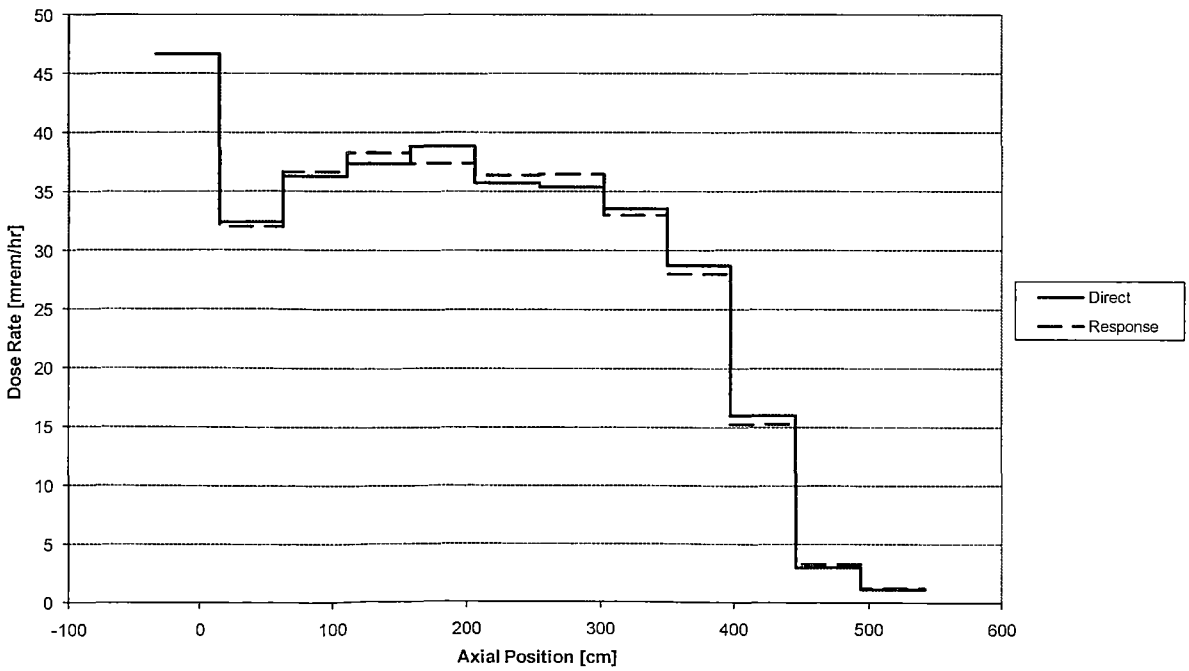

Figure 5.8.2-3 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – PWR High Burnup/High Enrichment

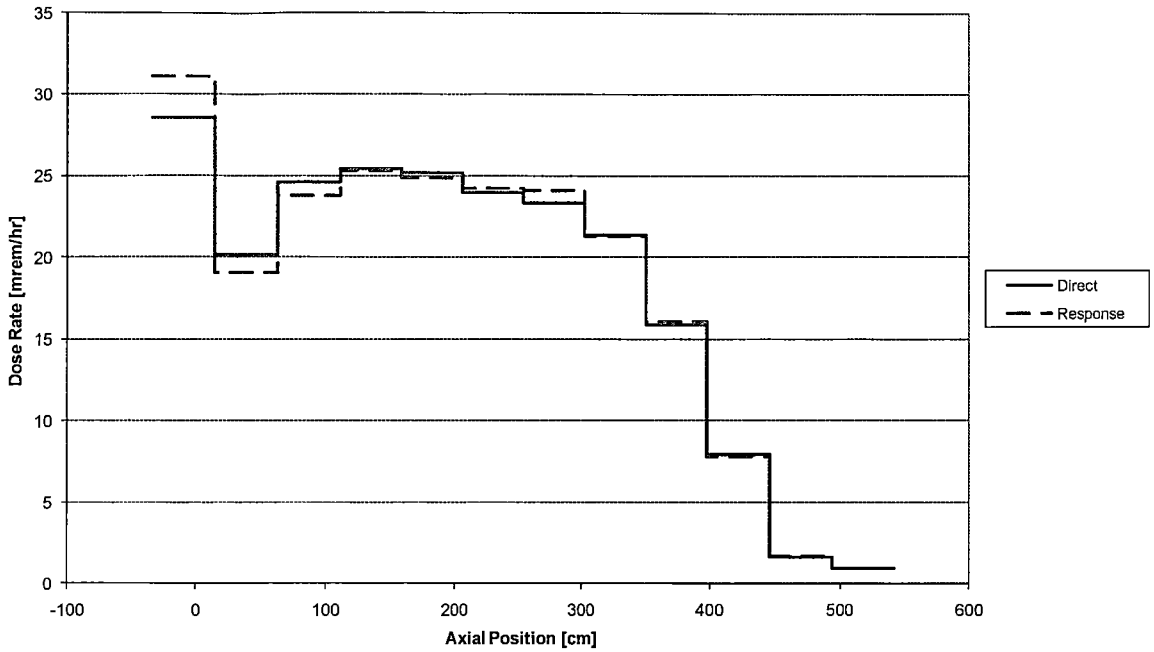

Figure 5.8.2-4 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – BWR Low Burnup/Low Enrichment

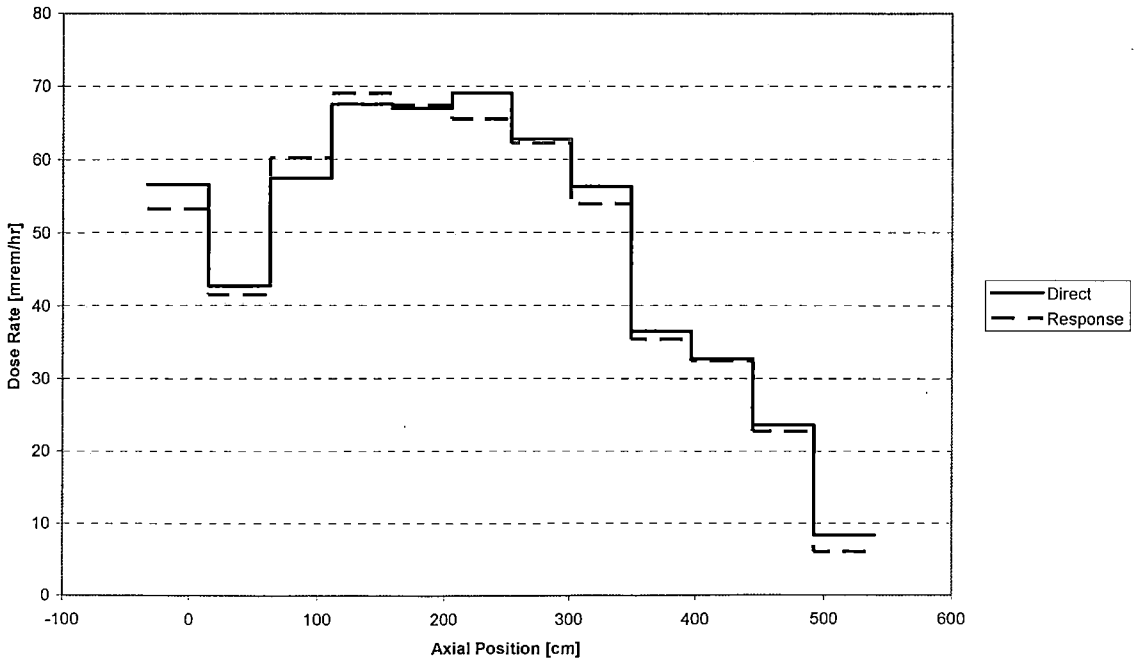

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Figure 5.8.2-5 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – BWR Medium Burnup/Medium Enrichment

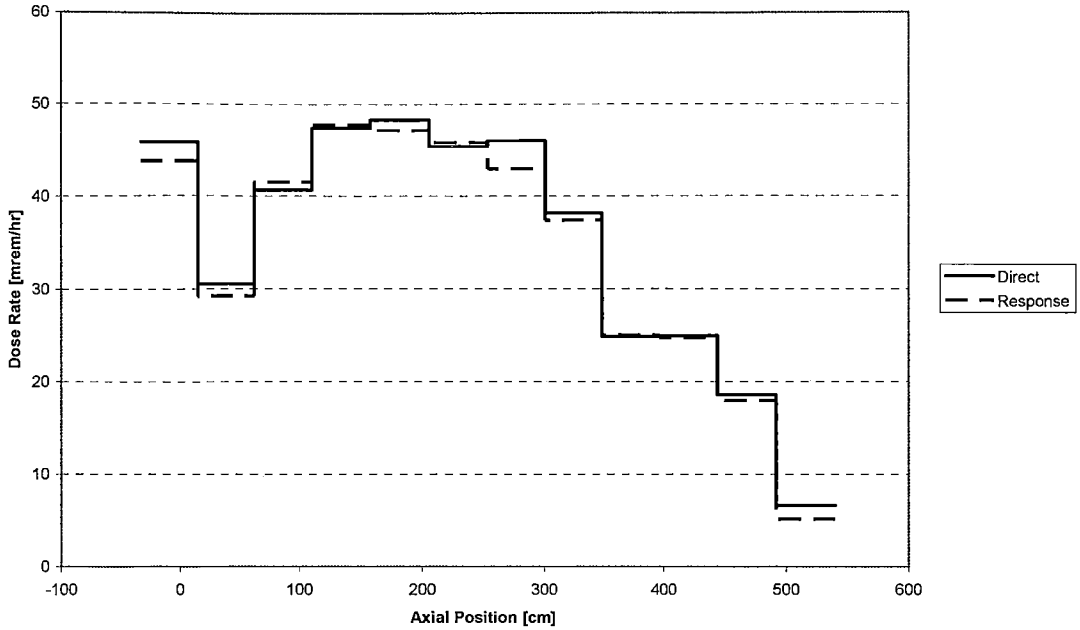


Figure 5.8.2-6 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – BWR High Burnup/High Enrichment

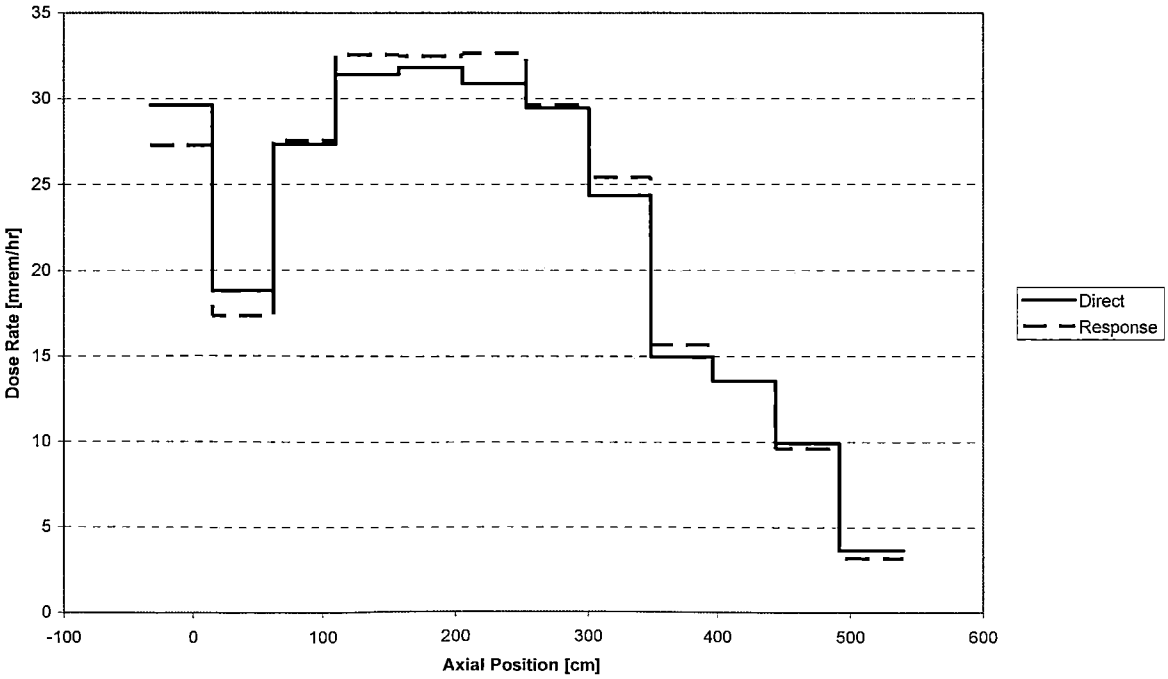


Figure 5.8.2-7 Comparison of Response Method to Direct Solution: Concrete Cask Top Surface – PWR – 32.5 GWd/MTU, 4.1 wt % ^{235}U

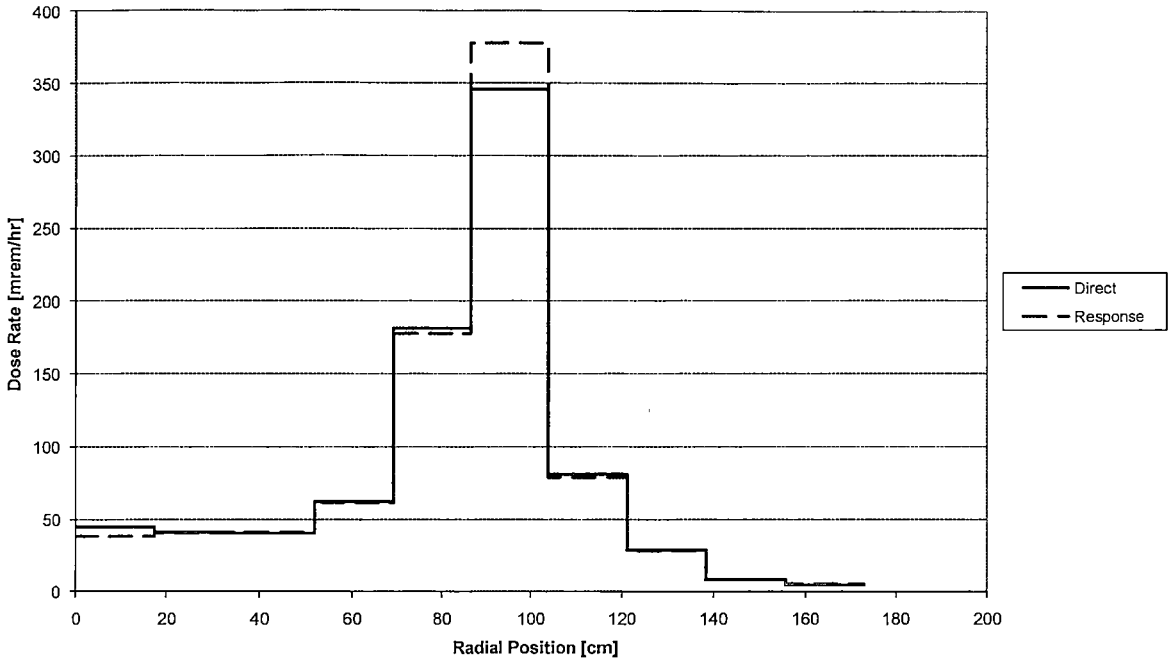


Figure 5.8.2-8 Comparison of Response Method to Direct Solution: Transfer Cask Radial Surface – PWR – 59 GWd/MTU, 3.1 wt % ^{235}U

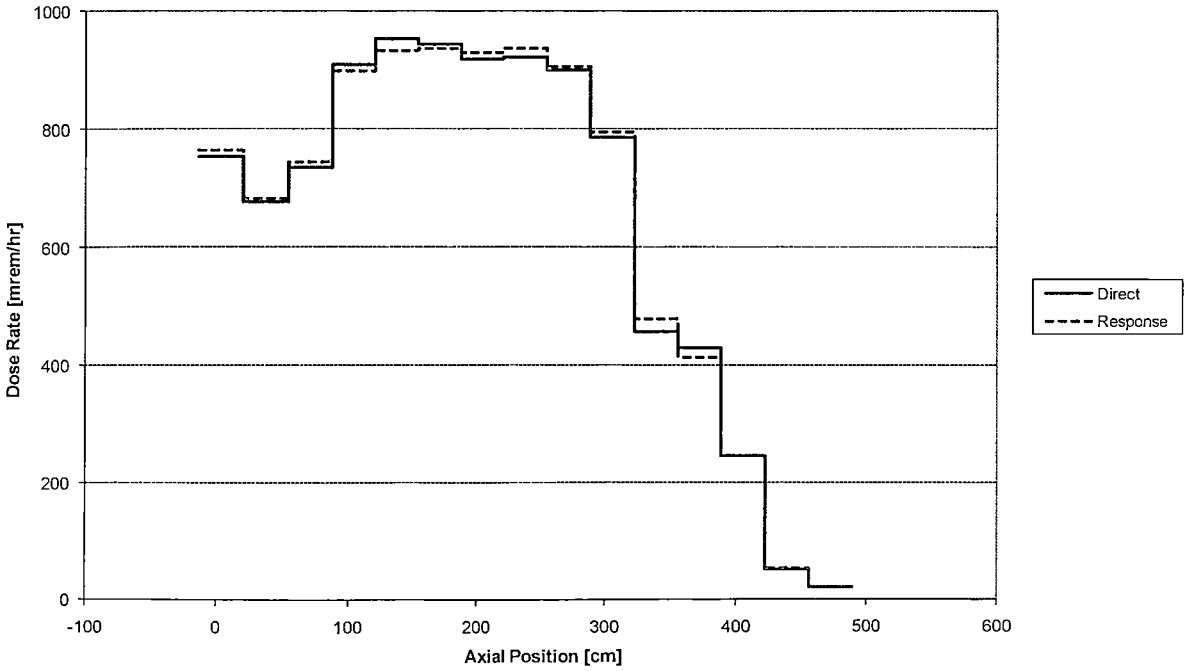


Figure 5.8.2-9 Comparison of Response Method to Direct Solution: Transfer Cask Top Surface – PWR – 44 GWd/MTU, 2.5 wt % ^{235}U

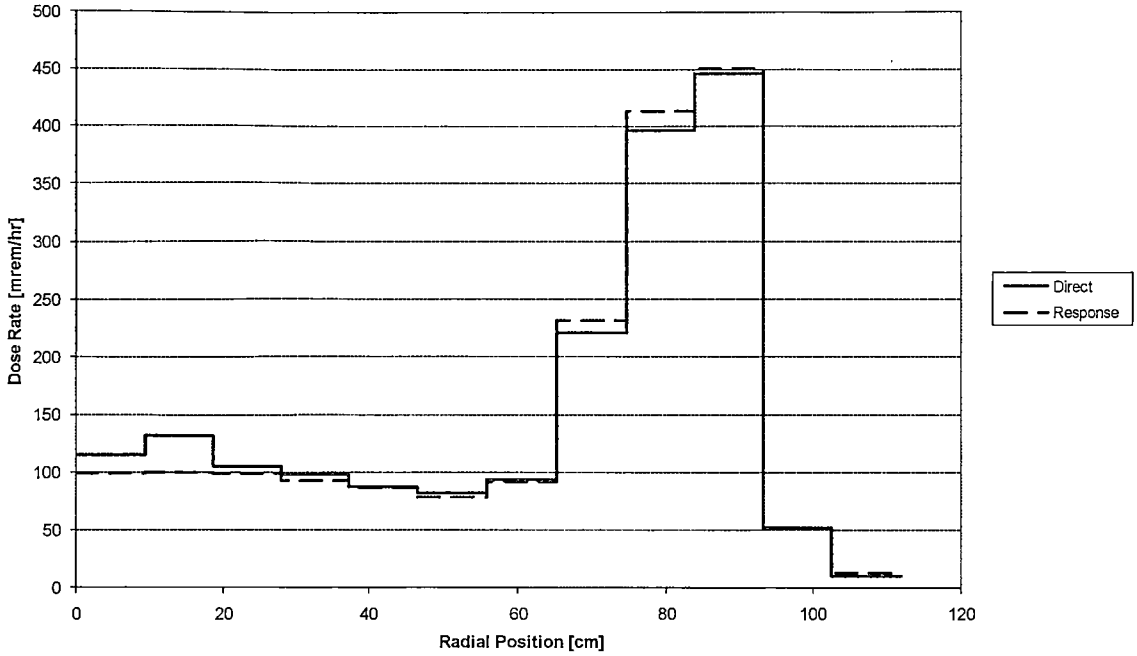


Figure 5.8.2-10 Concrete Cask Radial Dose Rates– Fresh Fuel versus Spent Fuel Isotopics – PWR – 60 GWd/MTU, 4.9 wt % ^{235}U

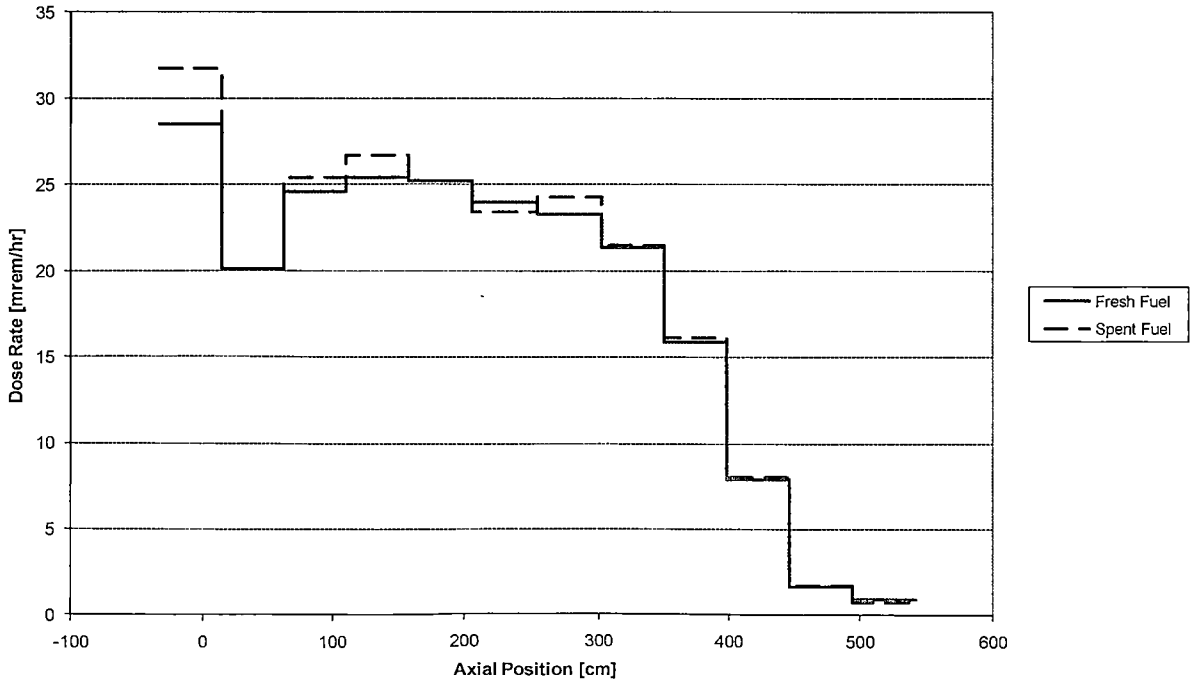


Figure 5.8.2-11 Transfer Cask Radial Dose Rates– Fresh Fuel versus Spent Fuel Isotopics – PWR – 60 GWd/MTU, 4.9 wt % ^{235}U

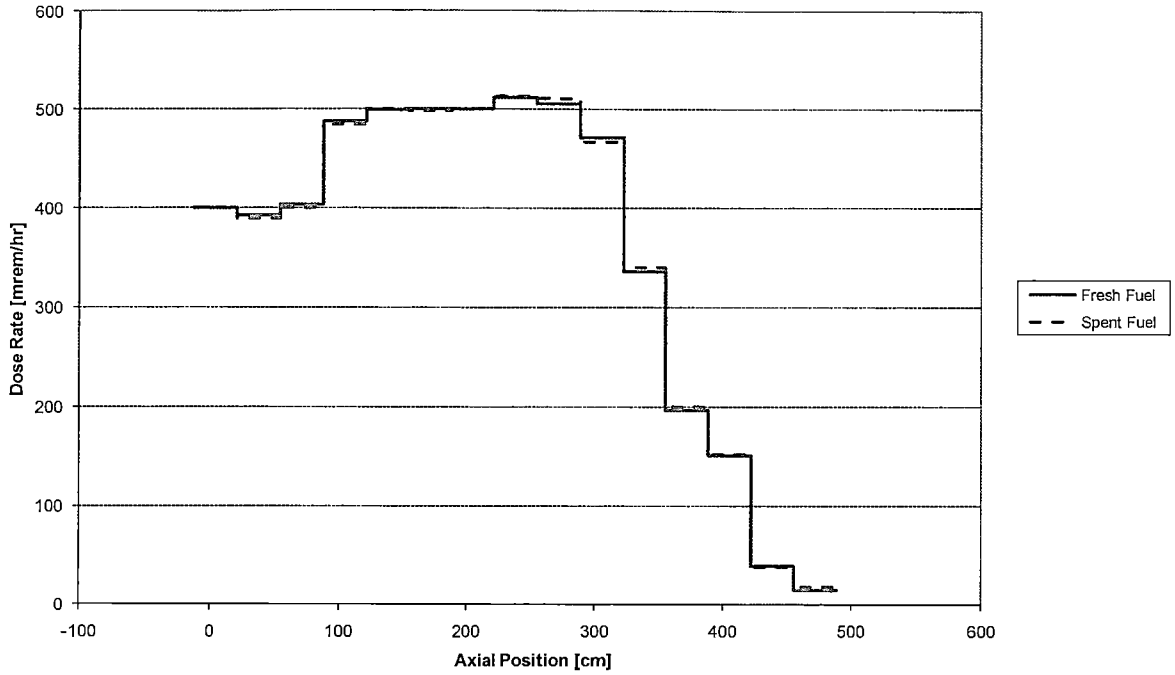


Figure 5.8.2-12 Comparison of Response Method to Direct Solution: Concrete Cask Radial Surface – PWR 40 GWd/MTU 3.7 wt % ^{235}U

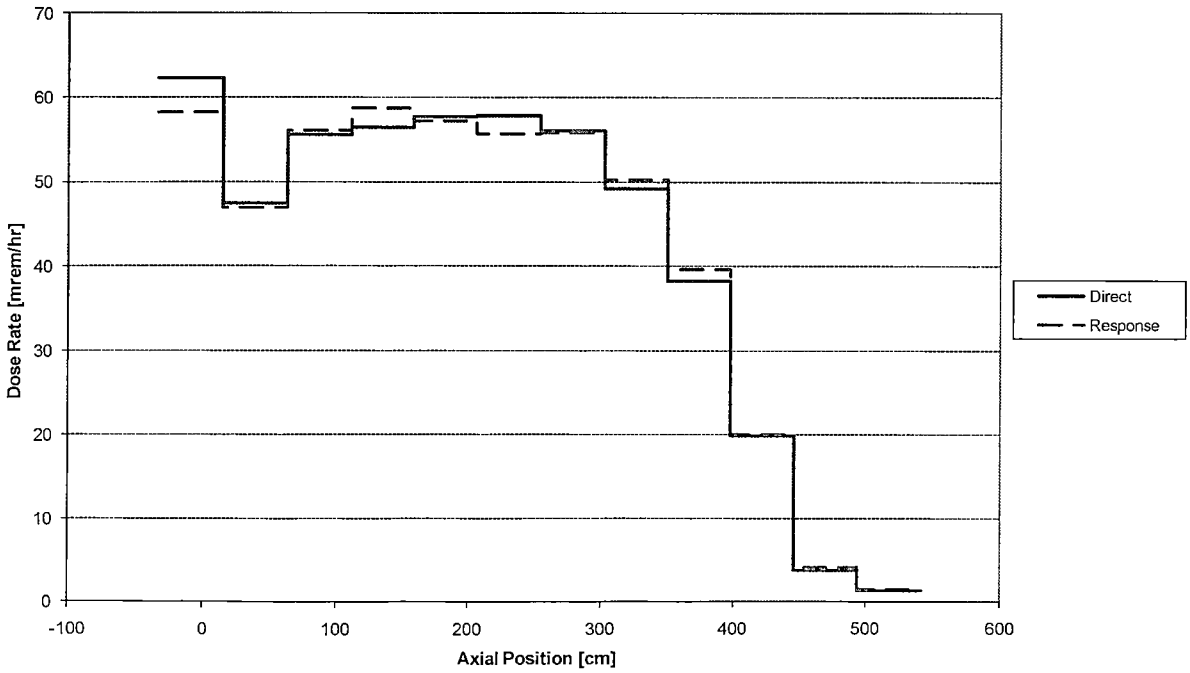


Table 5.8.2-1 Response Method to Direct Calculation Comparison – Concrete Cask

Subdet.	Avg. Axial [cm]	Total - Direct Dose Rate [mrem/hr]	Total - Direct FSD [%]	Total - DRM Dose Rate [mrem/hr]	Total - DRM FSD [%]	% Diff
1	-8.84	62.3	7.2%	58.2	1.8%	-6.5%
2	39.03	47.4	2.9%	46.9	0.4%	-1.0%
3	86.89	55.5	3.5%	56.1	0.4%	1.0%
4	134.75	56.4	3.5%	58.7	0.4%	4.0%
5	182.61	57.8	3.2%	57.2	0.4%	-0.9%
6	230.47	57.8	3.5%	55.6	0.4%	-3.7%
7	278.34	56.1	3.1%	55.7	0.4%	-0.6%
8	326.20	49.1	3.4%	50.2	0.4%	2.2%
9	374.06	38.3	3.0%	39.7	0.4%	3.6%
10	421.92	20.0	1.8%	20.1	0.5%	0.5%
11	469.78	3.8	2.4%	4.1	0.9%	10.4%
12	517.65	1.3	9.3%	1.5	11.3%	13.7%

Table 5.8.2-2 Sample Gamma Response Calculation for Concrete Cask Radial Surface Fuel Centerline (3.7 wt %, 40 GWd/MTU, 5-Year Cooled 17a Hybrid)

Energy Group	E-Lower (MeV)	E-Upper (MeV)	Response (mrem/hr/g/s)	Source (g/s)	Dose Rate (mrem/hr)
2	1.000E+01	1.200E+01	2.2772E-10	6.9797E+03	1.5894E-06
3	8.000E+00	1.000E+01	1.8168E-10	1.3500E+05	2.4526E-05
4	6.500E+00	8.000E+00	1.3788E-10	6.3583E+05	8.7668E-05
5	5.000E+00	6.500E+00	9.2216E-11	3.2414E+06	2.9891E-04
6	4.000E+00	5.000E+00	5.3101E-11	8.0770E+06	4.2890E-04
7	3.00E+00	4.00E+00	2.5759E-11	1.0271E+10	2.6457E-01
8	2.50E+00	3.00E+00	1.0675E-11	8.2537E+10	8.8110E-01
9	2.00E+00	2.50E+00	4.6235E-12	2.6372E+12	1.2193E+01
10	1.66E+00	2.00E+00	1.7032E-12	1.1071E+12	1.8856E+00
11	1.44E+00	1.66E+00	6.8242E-13	4.7865E+12	3.2664E+00
12	1.22E+00	1.44E+00	2.7596E-13	5.3865E+13	1.4865E+01
13	1.00E+00	1.22E+00	8.5758E-14	4.2944E+13	3.6828E+00
14	8.00E-01	1.00E+00	2.0240E-14	3.0365E+14	6.1458E+00
15	6.00E-01	8.00E-01	3.2053E-15	2.3209E+15	7.4389E+00
16	4.000E-01	6.000E-01	2.1141E-16	7.1107E+14	1.5033E-01
17	3.000E-01	4.000E-01	9.4503E-18	6.6212E+13	6.2572E-04
18	2.000E-01	3.000E-01	7.1661E-19	9.4005E+13	6.7366E-05
19	1.000E-01	2.000E-01	0.0000E+00	3.3053E+14	0.0000E+00
20	5.000E-02	1.000E-01	0.0000E+00	4.1028E+14	0.0000E+00
21	2.000E-02	5.000E-02	0.0000E+00	9.2930E+14	0.0000E+00
22	1.000E-02	2.000E-02	0.0000E+00	6.6321E+14	0.0000E+00
				Total (Evaluated Energy Lines)	50.6

Table 5.8.2-3 **Sample Neutron Response Calculation for Concrete Cask Radial Surface Fuel Centerline (3.7 wt %, 40 GWd/MTU, 5-Year Cooled 17a Hybrid)**

Energy Group	E-Lower (MeV)	E-Upper (MeV)	Response (mrem/hr/n/s)	Source (n/s)	Dose *Rate* (mrem/hr)
2	1.250E+01	1.360E+01	2.1419E-08	1.5460E+04	3.3114E-04
3	1.125E+01	1.250E+01	1.6960E-08	6.4440E+04	1.0929E-03
4	1.000E+01	1.125E+01	1.6059E-08	2.1410E+05	3.4383E-03
5	8.250E+00	1.000E+01	1.5224E-08	6.7150E+05	1.0223E-02
6	7.000E+00	8.250E+00	1.5503E-08	1.8030E+06	2.7951E-02
7	6.070E+00	7.000E+00	1.8514E-08	3.1120E+06	5.7616E-02
8	4.720E+00	6.070E+00	1.0623E-08	1.0410E+07	1.1059E-01
9	3.680E+00	4.720E+00	5.8063E-09	1.7700E+07	1.0277E-01
10	2.870E+00	3.680E+00	4.9283E-09	2.4000E+07	1.1828E-01
11	1.740E+00	2.870E+00	2.9063E-09	5.7070E+07	1.6586E-01
12	6.400E-01	1.740E+00	8.2280E-10	8.8720E+07	7.2999E-02
13	3.900E-01	6.400E-01	6.3757E-10	2.3080E+07	1.4715E-02
14	1.100E-01	3.900E-01	5.0655E-10	8.0080E+06	4.0564E-03
15	6.740E-02	1.100E-01	3.4506E-10	2.4200E+02	8.3505E-08
				Total (Evaluated Energy Lines)	0.69

Table 5.8.2-4 Sample Hardware Gamma (Upper End-Fitting) Response Calculation for Concrete Cask Radial Surface – Upper End-Fitting Elevation (3.7 wt%, 40 GWd/MTU, 5-Year Cooled 17a Hybrid)

Energy Group	E-Lower (MeV)	E-Upper (MeV)	Response (mrem/hr/g/s)	Source (g/s)	Dose Rate (mrem/hr)
7	3.000E+00	4.000E+00	2.3118E-10	8.6062E-16	1.9896E-25
8	2.500E+00	3.000E+00	9.6674E-11	2.8344E+04	2.7401E-06
9	2.000E+00	2.500E+00	4.1866E-11	1.8279E+07	7.6527E-04
10	1.660E+00	2.000E+00	1.6953E-11	2.2544E+02	3.8217E-09
11	1.440E+00	1.660E+00	6.6060E-12	4.8588E+00	3.2097E-11
12	1.22E+00	1.44E+00	2.8887E-12	1.73161E+12	5.0020E+00
13	1.00E+00	1.22E+00	9.9133E-13	1.82523E+12	1.8094E+00
14	8.000E-01	1.000E+00	3.1392E-13	2.5646E+10	8.0509E-03
15	6.000E-01	8.000E-01	1.1913E-15	3.2226E+06	3.8390E-09
16	4.000E-01	6.000E-01	0.0000E+00	9.2939E+06	0.0000E+00
17	3.000E-01	4.000E-01	0.0000E+00	1.4682E+08	0.0000E+00
18	2.000E-01	3.000E-01	0.0000E+00	1.1190E+08	0.0000E+00
19	1.000E-01	2.000E-01	0.0000E+00	2.2536E+09	0.0000E+00
20	5.000E-02	1.000E-01	0.0000E+00	9.3415E+09	0.0000E+00
21	2.000E-02	5.000E-02	0.0000E+00	2.6718E+10	0.0000E+00
22	1.000E-02	2.000E-02	0.0000E+00	3.1721E+10	0.0000E+00
				Total (Evaluated Energy Lines)	6.8

5.8.3 37-Assembly PWR System

This section presents the detailed evaluations of the concrete and transfer casks loaded with PWR fuel assemblies. It primarily addresses the PWR undamaged fuel basket configuration with a payload of 37 fuel assemblies and no inserts. This section applies a uniform heat load pattern to determine system dose rates. Preferential loading for heat load is discussed in Section 5.8.7. The effects of nonfuel hardware components to dose rates and heat load are discussed in Sections 5.8.5, 5.8.6 and 5.8.13. Model differences, dose rates, and minimum loading time impacts resulting from the damaged fuel basket configuration are discussed in Section 5.8.12. As stated in Section 5.8.12, the calculated site boundary dose rates for the undamaged fuel basket configuration are applicable to the damaged fuel basket configuration.

5.8.3.1 PWR Fuel and Basket Models

The three-dimensional shielding evaluation includes a homogenized fuel assembly model and a detailed three-dimensional basket model.

5.8.3.1.1 Fuel Assembly Model

Based on the fuel assembly physical parameters provided in Table 5.8.1-1 and the hardware masses in Table 5.8.1-2, homogenized treatments of fuel assembly source regions are developed. The homogenized fuel assembly is represented in the model as a stack of boxes with width equal to the fuel assembly width. The height of each box corresponds to the modeled height of the corresponding assembly region.

Sample fuel and nonfuel hardware homogenizations for the source regions for the 17a assembly are shown in Table 5.8.3-1 and Table 5.8.3-2. Similar composition sets are generated for the remaining fuel assembly hybrids.

5.8.3.1.2 Basket Model

The basket is composed of coated carbon steel tubes, pinned together at the corners, and held together by side and corner weldments. Twenty-one fuel tubes, in combination with the weldments, form 37 fuel openings. The corner weldments provide structural support, but do not serve as a physical restraint to the fuel assemblies. Pin spacers maintain the tube axial spacing within the TSC cavity. Each fuel tube nominally contains four metallic composite neutron absorber sheets. In dry storage and transfer, the presence of the neutron absorber sheets provides minimal shielding and could, therefore, be removed without a significant increase in exposure. Key basket characteristics are shown in Table 5.8.3-3. Radial and axial sketches of the basket within the TSC are shown in Figure 5.8.3-1 and Figure 5.8.3-2, respectively.

5.8.3.2 Minimum Cool-time Specification

SAS2H generates heat loads for all PWR fuel types listed in Section 5.8.1.1. Based on the desired 35.5 kW system heat load, minimum allowed cool times for each fuel type are calculated. Calculated heat loads account for fuel material (actinide and fission product) and hardware (light element) generated sources. Minimum cool times are conservatively rounded up to the nearest one-tenth of a year. A sample minimum cool time calculation for the 17a assembly is shown in Table 5.8.3-4. The resulting minimum cool times are listed in assembly specific loading tables.

The loading table removes combinations of high assembly average burnup and low enrichment (e.g., 60 GWd/MTU and 1.9 wt% ^{235}U) from the contents definition. Source term data covering these combinations produces unrealistic source terms due to the complete consumption of fissile uranium early in the burnup cycle and the SAS2H input of a fixed power density. To maintain power density, ORIGEN-S (SAS2H) will substantially increase flux levels, which would not occur during core operation of the assembly, to produce fissile material and to produce power by nonthermal fission. The increased flux level "breeds" higher actinides, which in turn increase source significantly. Since a high burnup and low enrichment combination would require repeated reinsertion of a burned assembly, the combination is excluded.

Minimum cool time tables are included in Section 5.8.9.

5.8.3.3 Transfer Cask Dose Rates

Using the dose response method, transfer cask dose rates are tabulated for all allowed cool times, assembly average burnup, and initial enrichment combinations for each of the assembly types.

5.8.3.3.1 Carbon Steel Transfer Cask

Maximum dose rates as a function of distance from the transfer cask surface are shown in Figure 5.8.3-3 for the cask radial surface, Figure 5.8.3-5 for the cask top, and Figure 5.8.3-7 for the cask bottom. Breakdowns of the cask surface radial and top dose rates into the source components are shown in Figure 5.8.3-4 and Figure 5.8.3-6. The bounding payloads with cask surface maximum and average dose rate for each cask surface are:

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	11.5	59	3.1	939	650
Top	14b	6.0	44	2.5	451	172
Bottom	14b	6.0	44	2.5	5,824	2,953

5.8.3.3.2 Stainless Steel Transfer Cask

Maximum dose rates as a function of distance from the transfer cask surface are shown in Figure 5.8.3-17 for the cask radial surface, Figure 5.8.3-19 for the cask top, and Figure 5.8.3-21 for the cask bottom. Breakdowns of the cask surface radial and top dose rates into the source components are shown in Figure 5.8.3-18 and Figure 5.8.3-20. The bounding payloads with cask surface maximum and average dose rate for each cask surface are:

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	11.5	59	3.1	922	630
Top	17b	5.6	37.5	2.3	505	206
Bottom	14b	6.0	44	2.5	5,239	2,713

5.8.3.4 Concrete Cask Dose Rates

Using the dose response method, concrete cask dose rates are tabulated for all allowed cool times, assembly average burnup, and initial enrichment combinations for each of the assembly types.

5.8.3.4.1 Standard Shield Concrete Cask (1.75-inch Liner)

Maximum dose rates as a function of distance from the concrete cask surface are shown in Figure 5.8.3-8 for the cask radial surface, Figure 5.8.3-10 for the cask top, and Figure 5.8.3-12 and Figure 5.8.3-13 for the cask air outlet and inlets, respectively. Breakdowns of the cask surface radial and top dose rates into the source components are shown in Figure 5.8.3-9 and Figure 5.8.3-11. Refer to Table 5.8.3-5 for the maximum concrete cask surface dose rates and the contents that develop the dose rates.

5.8.3.4.2 Augmented Shield Concrete Cask (3-inch Liner)

Maximum dose rates as a function of distance from the concrete cask surface are shown in Figure 5.8.3-22 for the cask radial surface, Figure 5.8.3-24 for the cask top, and Figure 5.8.3-26 and Figure 5.8.3-27 for the cask air outlet and inlets, respectively. Breakdowns of the cask surface radial and top dose rates into the source components are shown in Figure 5.8.3-23 and Figure 5.8.3-25. Refer to Figure 5.8.3-8 for the maximum concrete cask surface dose rates and the contents that develop the dose rates.

5.8.3.4.3 CC4

Maximum dose rates as a function of distance from the concrete cask surface are shown in Figure 5.8.3-28 for the cask radial surface and Figure 5.8.3-30 for the cask top. Breakdowns of the cask surface dose rates into the source components are shown in Figure 5.8.3-29 for radial, Figure 5.8.3-31 for top, Figure 5.8.3-32 for outlets, and Figure 5.8.3-33 for inlets. Refer to Table 5.8.3-9 for the maximum concrete cask surface dose rates and the contents that develop the dose rates.

5.8.3.5 NAC-CASC Site Boundary Evaluation

Detailed direct and skyshine dose rates as a function of distance are calculated for a single concrete cask and a 2×10 array of concrete casks based on the model description and method outlined in Section 5.5.3. All allowable payload combinations (i.e., fuel type, initial enrichment, assembly average burnup, and cool time) that meet per assembly heat load limits were reviewed to determine the payloads producing maximum top (axial) and side (radial) dose rates. These payload cases were then run through MCNP using a "direct" solution approach (full source spectrum), rather than the response function method, to generate cask top and side surface radiation currents. The surfaces were treated independently to generate a conservative hybrid source model for a design basis analysis cask.

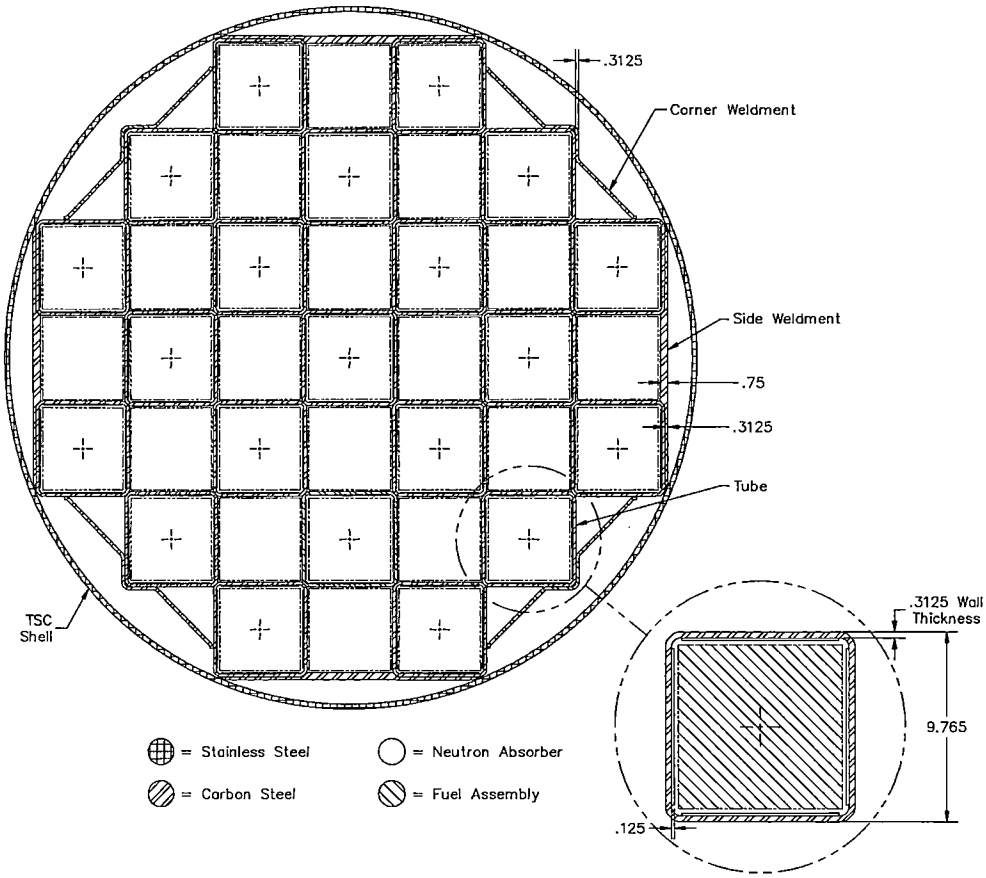
The maximum TSC heat load applied in the site boundary evaluation is 40 kW versus the 35.5 kW applied in the cask surface dose evaluations. The site boundary results obtained from the 40 kW pattern and standard shield concrete cask conservatively bound those of the maximum 35.5 kW pattern and use of the augmented shield concrete cask.

Table 5.8.3-6 lists the surface current description of the bounding PWR source for the cask radial and axial surfaces. The resulting boundary required to meet a 25 mrem/yr limit for an 8,760-hr exposure is listed in Table 5.8.3-7. Figure 5.8.3-16 contains a contour plot of the 25 mrem/yr boundary. Yearly exposure as a function of distance is plotted in Figure 5.8.3-14 for a single cask and in Figure 5.8.3-15 for the cask array. A breakdown of the neutron, gamma, and neutron induced gamma radiation components as a function of distance is provided below each plot.

Radial gamma results are scaled upward consistent with the combination of fuel, BPRA, and thimble plug dose rates discussed in Section 5.8.5.2.3. Restricted loading of CEAs into the TSC center slots results in no site boundary impacts of these components. The scaling of fuel assembly source derived surface currents to account for nonfuel hardware is performed within the NAC-CASC input files.

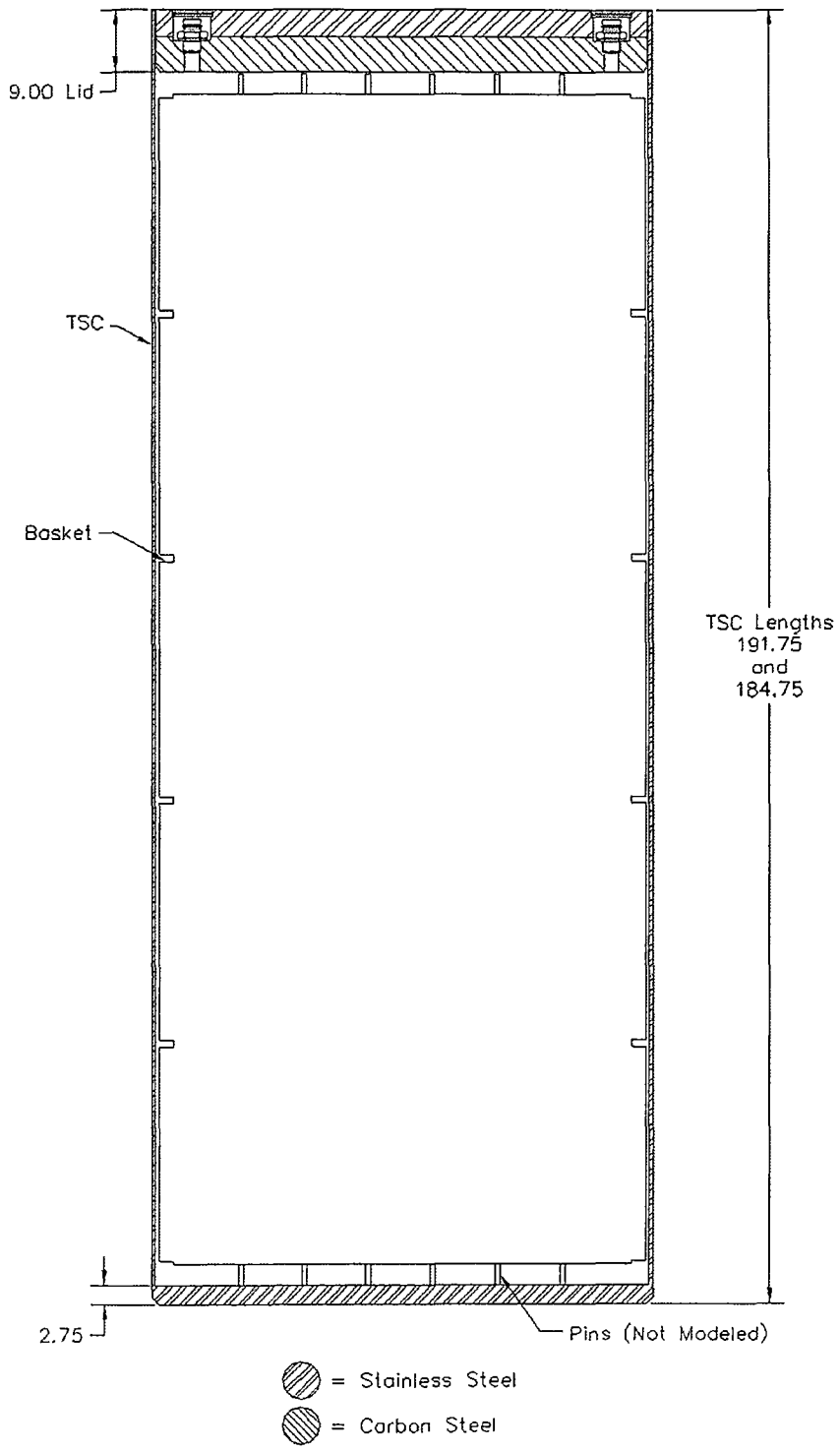
A sample PWR NAC-CASC input file is provided in Section 5.8.8. The detector location grid is truncated in the listed input file.

Figure 5.8.3-1 PWR Basket, Top View



(dimensions in inches)

Figure 5.8.3-2 PWR Basket and TSC, Side View



Note: Composite assembly TSC lid bounds stainless steel due to lower carbon steel density.

Figure 5.8.3-3 Transfer Cask Side Dose Rate Profile at Various Distances – PWR (Carbon Steel Transfer Cask)

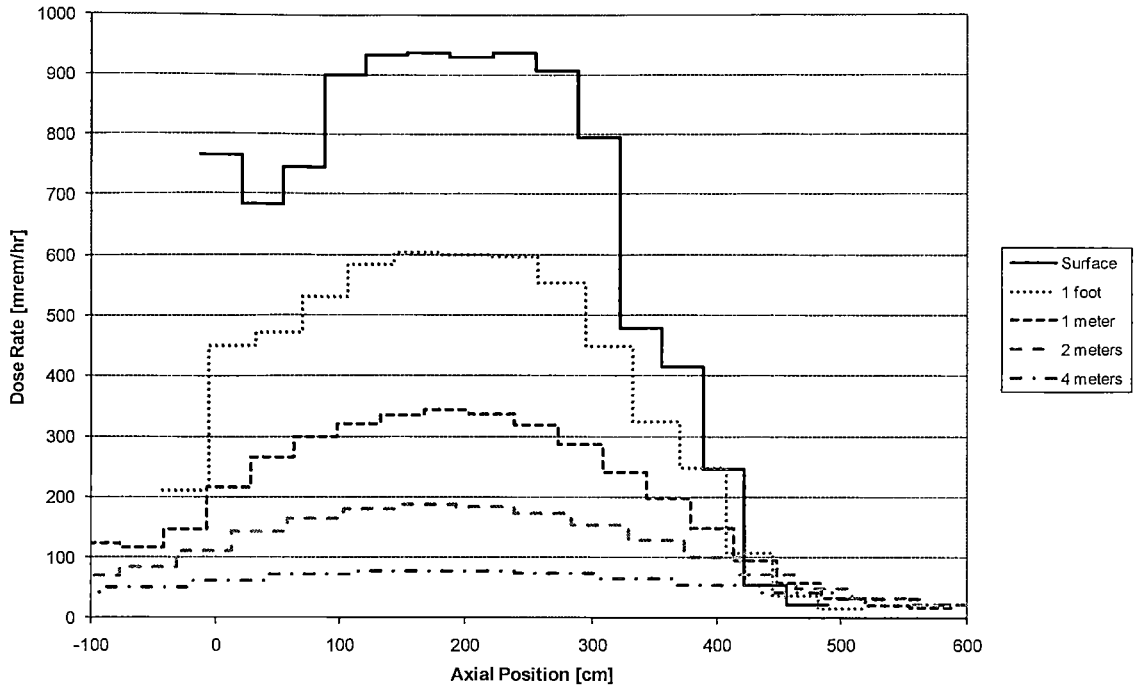


Figure 5.8.3-4 Transfer Cask Side Surface Dose Rate Profile by Source – PWR (Carbon Steel Transfer Cask)

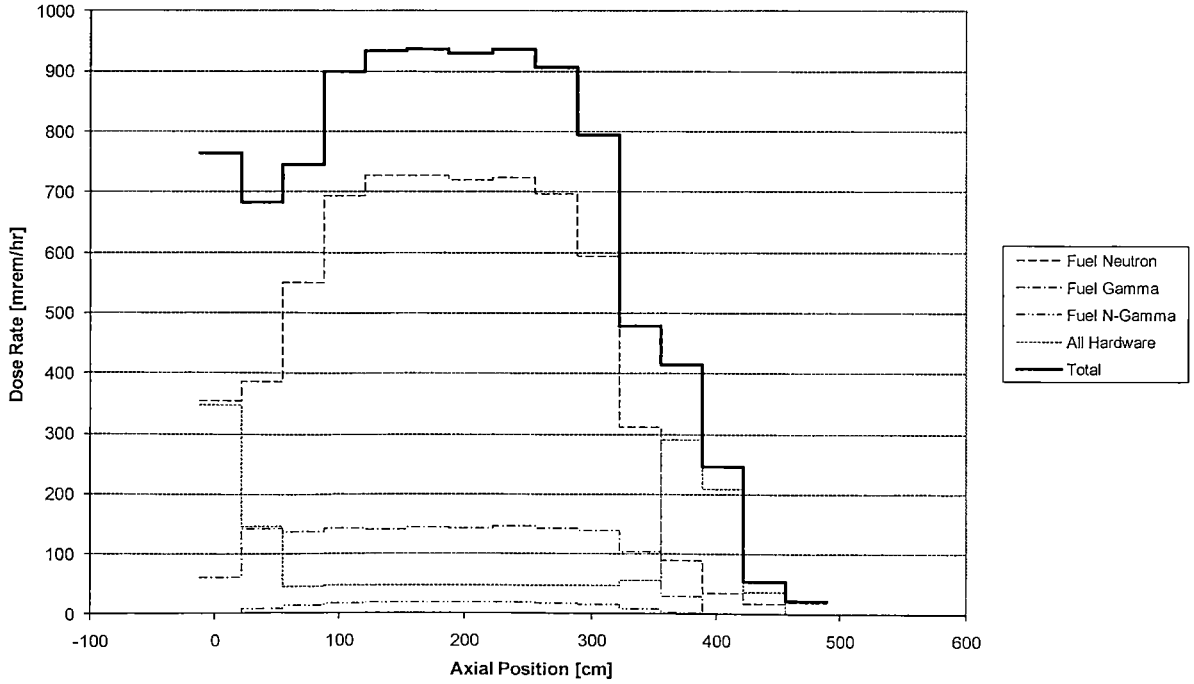


Figure 5.8.3-5 Transfer Cask Top Dose Rate Profile at Various Distances – PWR (Carbon Steel Transfer Cask)

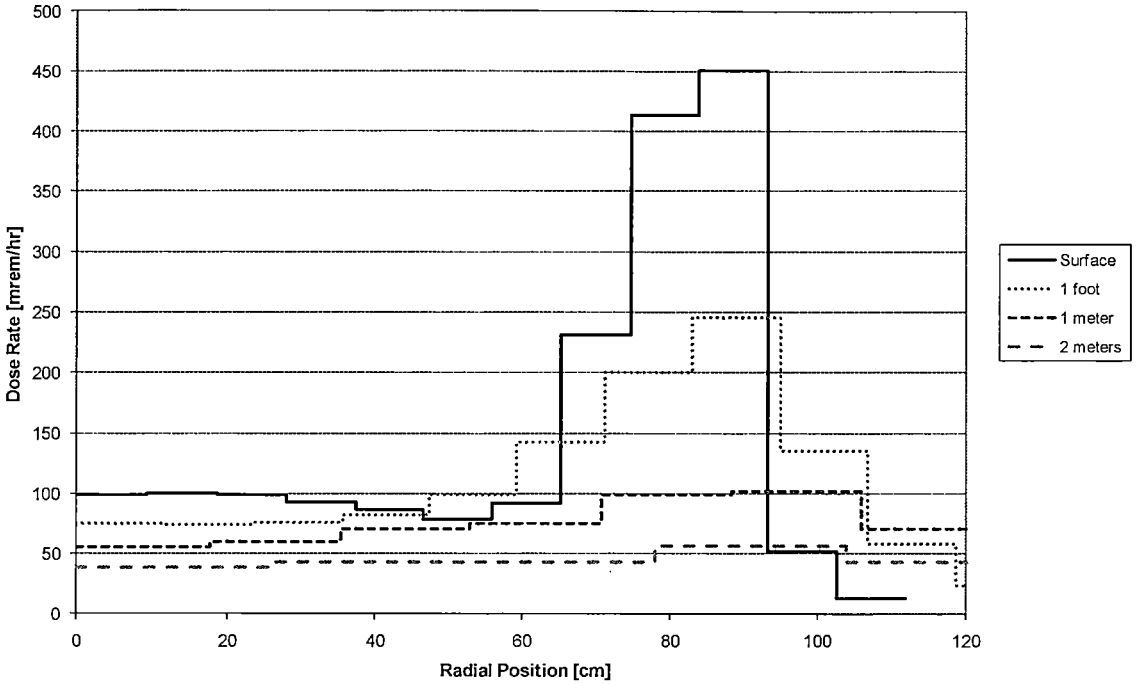


Figure 5.8.3-6 Transfer Cask Top Surface Dose Rate Profile by Source – PWR (Carbon Steel Transfer Cask)

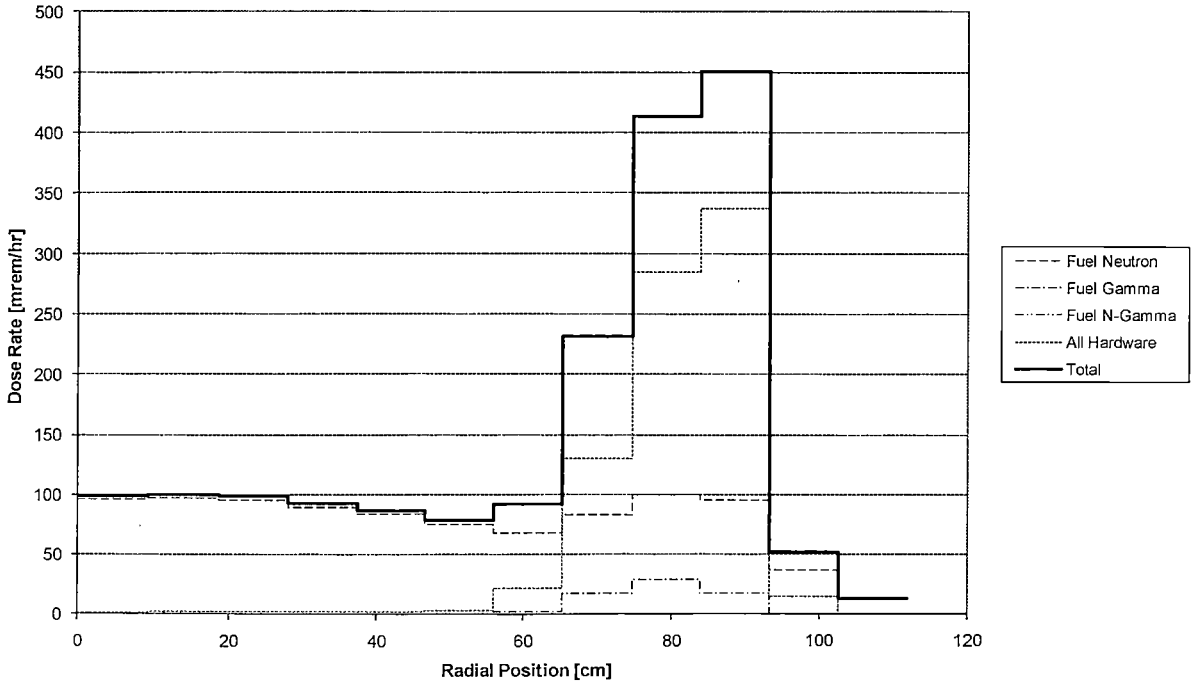


Figure 5.8.3-7 Transfer Cask Bottom Dose Rate Profile at Various Distances – PWR (Carbon teel Transfer Cask)

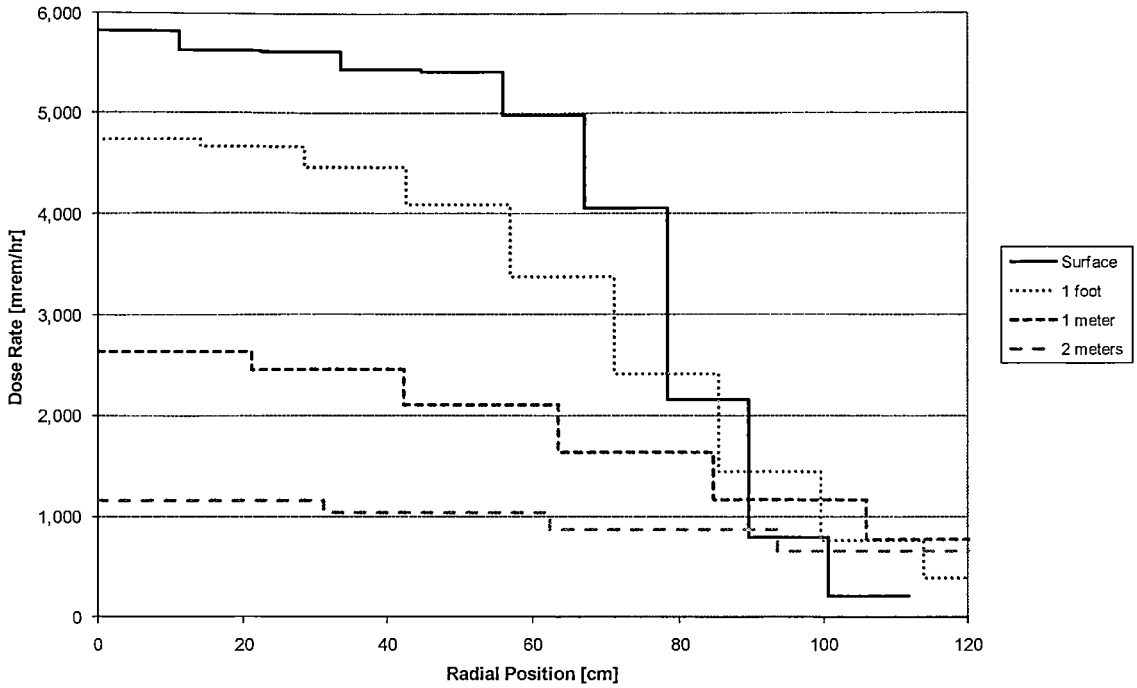


Figure 5.8.3-8 Concrete Cask Side Dose Rate Profile at Various Distances – PWR (Standard Shield Concrete Cask)

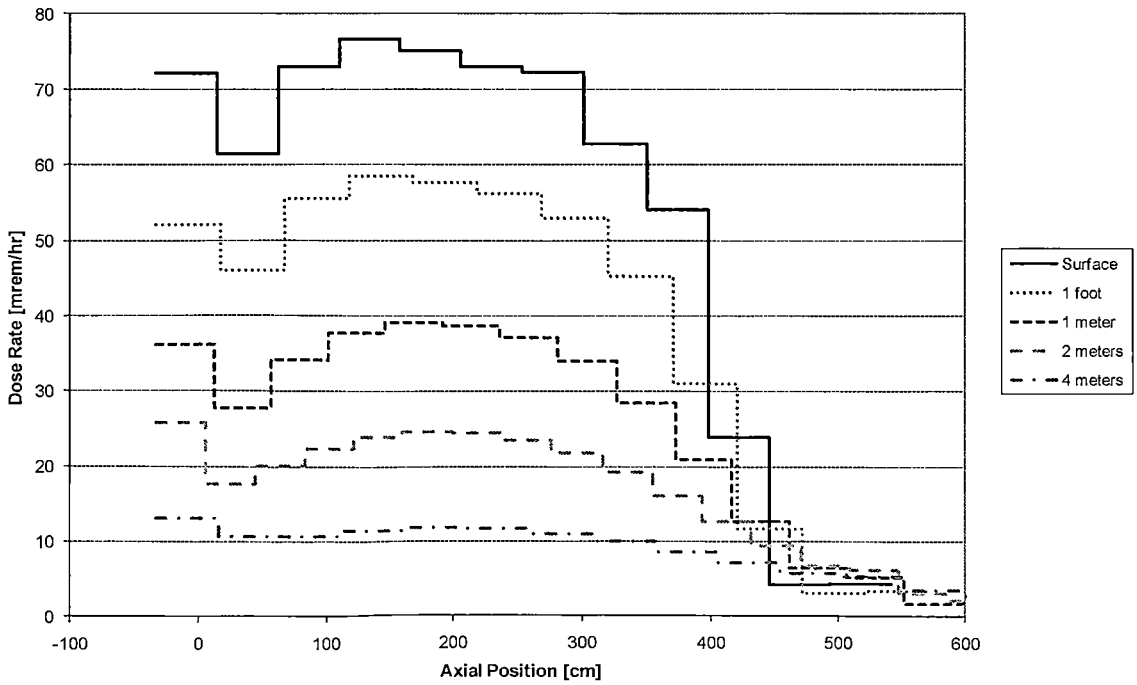


Figure 5.8.3-9 Concrete Cask Side Surface Dose Rate Profile by Source – PWR (Standard Shield Concrete Cask)

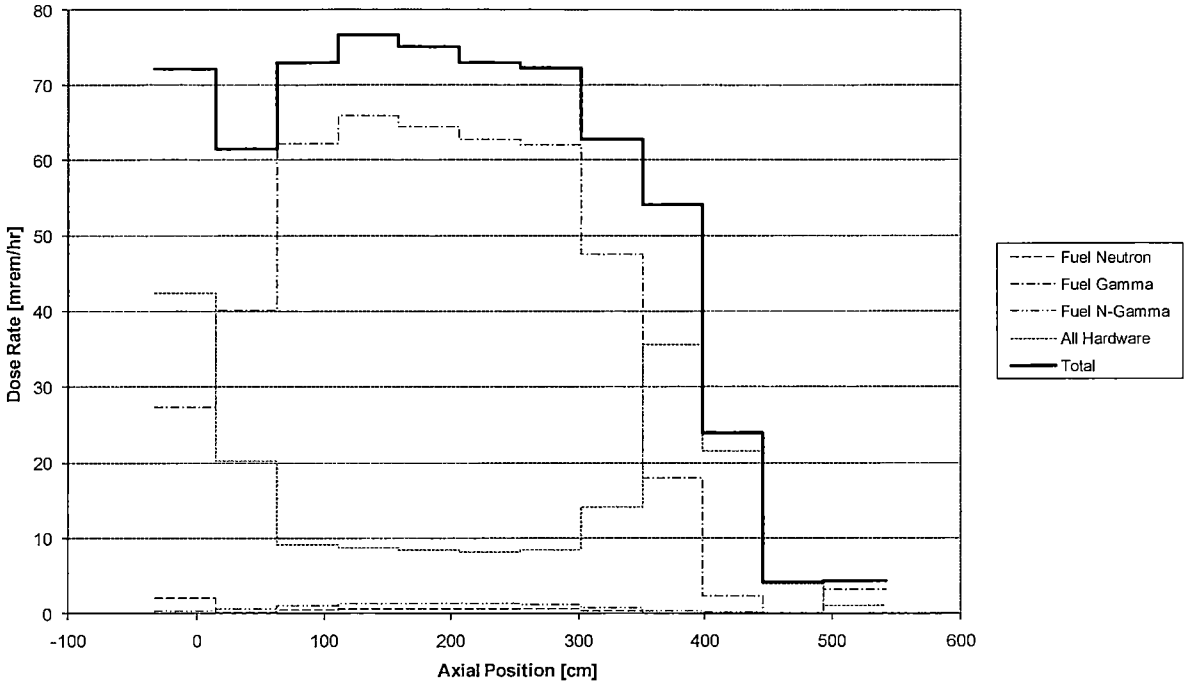


Figure 5.8.3-10 Concrete Cask Top Dose Rate Profile at Various Distances – PWR (Standard Shield Concrete Cask)

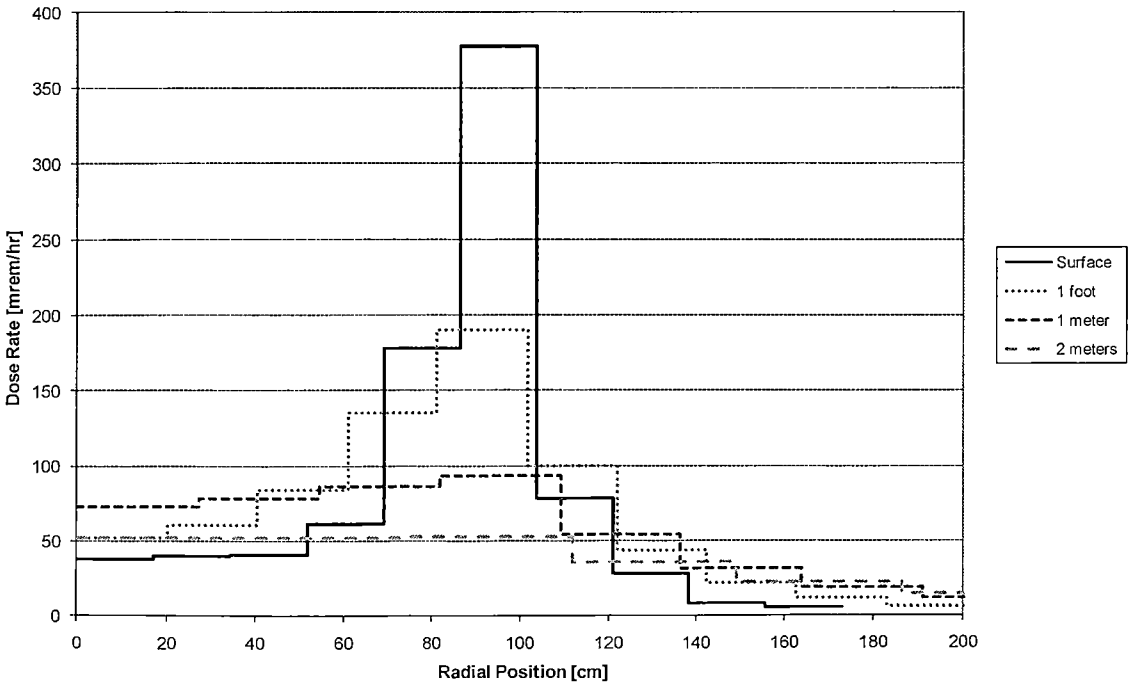


Figure 5.8.3-11 Concrete Cask Top Surface Dose Rate Profile by Source – PWR (Standard Shield Concrete Cask)

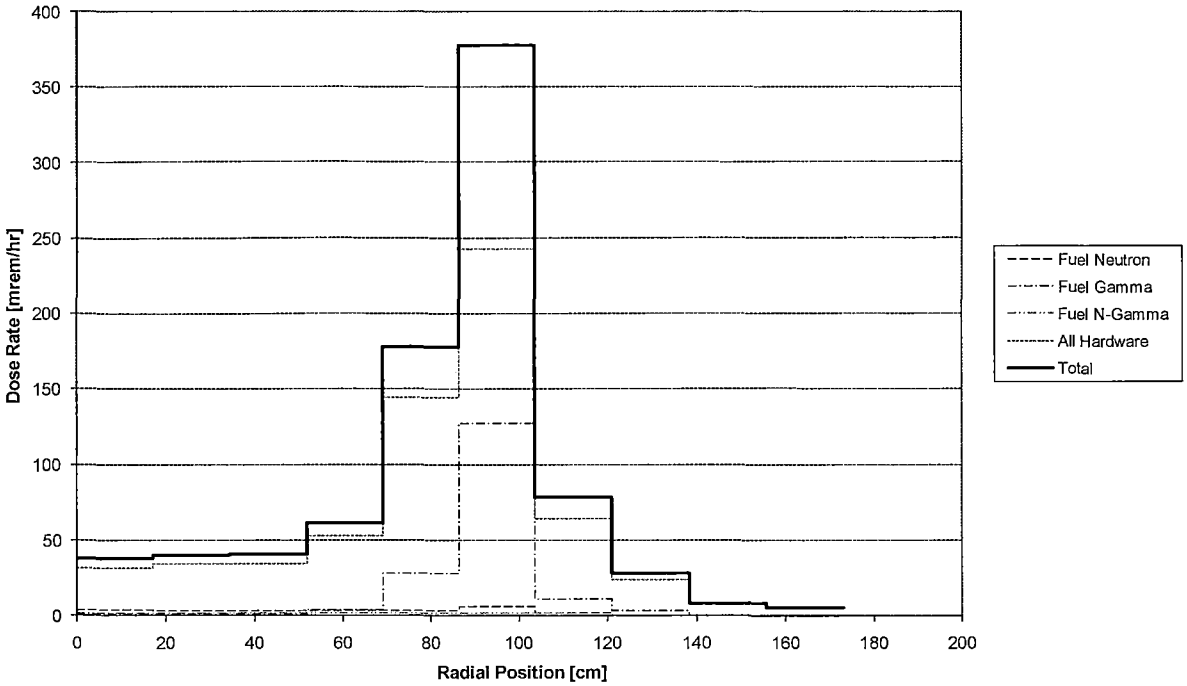


Figure 5.8.3-12 Concrete Cask Air Outlet Elevation Surface Dose Rate Profile – PWR (Standard Shield Concrete Cask)

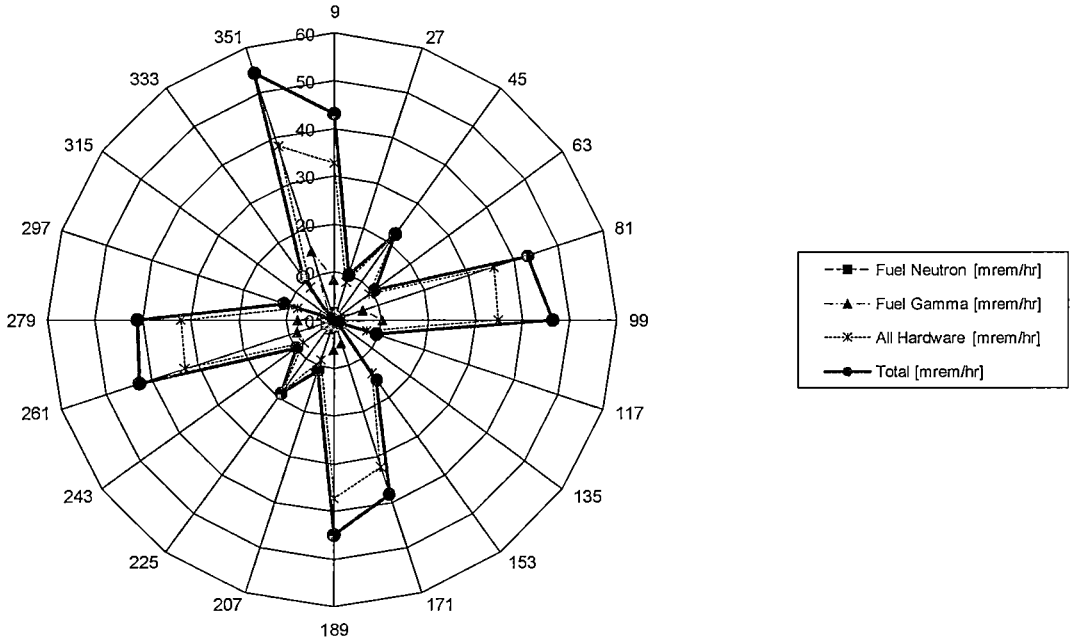


Figure 5.8.3-13 Concrete Cask Air Inlet Elevation Surface Dose Rate Profile – PWR (Standard Shield Concrete Cask)

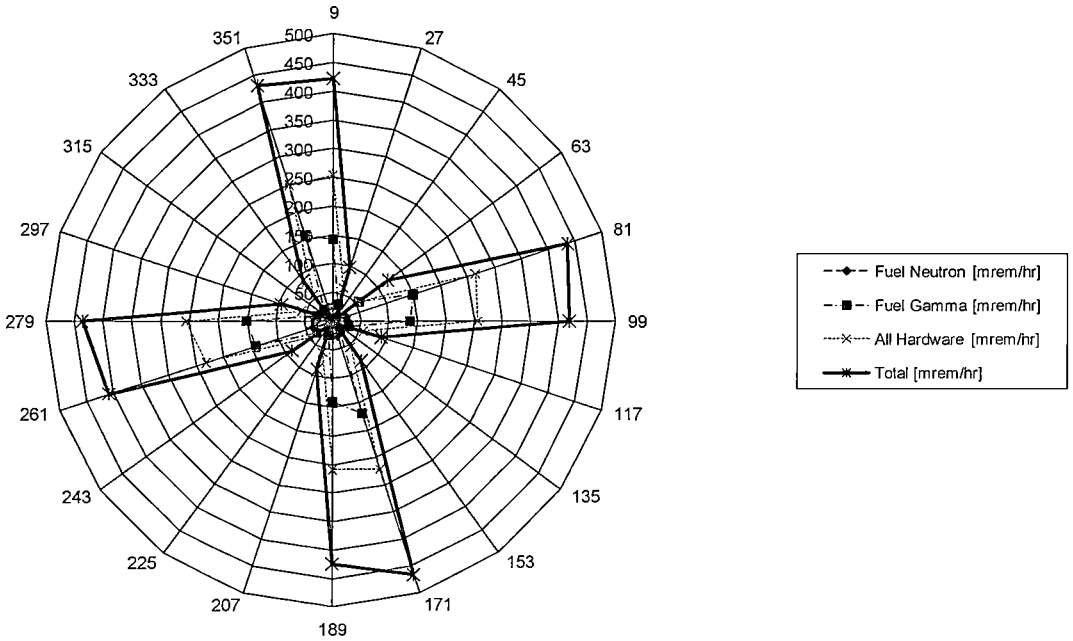
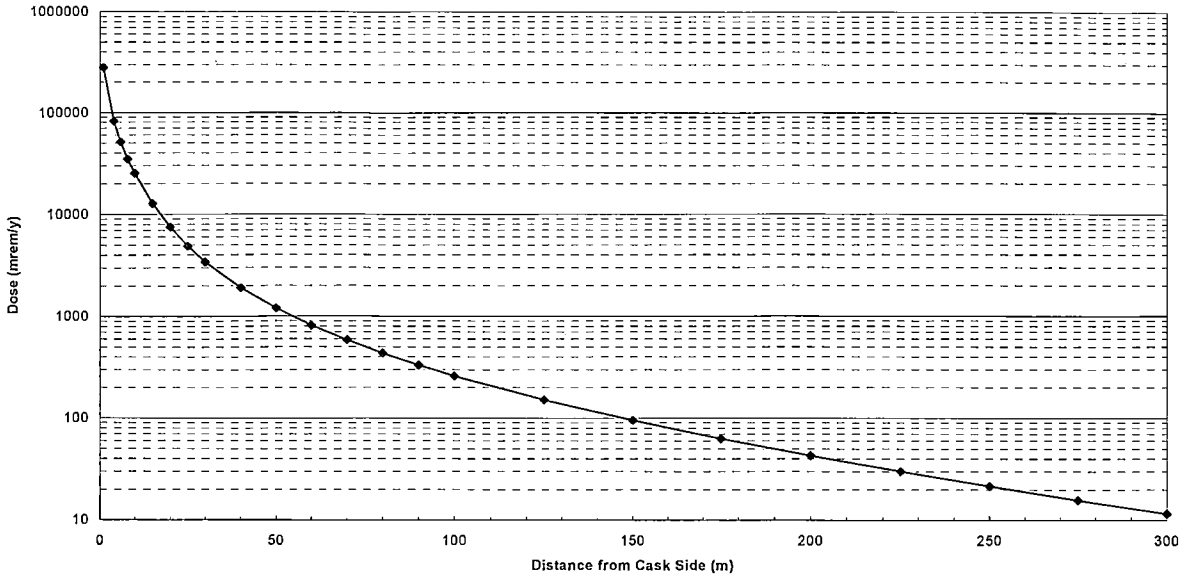
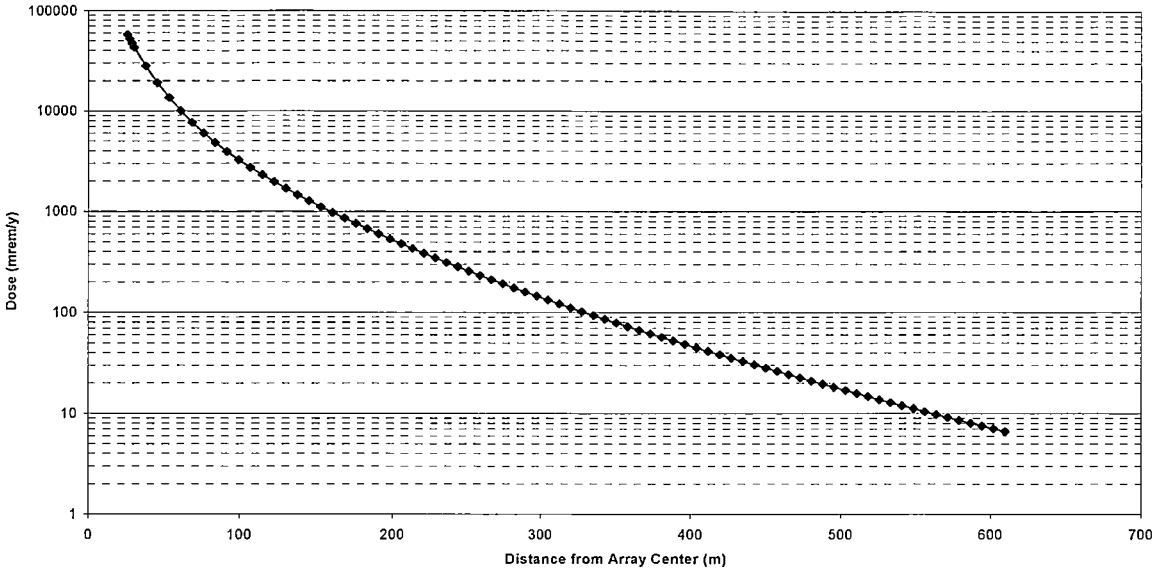


Figure 5.8.3-14 Exposures from a Single Concrete Cask Containing a PWR TSC



Distance (m)	Dose Rate (mrem/year)					
	Radial Gamma	Radial Neutron	Axial Gamma	Axial Neutron	Total n-γ	Total
10	2.44E+04	2.85E+02	2.29E+02	7.87E+00	8.50E+01	2.50E+04
25	4.66E+03	5.92E+01	1.12E+02	4.41E+00	2.07E-01	4.84E+03
50	1.11E+03	1.65E+01	5.22E+01	2.25E+00	6.14E-03	1.18E+03
100	2.34E+02	4.16E+00	1.79E+01	8.26E-01	2.01E-03	2.56E+02
125	1.36E+02	2.56E+00	1.14E+01	5.39E-01	1.79E-03	1.50E+02
150	8.48E+01	1.68E+00	7.49E+00	3.63E-01	1.63E-03	9.43E+01
175	5.57E+01	1.14E+00	5.03E+00	2.50E-01	1.55E-03	6.22E+01
200	3.80E+01	8.04E-01	3.44E+00	1.76E-01	1.48E-03	4.25E+01
225	2.67E+01	5.80E-01	2.38E+00	1.26E-01	1.39E-03	2.98E+01
250	1.91E+01	4.27E-01	1.66E+00	9.16E-02	1.32E-03	2.13E+01
275	1.40E+01	3.19E-01	1.17E+00	6.74E-02	1.23E-03	1.55E+01
300	1.04E+01	2.42E-01	8.30E-01	5.02E-02	1.15E-03	1.15E+01

Figure 5.8.3-15 Exposures from 2×10 Concrete Cask Array Containing PWR TSCs (X-Axis)



Distance (m)	Dose Rate (mrem/year)					
	Radial Gamma	Radial Neutron	Axial Gamma	Axial Neutron	Total n-γ	Total
50	1.47E+04	2.05E+02	1.04E+03	4.51E+01	2.18E-01	1.60E+04
100	2.75E+03	4.82E+01	3.62E+02	1.68E+01	5.79E-02	3.18E+03
150	9.80E+02	1.92E+01	1.53E+02	7.40E+00	3.43E-02	1.16E+03
200	4.38E+02	9.16E+00	7.01E+01	3.59E+00	2.61E-02	5.21E+02
250	2.21E+02	4.87E+00	3.38E+01	1.86E+00	2.16E-02	2.62E+02
300	1.20E+02	2.77E+00	1.69E+01	1.02E+00	1.81E-02	1.41E+02
350	6.85E+01	1.65E+00	8.68E+00	5.82E-01	1.51E-02	7.95E+01
400	4.07E+01	1.02E+00	4.55E+00	3.44E-01	1.24E-02	4.66E+01
450	2.48E+01	6.51E-01	2.42E+00	2.09E-01	1.00E-02	2.81E+01
500	1.55E+01	4.26E-01	1.31E+00	1.30E-01	7.96E-03	1.74E+01
550	9.96E+00	2.84E-01	7.18E-01	8.26E-02	6.22E-03	1.10E+01
600	6.53E+00	1.93E-01	3.99E-01	5.33E-02	4.79E-03	7.18E+00

Figure 5.8.3-16 Contour of the Controlled Area Boundary for the PWR 2x10 Cask Array

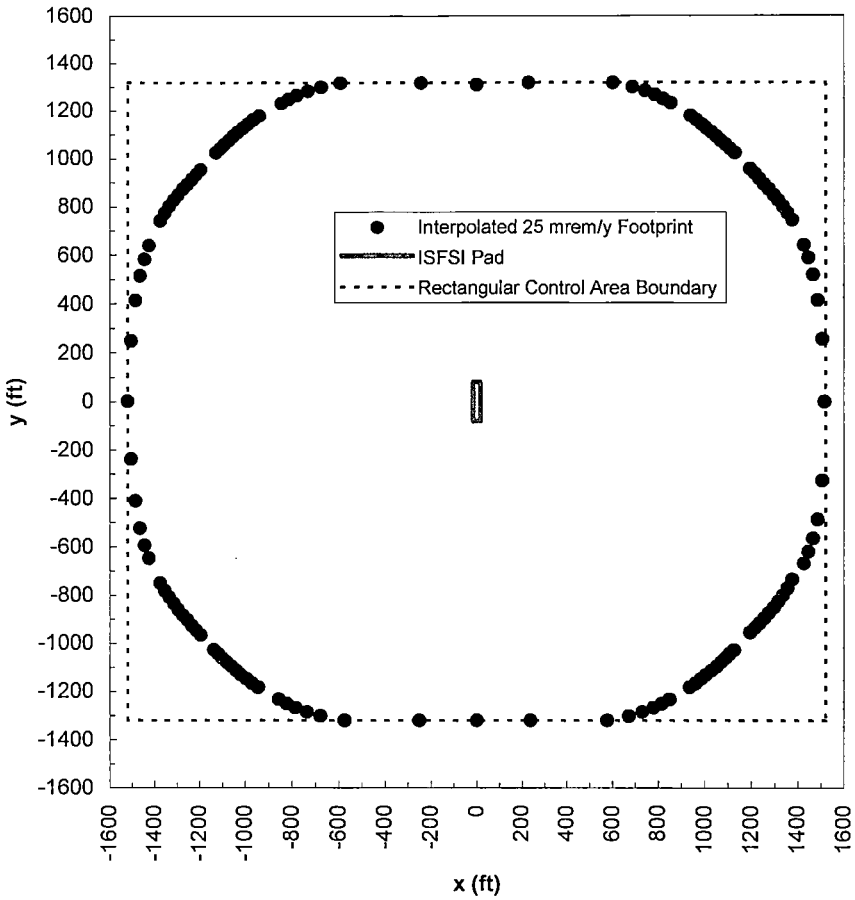


Figure 5.8.3-17 Transfer Cask Side Dose Rate Profile at Various Distances – PWR (Stainless Steel Transfer Cask)

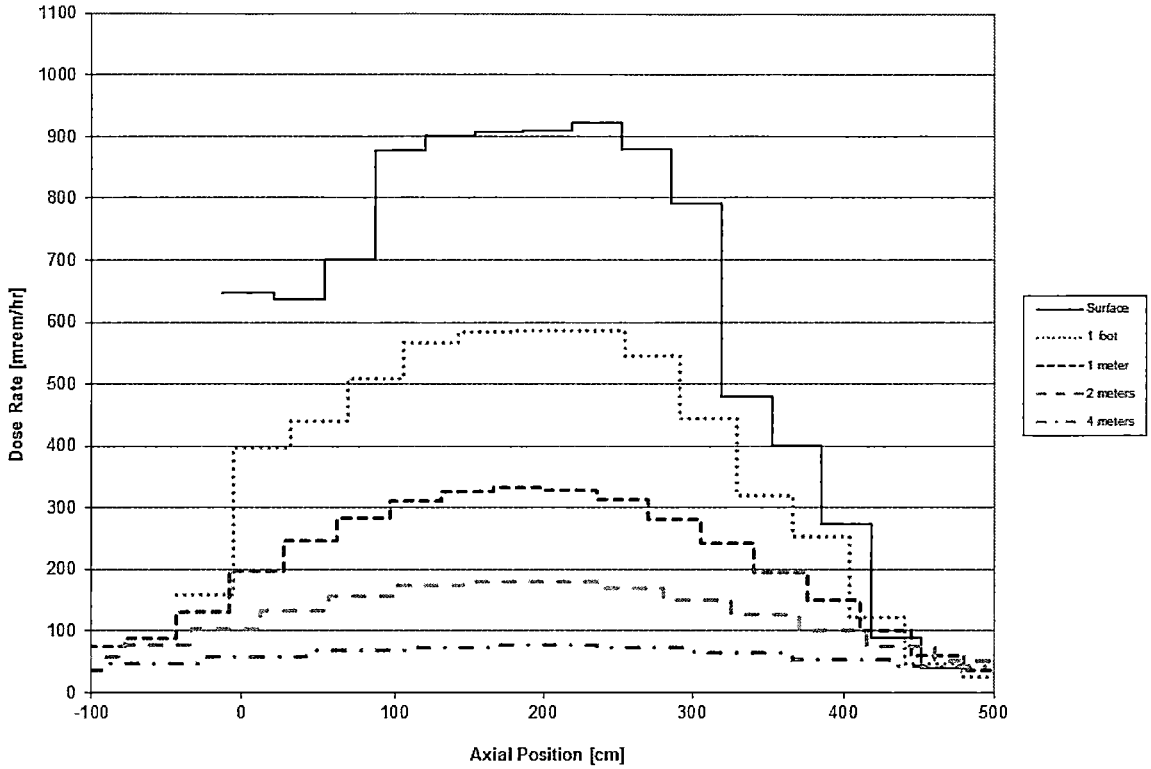


Figure 5.8.3-18 Transfer Cask Side Surface Dose Rate Profile by Source – PWR (Stainless Steel Transfer Cask)

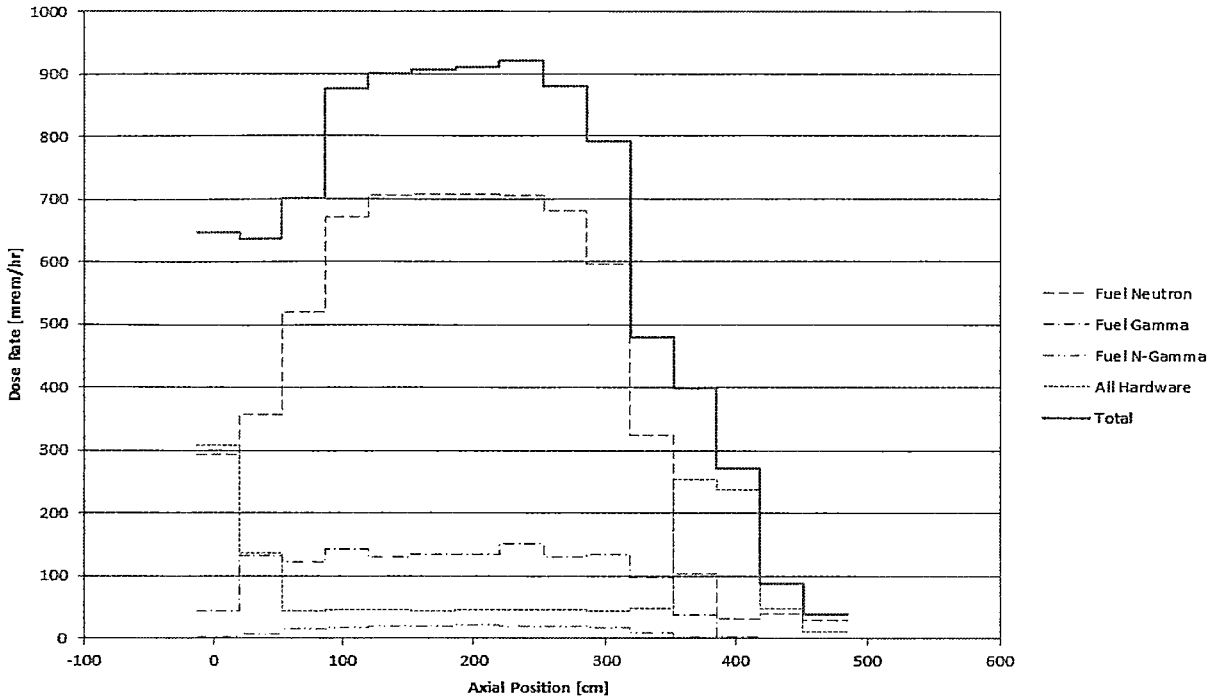


Figure 5.8.3-19 Transfer Cask Top Dose Rate Profile at Various Distances – PWR (Stainless Steel Transfer Cask)

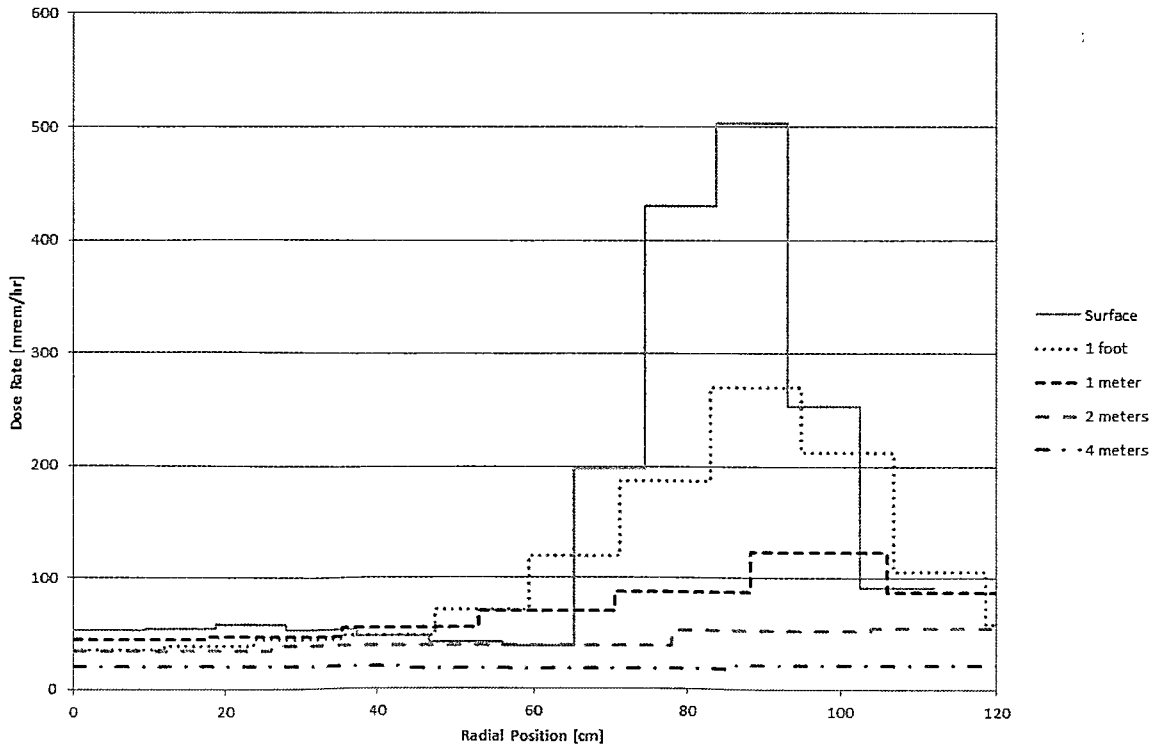


Figure 5.8.3-20 Transfer Cask Top Surface Dose Rate Profile by Source – PWR (Stainless Steel Transfer Cask)

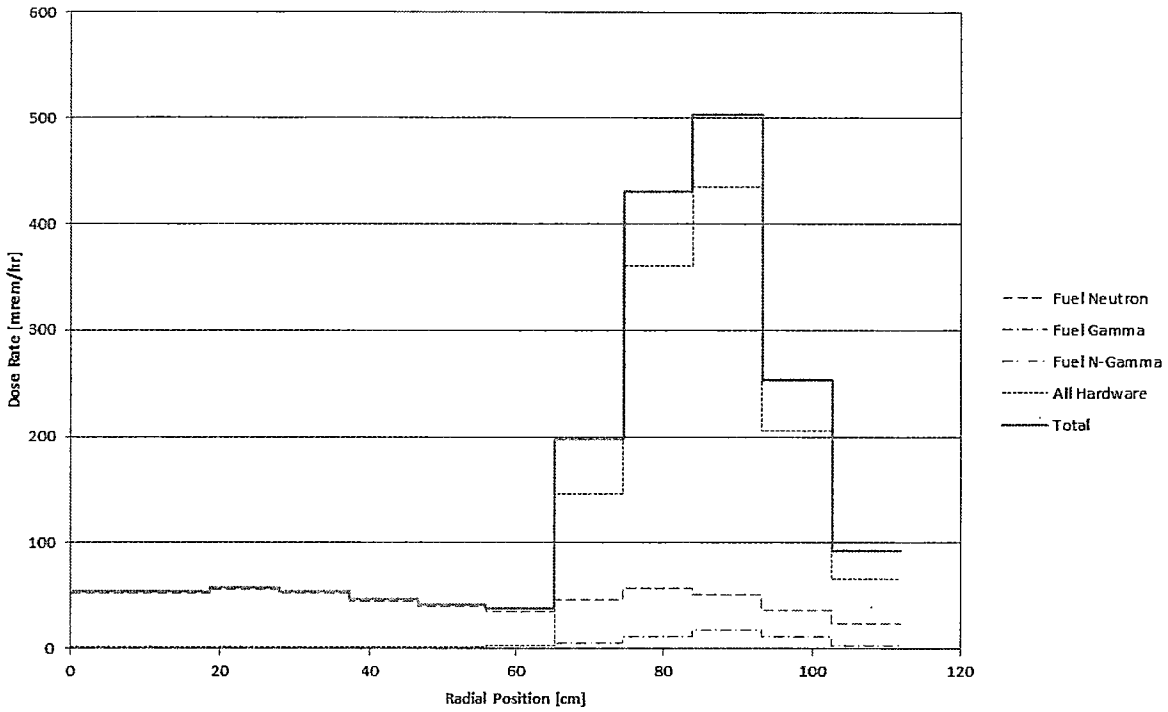


Figure 5.8.3-21 Transfer Cask Bottom Dose Rate Profile at Various Distances – PWR (Stainless Steel Transfer Cask)

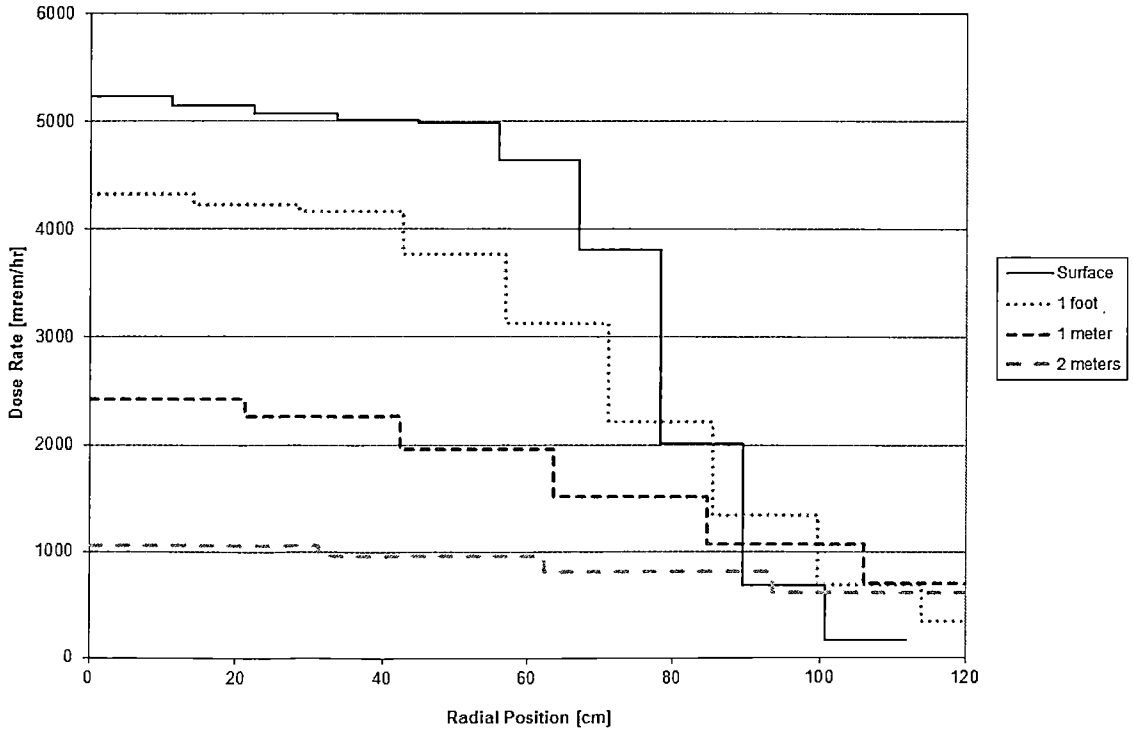


Figure 5.8.3-22 Concrete Cask Side Dose Rate Profile at Various Distances – PWR (Augmented Shield Concrete Cask)

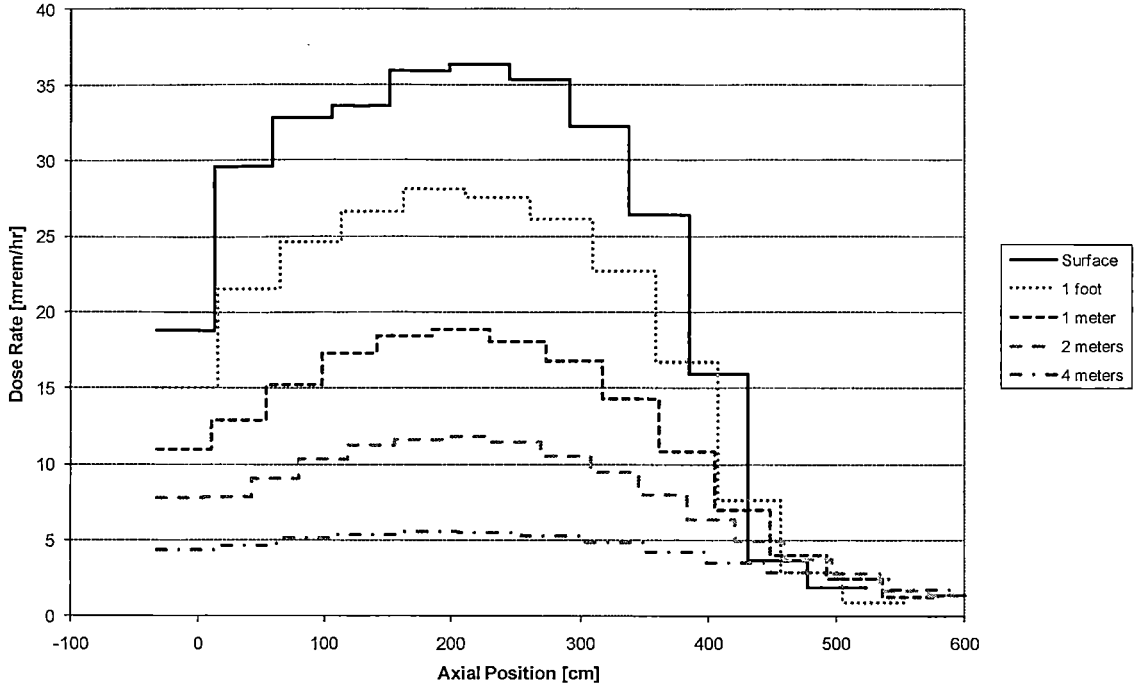


Figure 5.8.3-23 Concrete Cask Side Surface Dose Rate Profile by Source – PWR (Augmented Shield Concrete Cask)

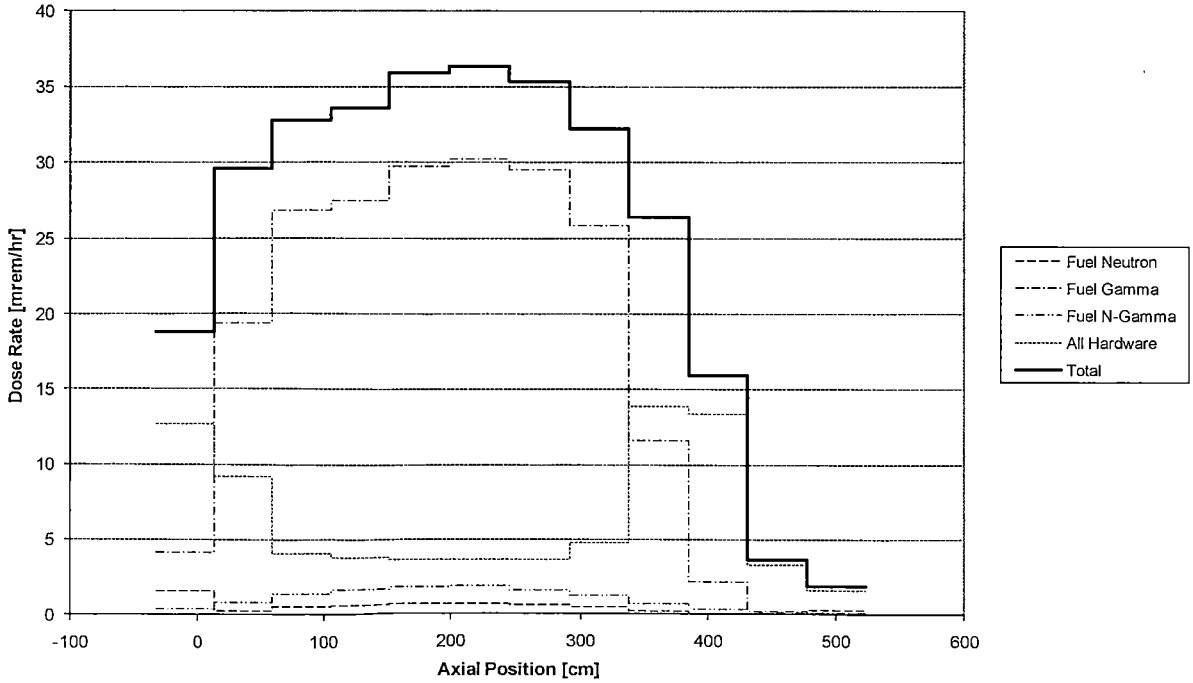


Figure 5.8.3-24 Concrete Cask Top Dose Rate Profile at Various Distances – PWR (Augmented Shield Concrete Cask)

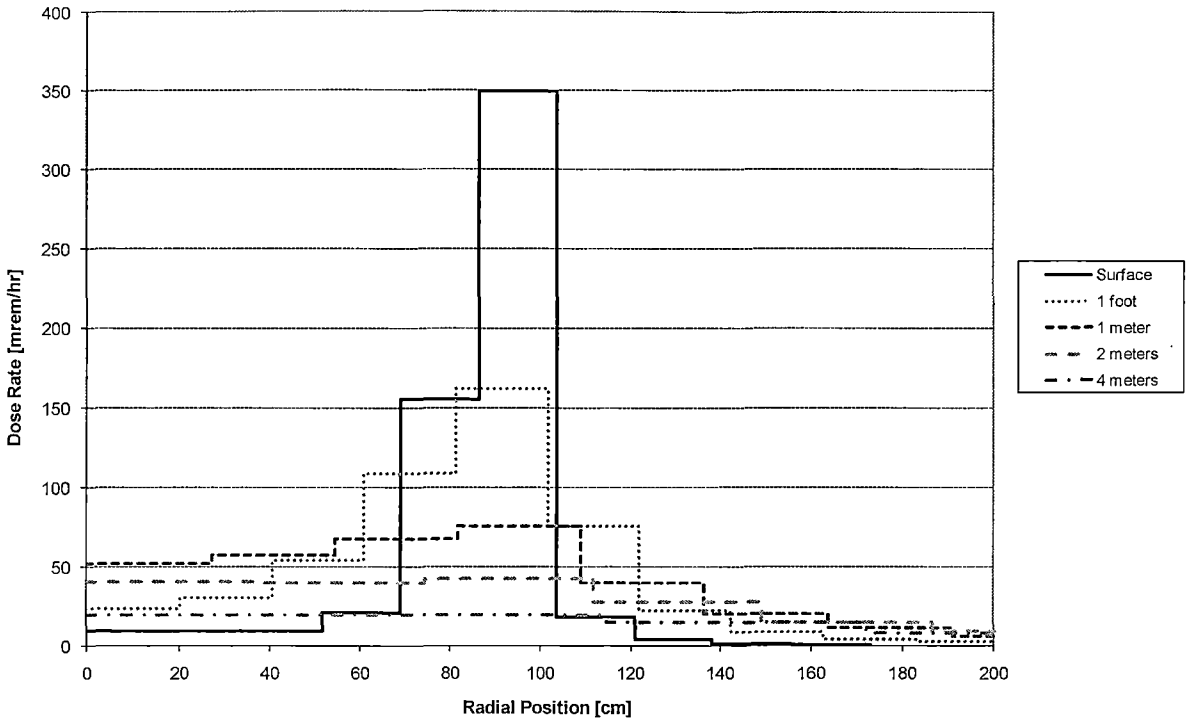


Figure 5.8.3-25 Concrete Cask Top Surface Dose Rate Profile by Source – PWR (Augmented Shield Concrete Cask)

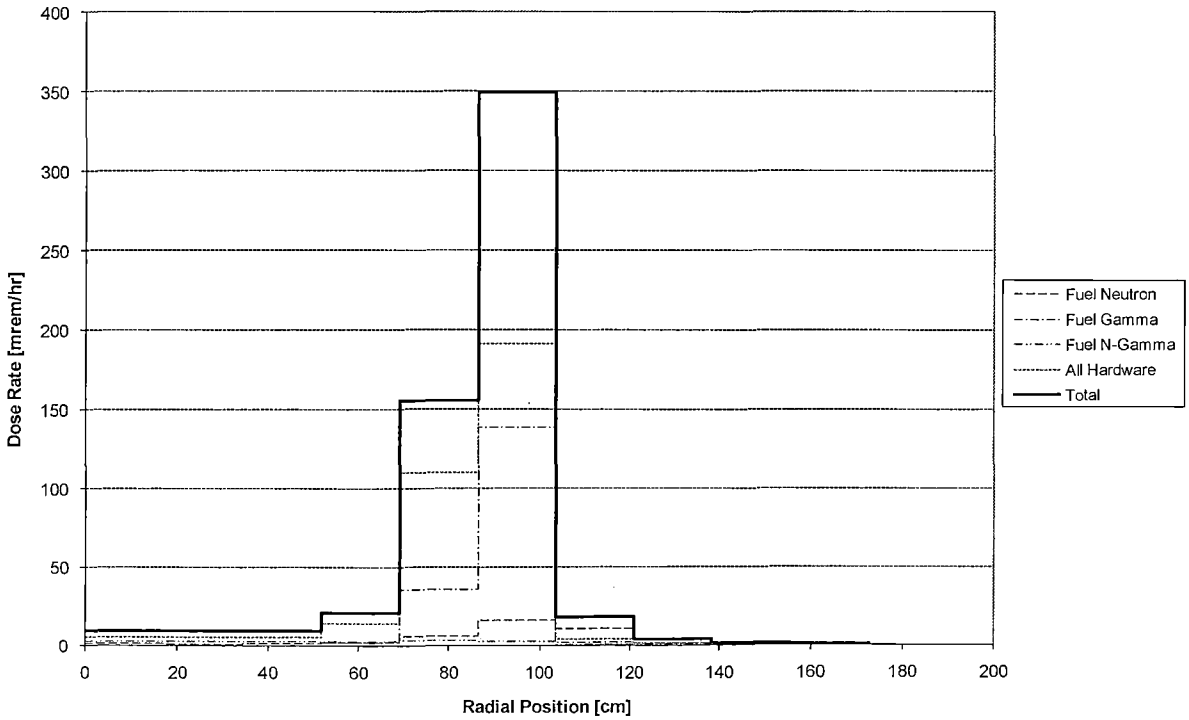


Figure 5.8.3-26 Concrete Cask Air Outlet Elevation Surface Dose Rate Profile – PWR (Augmented Shield Concrete Cask)

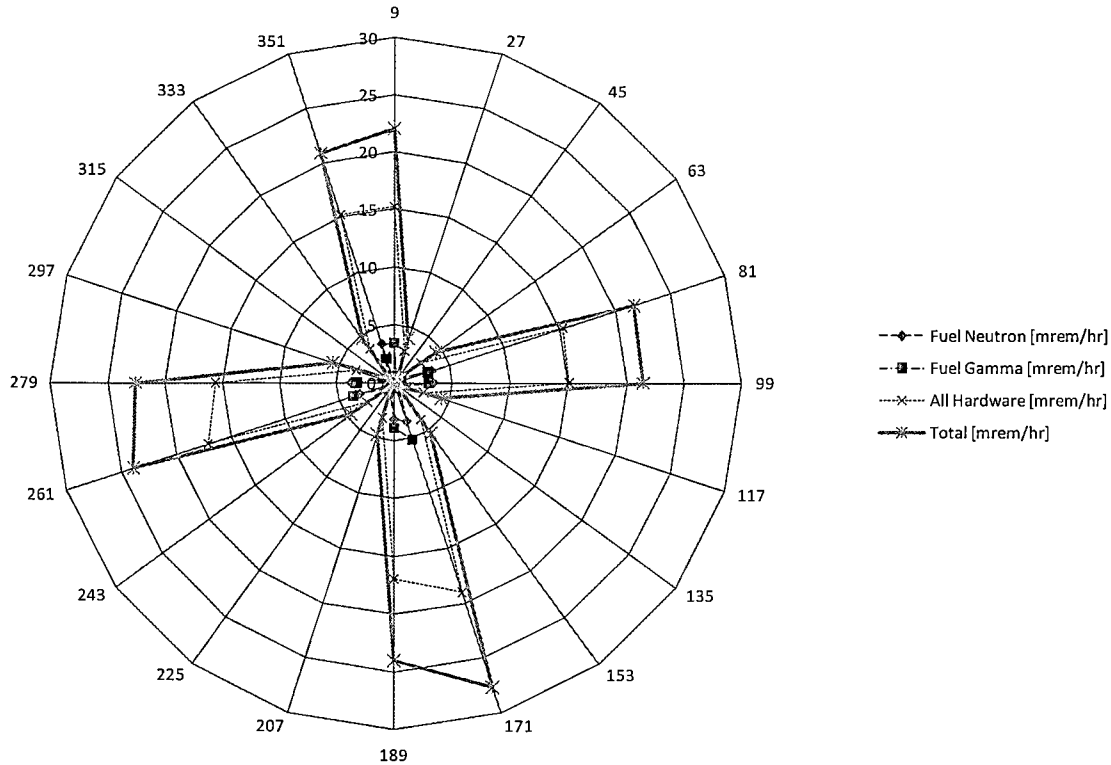


Figure 5.8.3-27 Concrete Cask Air Inlet Elevation Surface Dose Rate Profile – PWR (Augmented Shield Concrete Cask)

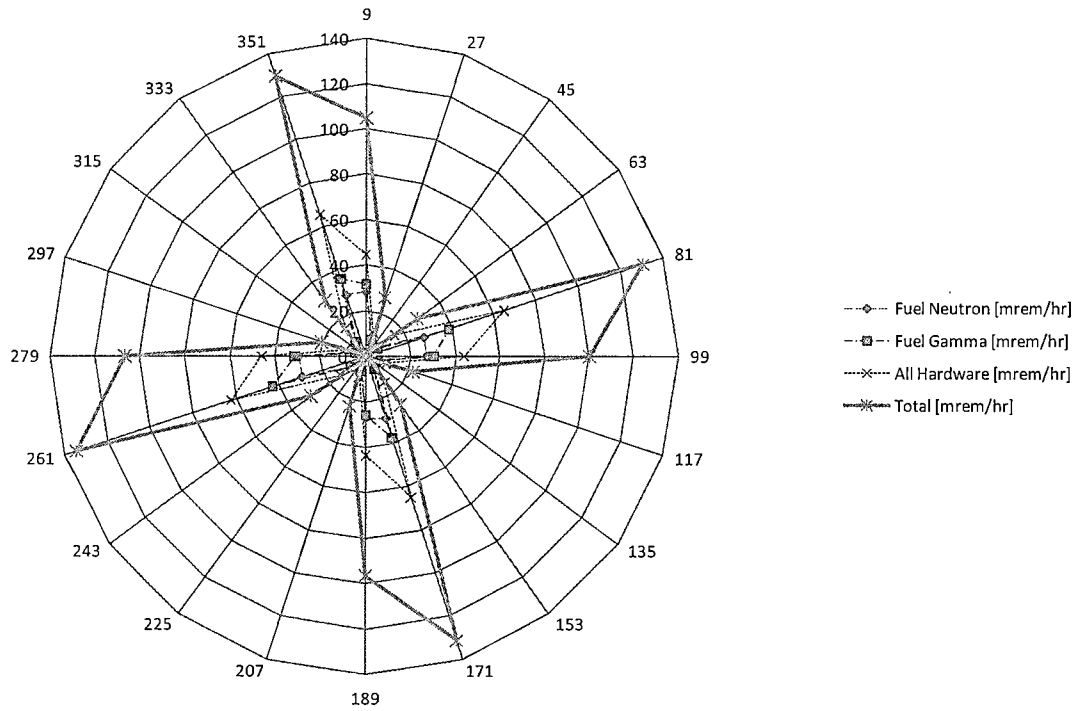


Figure 5.8.3-28 Concrete Cask Side Dose Rate Profile at Various Distances – PWR (CC4)

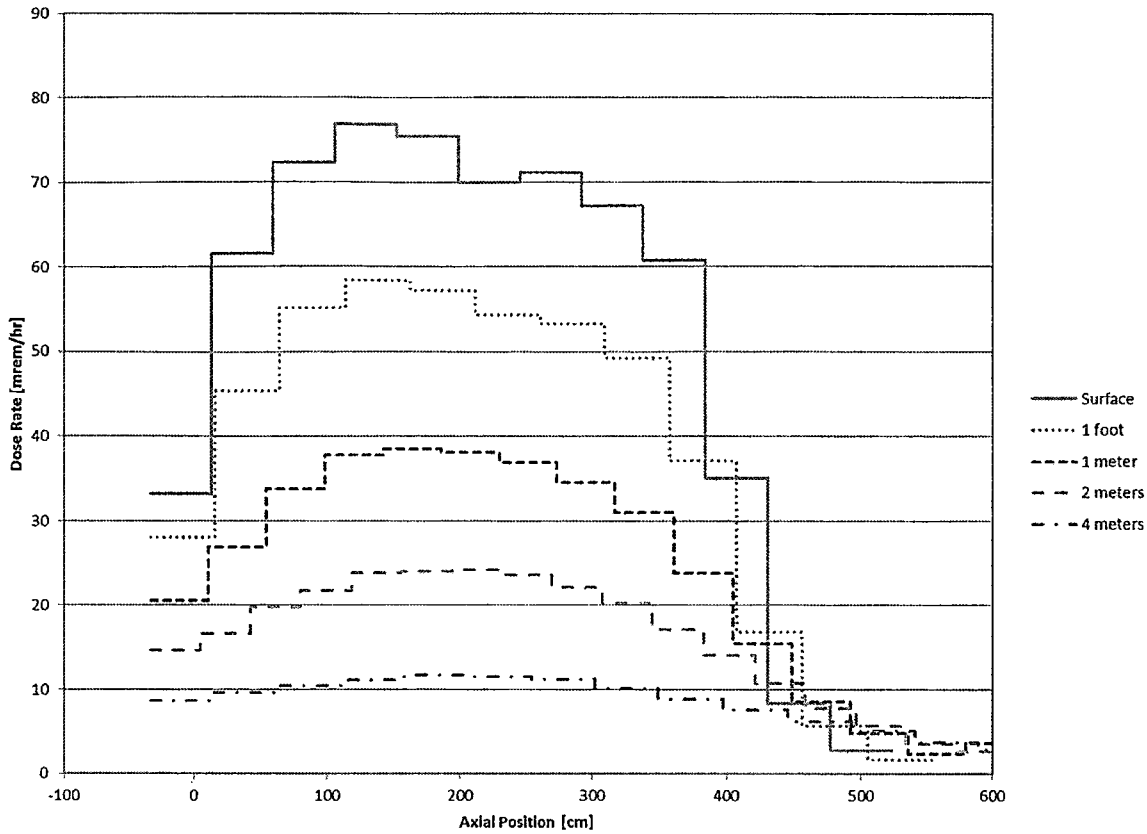


Figure 5.8.3-29 Concrete Cask Side Surface Dose Rate Profile by Source – PWR (CC4)

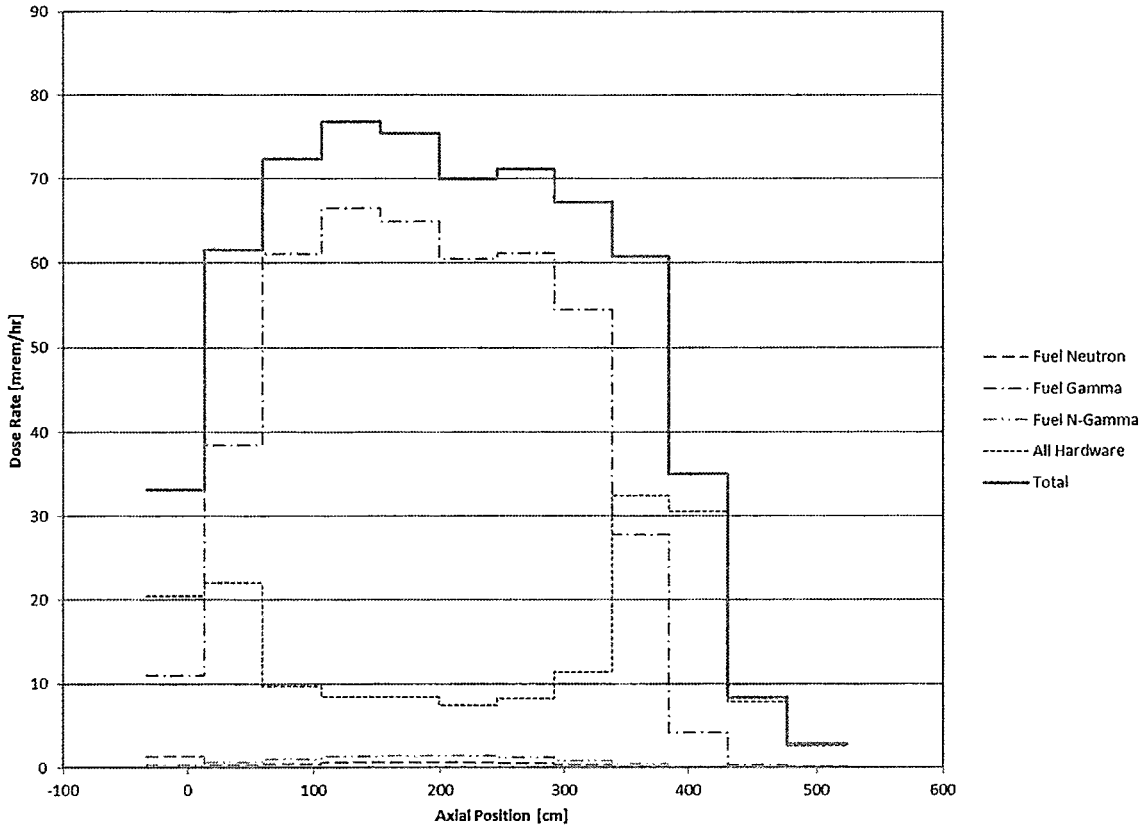


Figure 5.8.3-30 Concrete Cask Top Dose Rate Profile at Various Distances – PWR (CC4)

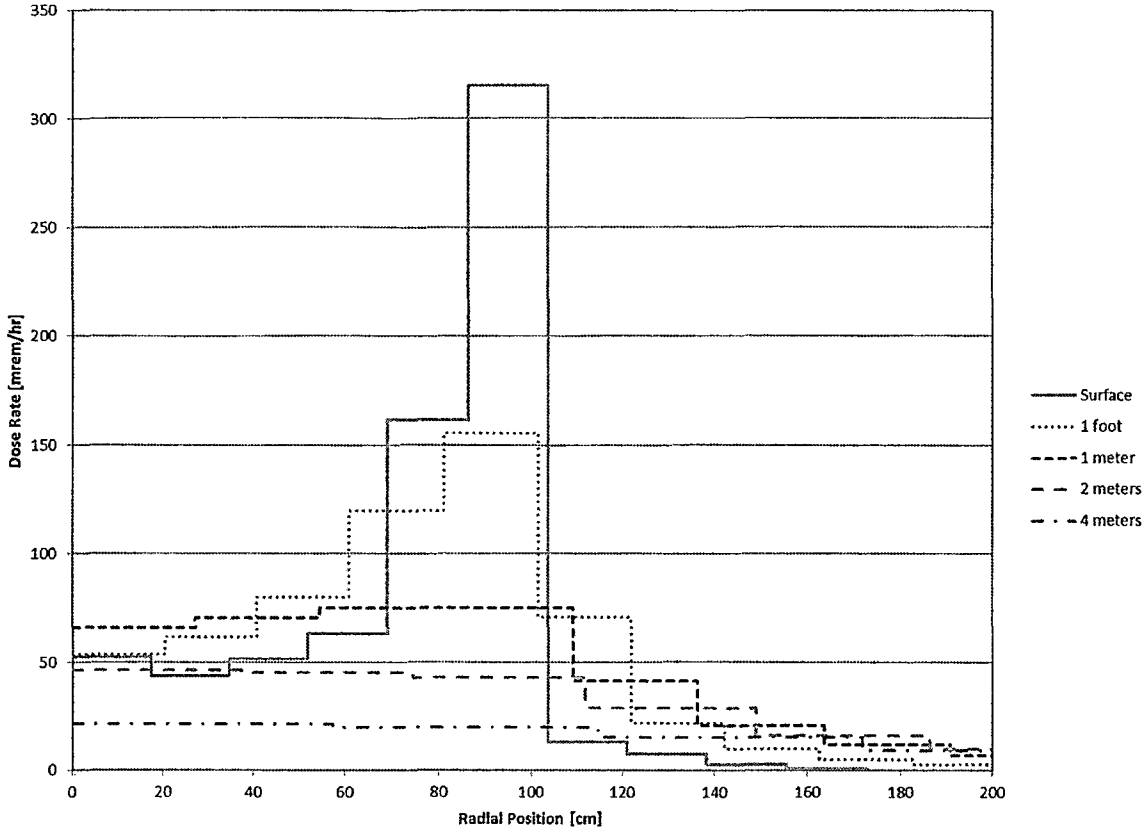


Figure 5.8.3-31 Concrete Cask Top Surface Dose Rate Profile by Source – PWR (CC4)

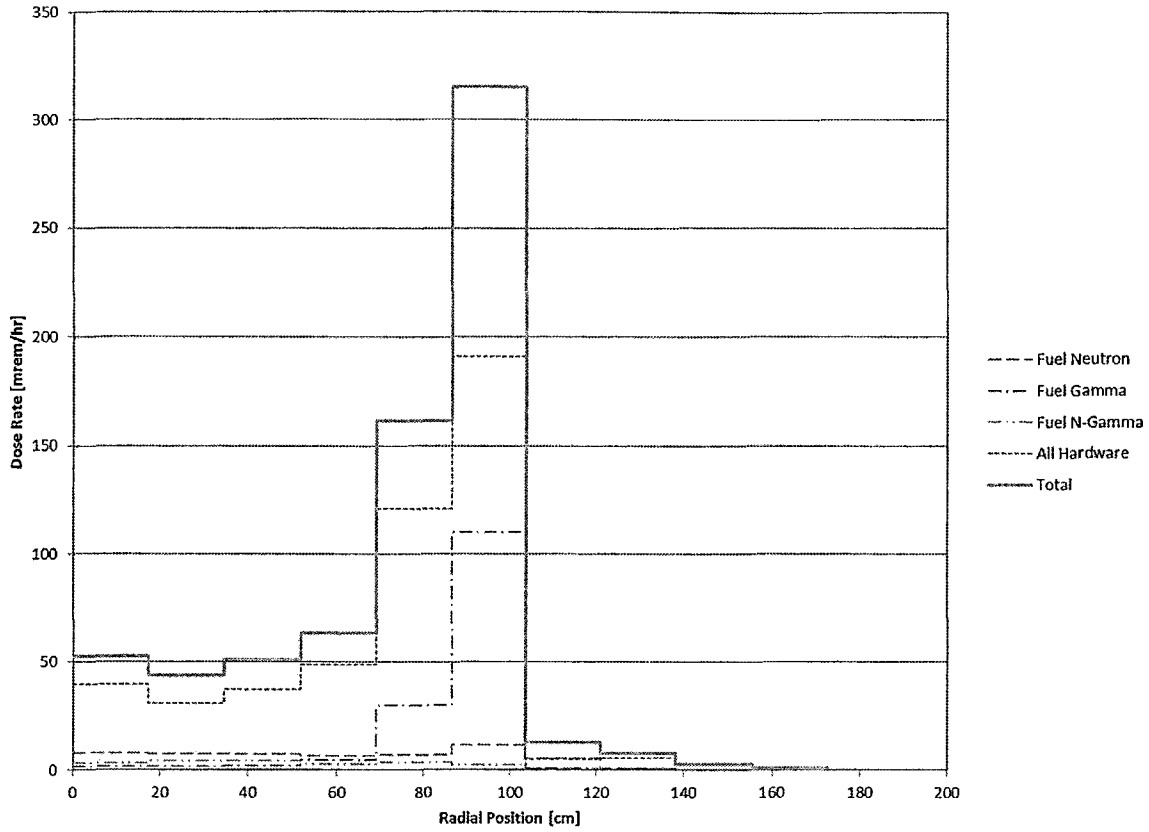


Figure 5.8.3-32 Concrete Cask Air Outlet Elevation Surface Dose Rate Profile – PWR (CC4)

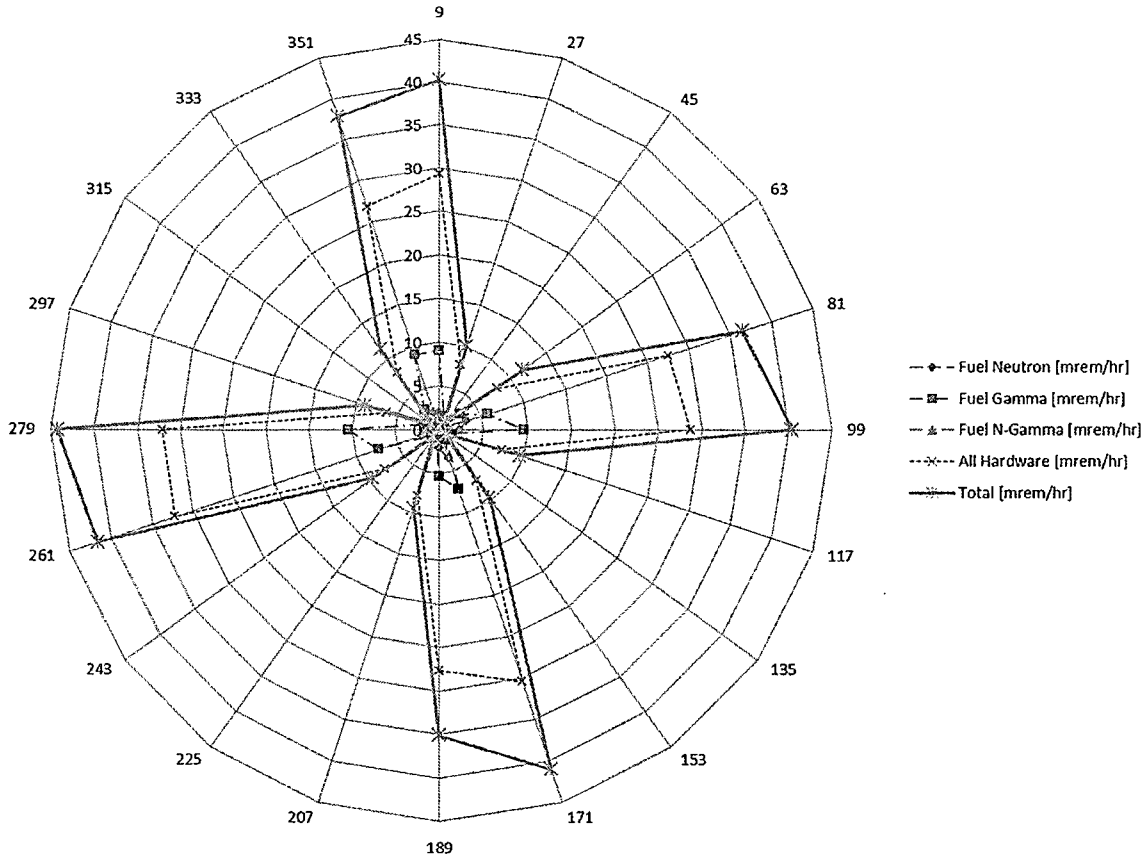


Figure 5.8.3-33 Concrete Cask Air Inlet Elevation Surface Dose Rate Profile – PWR (CC4)

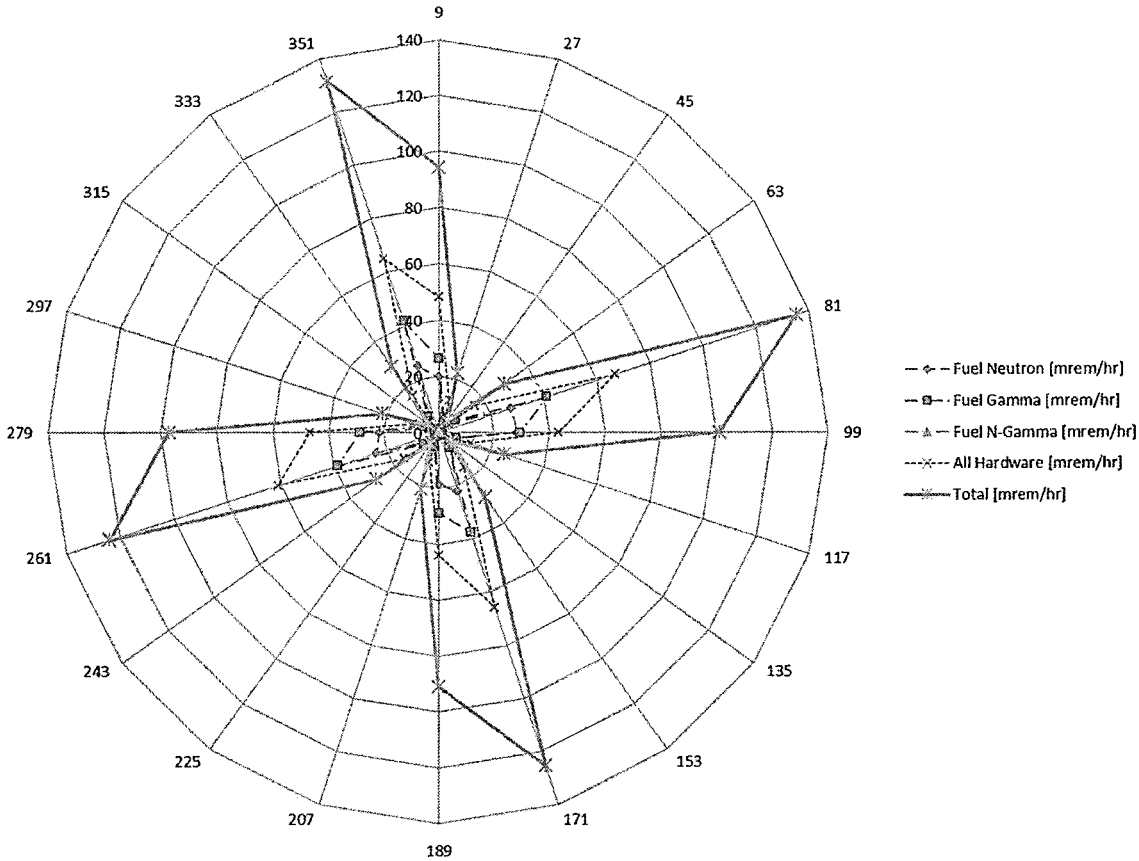


Table 5.8.3-1 PWR Fuel Region Homogenization Sample Calculation

Component	Area [cm²]	Area Fraction	Volume Fraction of Components		
			UO_2	Void	Clad
Fuel	1.3913E+02	3.0375E-01	3.0375E-01		
Gap	5.6649E+00	1.2367E-02		1.2367E-02	
Clad	4.2318E+01	9.2389E-02			9.2389E-02
Guide Tube	3.4075E+00	7.4392E-03			7.4392E-03
Instrument Tube	1.4198E-01	3.0997E-04			3.0997E-04
Inside Tubes	2.5881E+01	5.6502E-02		5.6502E-02	
Interstitial[a]	2.4150E+02	5.2725E-01		5.2725E-01	
Total	458.0473162	1.0000E+00	3.0375E-01	5.9612E-01	1.0014E-01

Table 5.8.3-2 PWR Nonfuel Hardware Homogenization Sample Calculation

Region	Assy Mass SS [kg/assy]	SS Volume [cm³/assy]	Modeled Dimensions		Volume Fraction
			Height [cm]	Volume [cm³/assy]	
Lower Nozzle	5.90	7.4307E+02	6.8580	3.1413E+03	2.3655E-01
Lower Plenum[b]	0.00	0.0000E+00	1.7399	7.9696E+02	0.0000E+00
Fuel Hardware	5.44	6.8514E+02	365.7600	1.6754E+05	4.0895E-03
Upper Plenum	5.41	6.8086E+02	22.2123	1.0174E+04	6.6919E-02
Upper Nozzle	7.85	9.8866E+02	9.3218	4.2698E+03	2.3155E-01

Table 5.8.3-3 Key PWR Basket Geometry Features

Feature	Material	Dimension
Tube	Carbon Steel	9.76 in outer width, $^5/_{16}$ in thick
Side Weldment	Carbon Steel	0.75 in thick
Corner Weldment	Carbon Steel	$^5/_{16}$ in thick
Top Spacer Pin	--	3.0 in long
Bottom Spacer Pin	--	3.0 in long
Location of Drain/Vent Port	--	29.98 in radius

[a] Space in fuel assembly width envelope outside fuel rods, guide tubes, and instrument tube.
[b] Represents the fuel rod end-cap.

Table 5.8.3-4 17a Minimum Cool-time Solution, 45 GWd/MTU at 3.9 wt% ^{235}U

Parameter	Value
6 yr Heat Load (W)	1036
7 yr Heat Load (W)	933
Minimum Cool Time[a] (yr)	6.74
Rounded Limit (yr)	6.8
Heat Load at Limit (W)	954

[a] Conservatively based on a linear interpolation of the exponential decay curve.

Table 5.8.3-5 Maximum Standard Shield Concrete Cask Surface Dose Rates

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	4	32.5	2.3	76.7	54.4
Top	16a	4.4	32.5	2.1	378	82.3
Air Inlet	14b	4.8	37.5	2.3	425	--
Air Outlet	16a	4.4	32.5	2.1	38.3	--

Table 5.8.3-6 PWR Bounding Surface Current Input Data[a]

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Cask Surface Neutron Source (n/sec)	Cask Surface Gamma Source (γ/sec)
Radial	14a	4.1	37.5	2.5	2.768E+07	2.602E+10
Top	16a	4.6	37.5	2.3	2.331E+07	1.350E+10

Table 5.8.3-7 Rectangular Controlled Area Boundary for the 2×10 PWR Cask Array

Direction Basis	Distance From the Center of the Array [ft]	Distance from the Center of the Array [m]
x direction (Perpendicular to Long Side of the Array)	1521	463
y direction (Perpendicular to the Short Side of the Array)	1319	402

Table 5.8.3-8 Maximum Augmented Shield Concrete Cask Surface Dose Rates

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	4.0	32.5	2.3	36.5	25.2
Top	14b	4.8	37.5	2.3	350	58.2
Air Inlet	14b	6.0	44	2.5	117	--
Air Outlet	17b	5.6	37.5	2.3	21.8	--

[a] Based on cask heat load of 40 kW

Table 5.8.3-9 Maximum CC4 Surface Dose Rates

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	4.0	32.5	2.3	76.8	52.9
Top	14b	4.8	37.5	2.3	315.3	61.5
Air Inlet	14b	6.0	44	2.5	112.4	--
Air Outlet	17b	4.7	32.5	2.1	36.8	--

5.8.4 87-Assembly BWR System

This section presents the detailed evaluation of the concrete and transfer casks loaded with BWR fuel assemblies.

5.8.4.1 BWR Fuel and Basket Models

The three-dimensional shielding evaluation includes a homogenized fuel assembly model and a detailed three-dimensional basket model.

5.8.4.1.1 Fuel Assembly Model

Based on the fuel assembly physical parameters provided in Table 5.8.1-4 and the hardware masses in Table 5.8.1-5, homogenized treatments of fuel assembly source regions are developed. The homogenized fuel assembly is represented in the model as a stack of boxes with width equal to the fuel assembly width. The height of each box corresponds to the modeled height of the corresponding assembly region.

Sample fuel and nonfuel hardware homogenizations for the source regions for the 08b assembly are shown in Table 5.8.4-1 and Table 5.8.4-2, respectively. The resulting fuel compositions on an atom/barn-cm basis are shown in Table 5.8.4-3. Similar compositions sets are generated for the remaining fuel assembly hybrids. Note that the Zirc-2 fuel assembly channel is not included in the model.

5.8.4.1.2 Basket Model

The basket is composed of coated carbon steel tubes, pinned together at the corners, and held together by side and corner weldments. Forty-five fuel tubes, in combination with the weldments, form 89 fuel openings. Two openings are located below the vent port covers. To minimize exposure and meet ALARA constraints, basket capacity is reduced to 87 assemblies. Pin spacers maintain the tube axial spacing within the TSC cavity. Each tube contains four metallic composite neutron absorber sheets. In dry storage and transfer, the presence of the neutron absorber sheets provides minimal shielding and could, therefore, be removed without a significant increase in exposure. Key basket characteristics are shown in Table 5.8.4-4. Radial and axial sketches of basket within the TSC are shown in Figure 5.8.4-1 and Figure 5.8.4-2.

5.8.4.2 Minimum Cool-time Specification

SAS2H generates heat loads for all BWR fuel types listed in Section 5.8.1.2. Based on a 35 kW per cask (0.402 kW per assembly) heat load, minimum allowed cool times for each fuel type are calculated. Calculated heat loads account for fuel material (actinide and fission product) and

hardware (light element) generated sources. Minimum cool times are conservatively rounded up to the nearest one-tenth of a year. A sample minimum cool time calculation for the 09b hybrid BWR assembly is shown in Table 5.8.4-5. The resulting minimum cool times are listed in an assembly specific loading table (see Table 5.8.4-6). Note that cool times for maximum assembly average burnups less than or equal to 30,000 MWd/MTU are not tabulated since they are equal to four years for all seven BWR fuel types. However, the following minimum enrichments for these assembly average burnups must be invoked.

Max. Assembly Avg. Burnup (MWd/MTU)	Min. Assembly Avg. Initial Enrichment (wt % ^{235}U)
5,000	0.7
10,000	1.3
15,000	1.5
20,000	1.7
25,000	1.9
30,000	2.1

Note that the loading table removes combinations of high burnup and low enrichment (e.g., 60 GWd/MTU and 1.9 wt% ^{235}U) from the payload definition. Source term data covering these combinations is generated, but produces unrealistic source terms due to the complete consumption of fissile uranium early in the burnup cycle and the SAS2H input of a fixed power density. To maintain power density, ORIGEN-S (SAS2H) will substantially increase flux levels, which would not occur during core operation of the assembly, to produce fissile material and to produce power by nonthermal fission. The increased flux level "breeds" higher actinides, which in turn increase source significantly. Since a high burnup and low enrichment combination would require repeated reinsertion of a burned assembly, the combination is excluded.

Minimum cool time tables for the thermal analysis limited heat load are included in Section 5.8.9.

5.8.4.3 Transfer Cask Dose Rates

Using the dose response method, cask dose rates are tabulated for all allowed cool time, assembly average burnup, and initial enrichment combinations for each of the assembly types. Maximum dose rates as a function of distance from the cask surface are shown in Figure 5.8.4-3 for the cask radial surface, Figure 5.8.4-5 for the cask top, and Figure 5.8.4-7 for the cask bottom. Breakdowns of the cask surface radial and top dose rates into the source components are shown

in Figure 5.8.4-4 and Figure 5.8.4-6. Refer to Table 5.8.4-7 for the maximum transfer cask radial, top, and bottom surface rates, and the contents that develop those dose rates.

5.8.4.4 Concrete Cask Dose Rates

Using the dose response method, concrete cask dose rates are tabulated for all allowed cool time, assembly average burnup, and initial enrichment combinations for each of the assembly types. Maximum dose rates as a function of distance from the concrete cask surface are shown in Figure 5.8.4-8 for the cask radial surface, Figure 5.8.4-10 for the cask top, and Figure 5.8.4-12 and Figure 5.8.4-13 for the cask air outlet and inlets, respectively. Breakdowns of the cask surface radial and top dose rates into the source components are shown in Figure 5.8.4-9 and Figure 5.8.4-11. Refer to Table 5.8.4-8 for the maximum concrete dose surface rates and the contents that develop those dose rates.

5.8.4.5 NAC-CASC / Site Boundary Evaluation

Detailed direct and skyshine dose rates as a function of distance are calculated for a single concrete cask and a 2×10 array of concrete casks based on the model description and method outlined in Section 5.5.3. All allowable payload combinations (i.e., fuel type, initial enrichment, assembly average burnup, and cool time) that meet per assembly heat load limits were reviewed to determine the payloads producing maximum top (axial) and side (radial) dose rates. These payload cases were then run through MCNP using a "direct" solution approach (full source spectrum), rather than the response function method, to generate cask top and side surface radiation currents. The surfaces were treated independently to generate a conservative hybrid source model for a design basis analysis cask.

The maximum TSC heat load applied in the site boundary evaluation is 38 kW versus the 35 kW applied in the cask surface dose evaluations. The site boundary results obtained from the 38 kW pattern conservatively bound those of the maximum 35 kW pattern.

Table 5.8.4-9 lists the surface current description of the bounding BWR source for the cask radial and axial surfaces. The resulting boundary required to meet a 25 mrem/yr limit for an 8,760-hr exposure is listed in Table 5.8.4-10. Figure 5.8.4-16 contains a contour plot of the 25 mrem/yr boundary. Yearly exposure as a function of distance is plotted in Figure 5.8.4-14 for a single cask and in Figure 5.8.4-15 for the cask array. A breakdown of the neutron, gamma, and neutron induced gamma radiation components as a function of distance is provided below each plot.

A sample BWR NAC-CASC input file is provided in Section 5.8.8. The detector location grid is truncated in the listed input file.

Figure 5.8.4-1 BWR Basket Top View

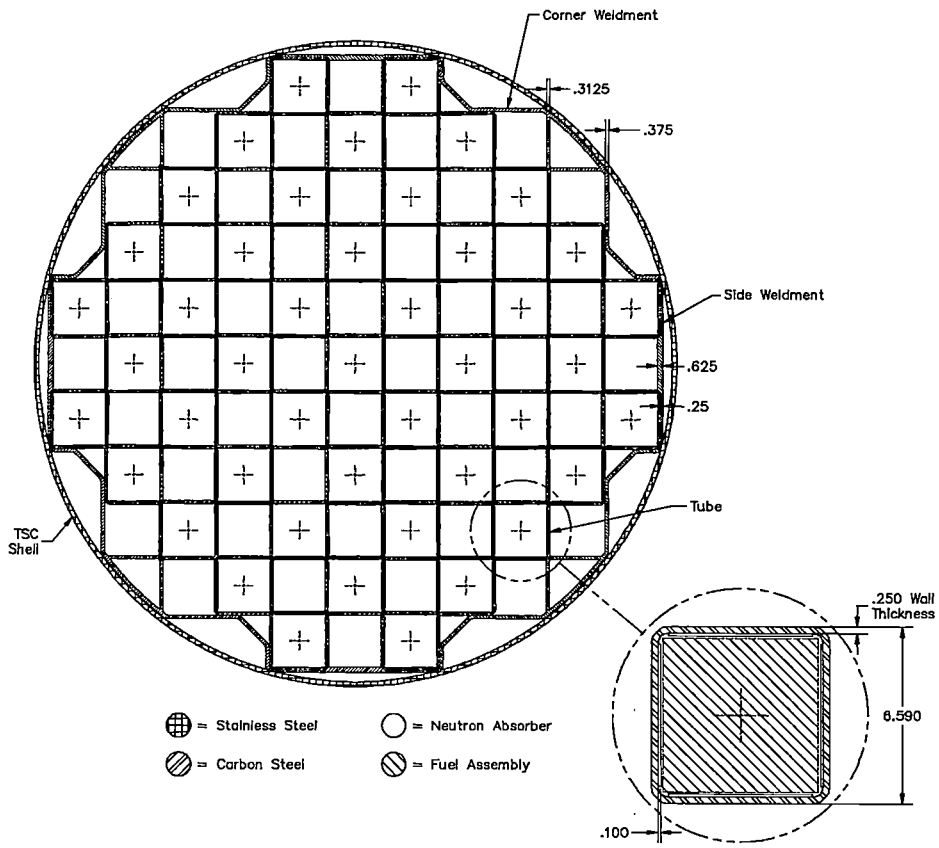


Figure 5.8.4-2 BWR Basket and TSC Side View

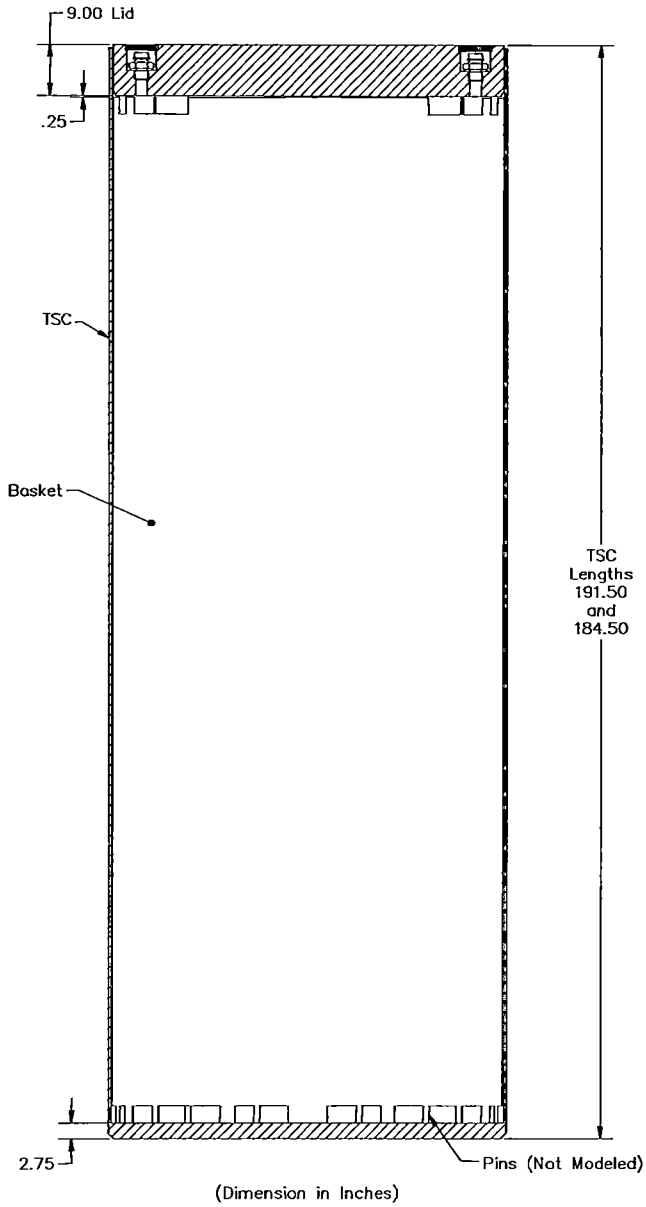


Figure 5.8.4-3 Transfer Cask Side Dose Rate Profile at Various Distances – BWR

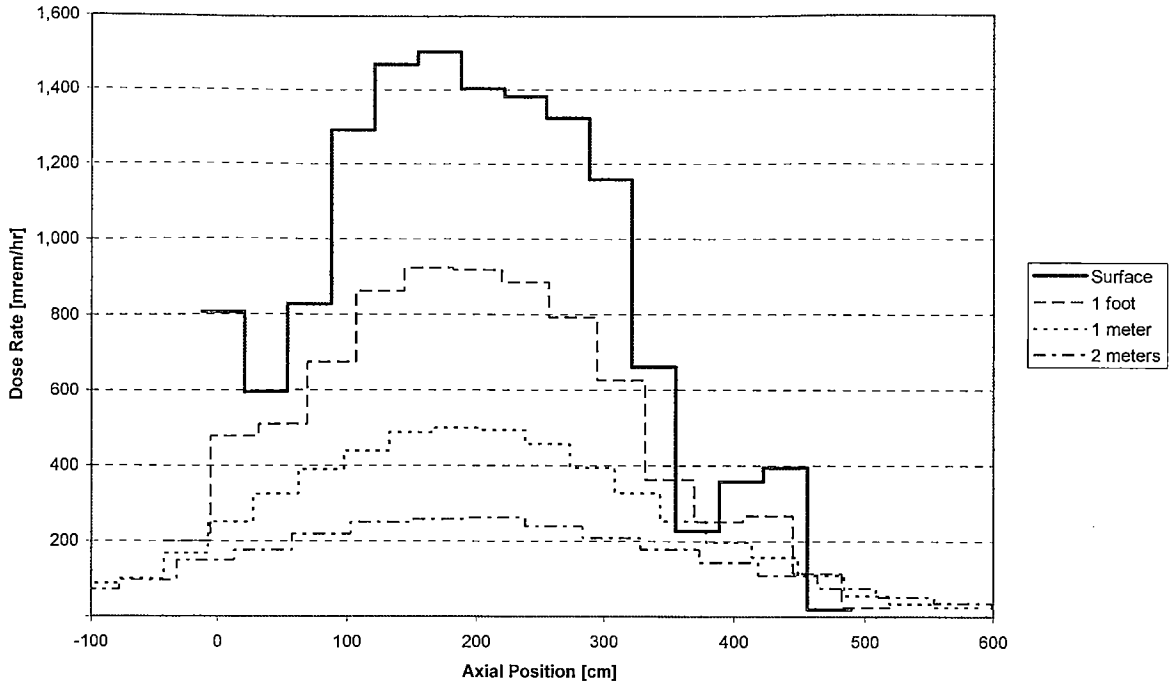


Figure 5.8.4-4 Transfer Cask Side Surface Dose Rate Profile by Source – BWR

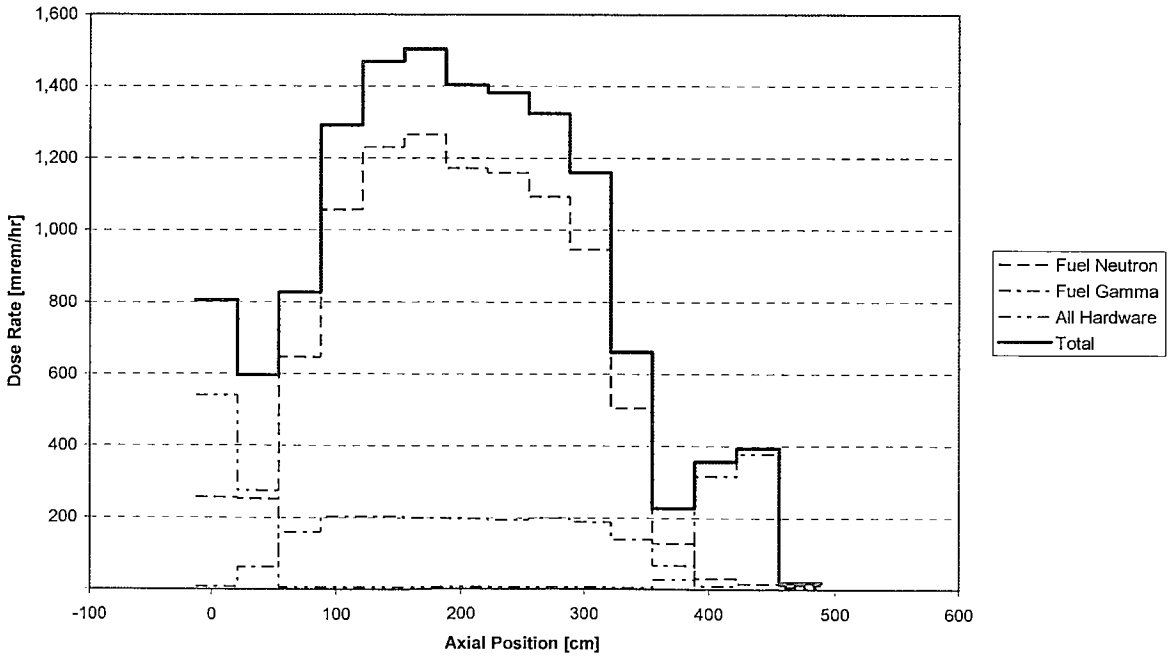


Figure 5.8.4-5 Transfer Cask Top Dose Rate Profile at Various Distances – BWR

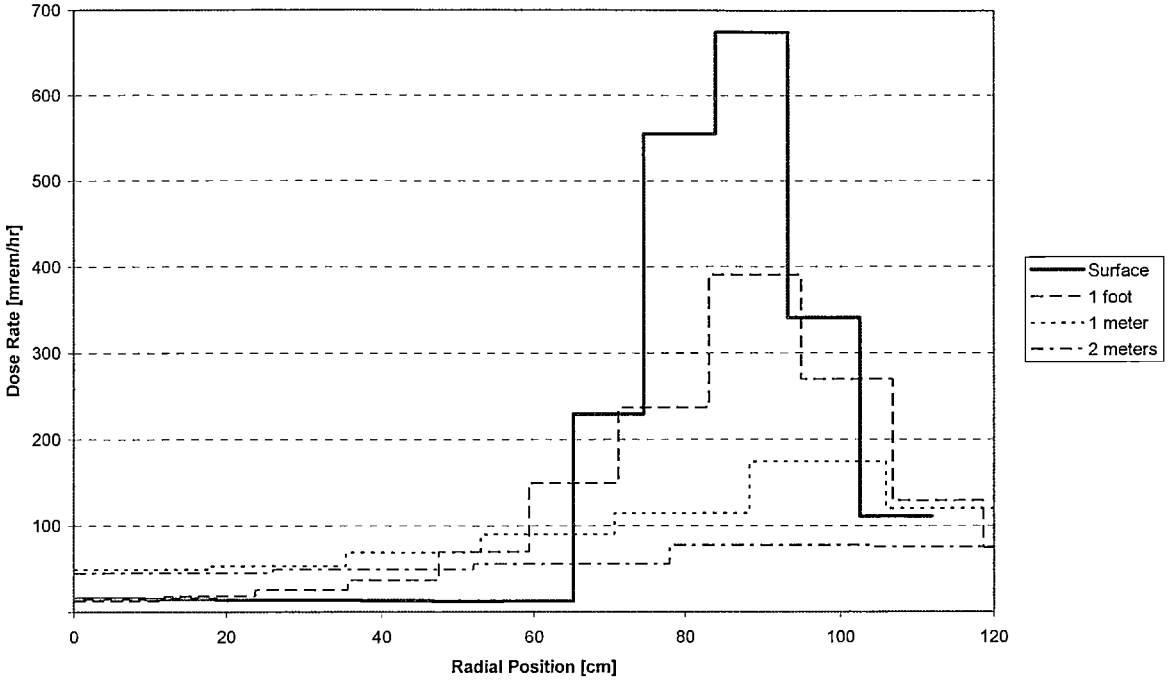


Figure 5.8.4-6 Transfer Cask Top Surface Dose Rate Profile by Source – BWR

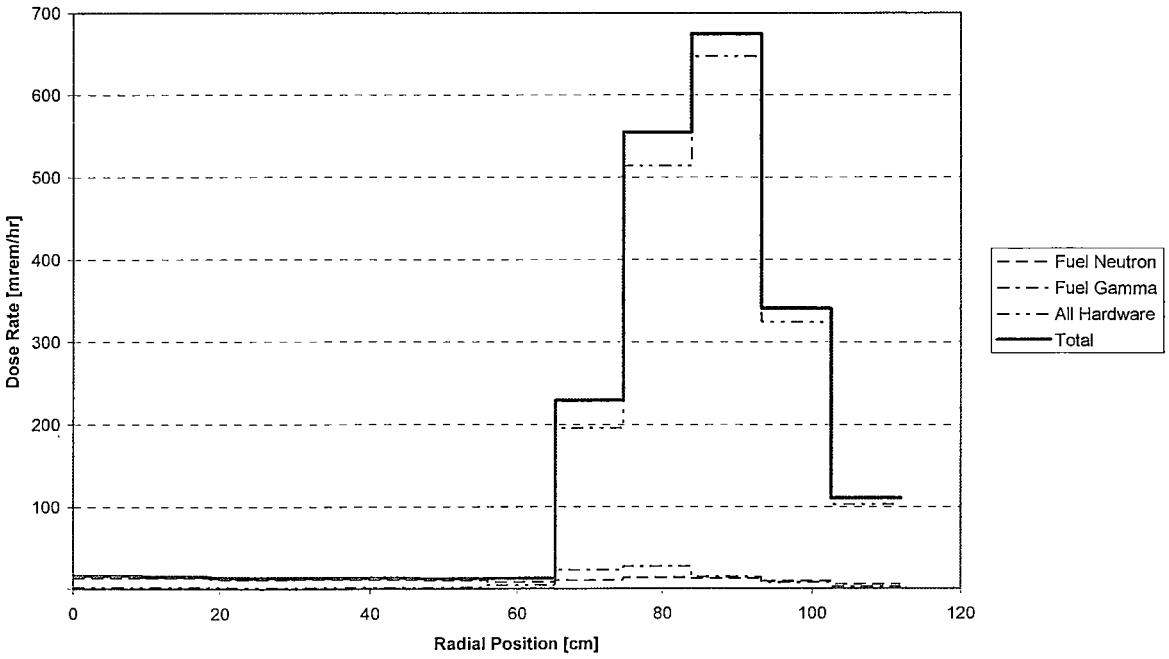


Figure 5.8.4-7 Transfer Cask Bottom Dose Rate Profile at Various Distances – BWR

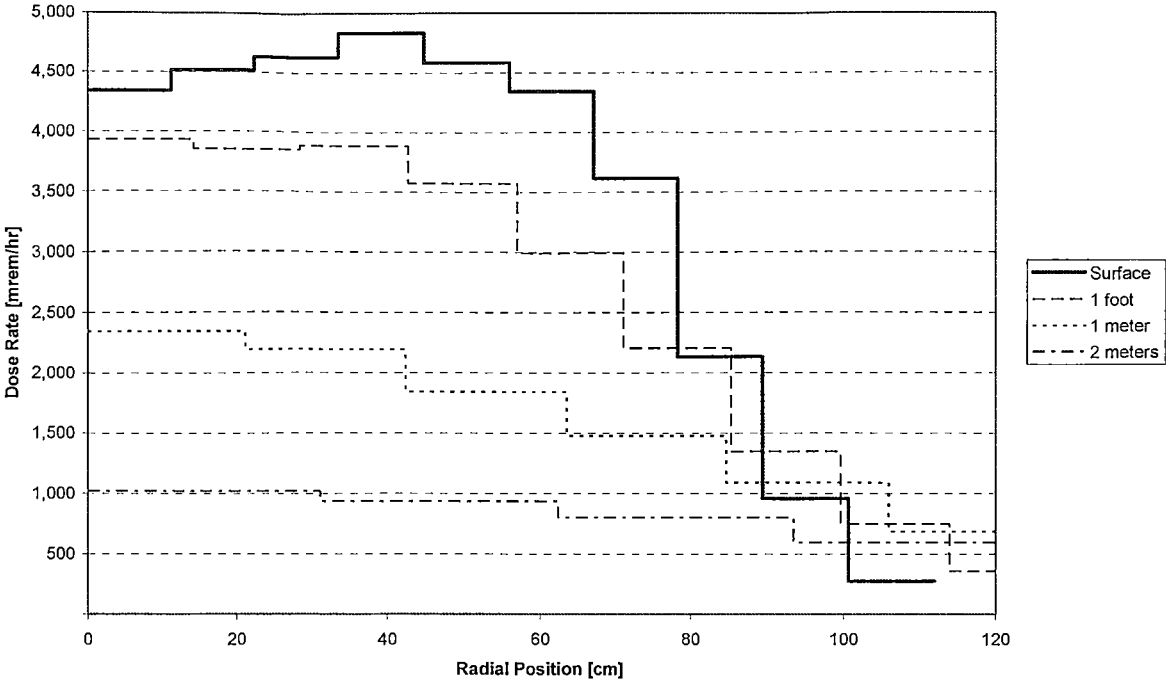


Figure 5.8.4-8 Concrete Cask Side Dose Rate Profile at Various Distances – BWR

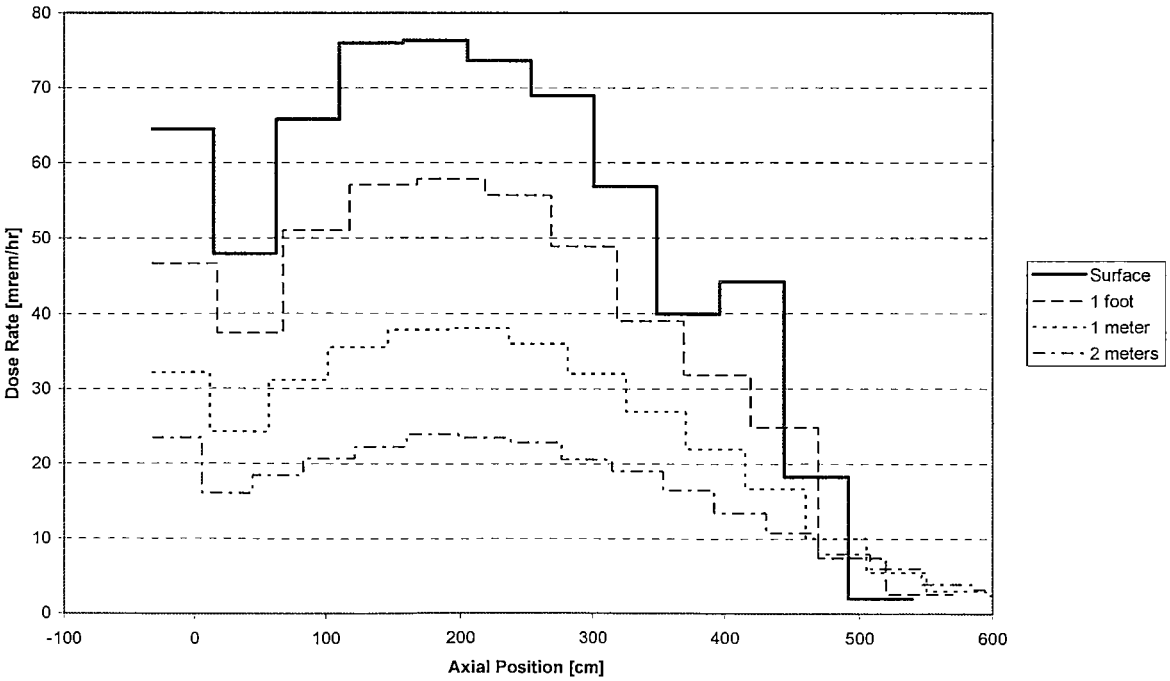


Figure 5.8.4-9 Concrete Cask Side Surface Dose Rate Profile by Source –BWR

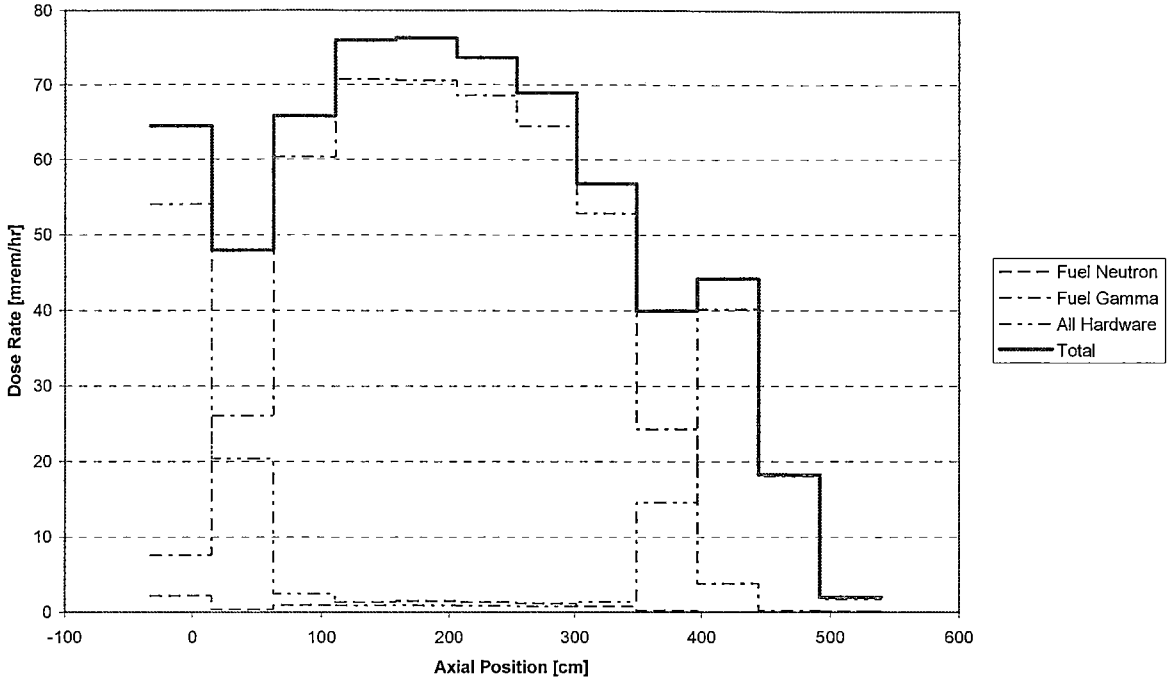


Figure 5.8.4-10 Concrete Cask Top Dose Rate Profile at Various Distances – BWR

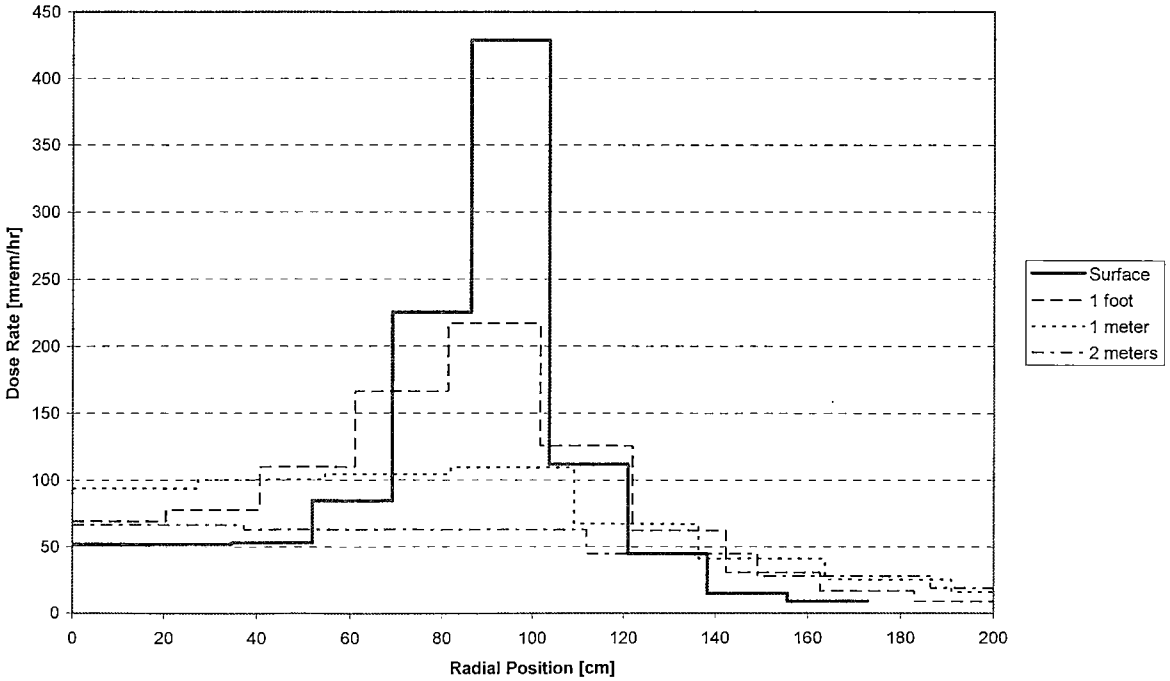


Figure 5.8.4-11 Concrete Cask Top Surface Dose Rate Profile by Source –BWR

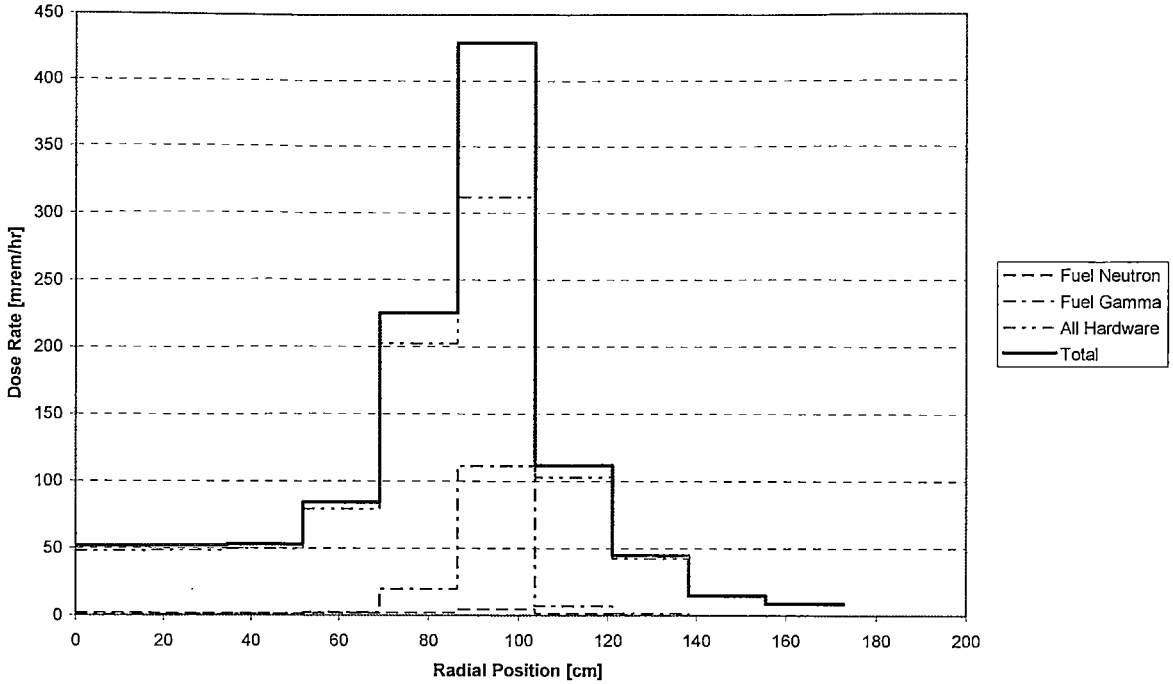


Figure 5.8.4-12 Concrete Cask Air Outlet Elevation Surface Dose Rate Profile – BWR

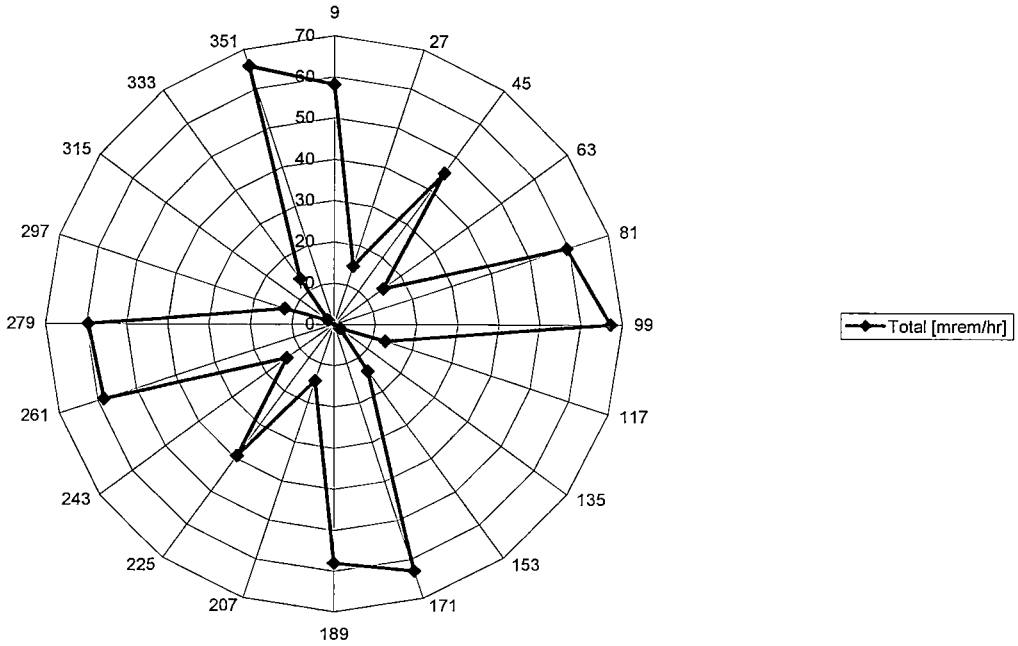


Figure 5.8.4-13 Concrete Cask Air Inlet Elevation Surface Dose Rate Profile – BWR

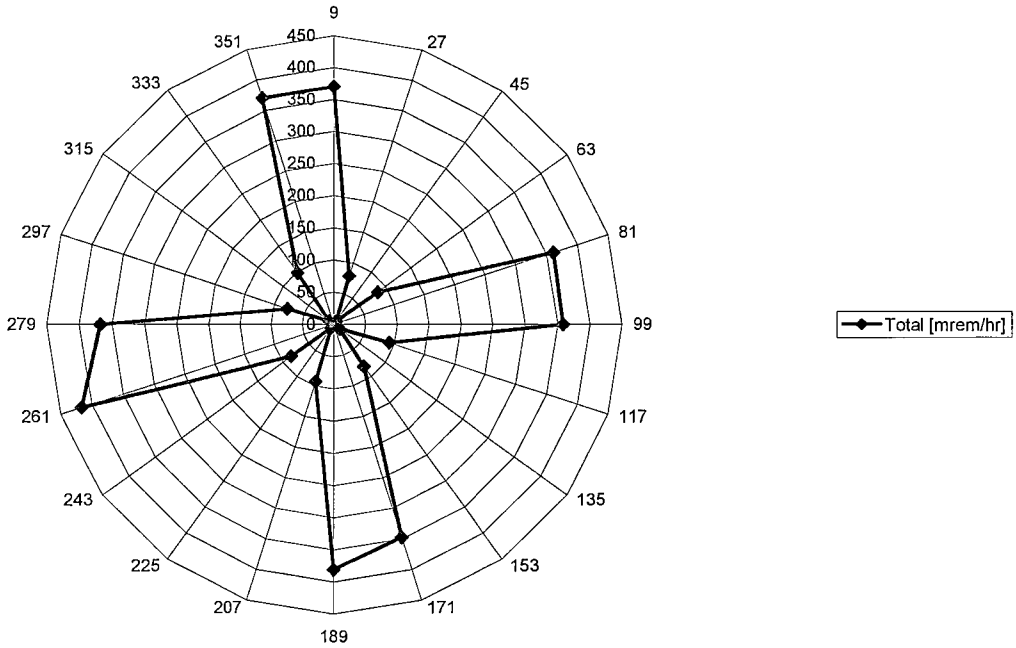
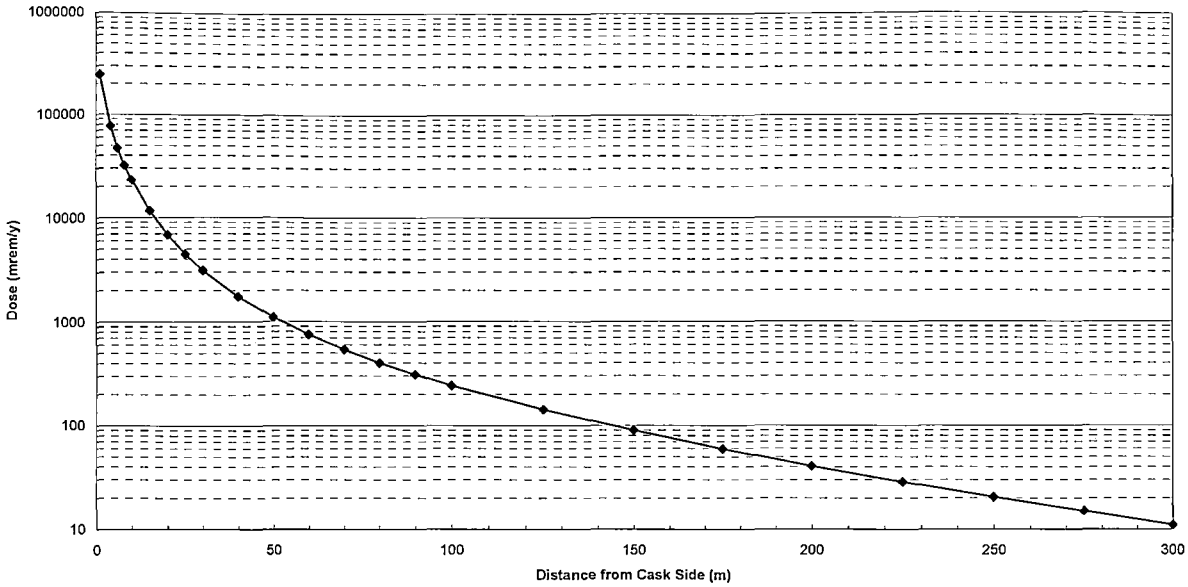
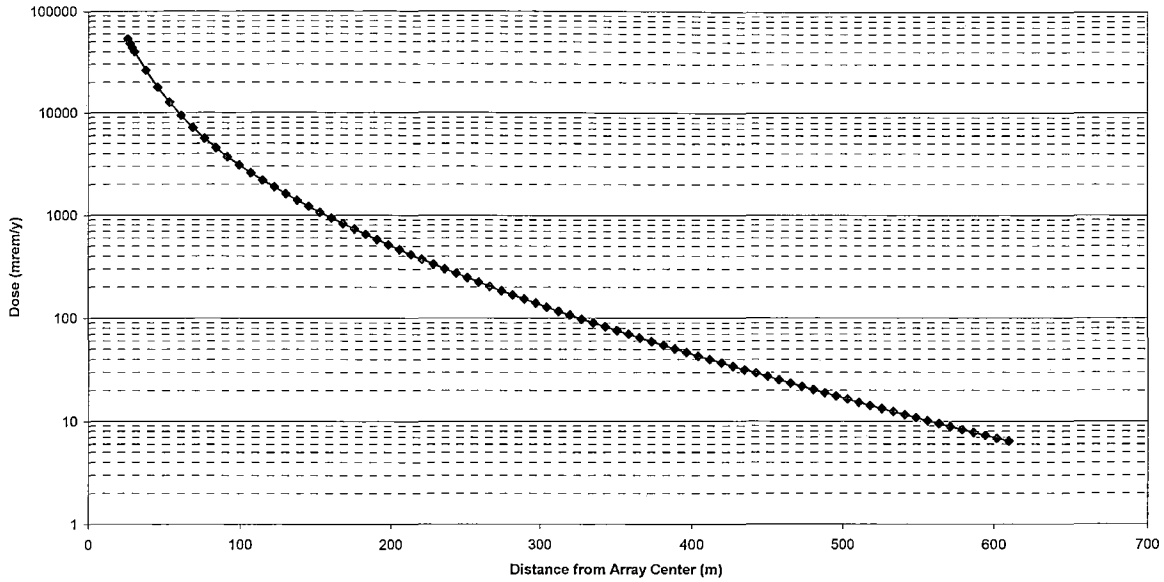


Figure 5.8.4-14 Exposures from a Single Concrete Cask - BWR



Distance (m)	Dose Rate (mrem/year) Radial Gamma	Radial Neutron	Axial Gamma	Axial Neutron	Total n-γ	Total
10	2.24E+04	3.98E+02	2.53E+02	5.98E+00	2.70E+02	2.33E+04
25	4.23E+03	8.13E+01	1.24E+02	3.37E+00	1.03E-01	4.44E+03
50	1.02E+03	2.23E+01	5.82E+01	1.72E+00	4.07E-03	1.10E+03
100	2.16E+02	5.64E+00	2.00E+01	6.28E-01	1.96E-03	2.42E+02
125	1.25E+02	3.49E+00	1.28E+01	4.08E-01	1.71E-03	1.42E+02
150	7.84E+01	2.30E+00	8.46E+00	2.74E-01	1.59E-03	8.95E+01
175	5.17E+01	1.58E+00	5.70E+00	1.88E-01	1.48E-03	5.92E+01
200	3.53E+01	1.12E+00	3.91E+00	1.32E-01	1.42E-03	4.05E+01
225	2.48E+01	8.18E-01	2.71E+00	9.39E-02	1.33E-03	2.85E+01
250	1.78E+01	6.07E-01	1.90E+00	6.79E-02	1.26E-03	2.04E+01
275	1.30E+01	4.58E-01	1.34E+00	4.98E-02	1.18E-03	1.49E+01
300	9.69E+00	3.51E-01	9.57E-01	3.69E-02	1.10E-03	1.10E+01

Figure 5.8.4-15 Exposures from a 2×10 Concrete Cask - BWR



Distance (m)	Dose Rate (mrem/year)					
	Radial Gamma	Radial Neutron	Axial Gamma	Axial Neutron	Total n-γ	Total
50	1.34E+04	2.83E+02	1.17E+03	3.46E+01	2.21E-01	1.49E+04
100	2.53E+03	6.59E+01	4.07E+02	1.28E+01	5.61E-02	3.01E+03
150	9.05E+02	2.66E+01	1.72E+02	5.58E+00	3.22E-02	1.11E+03
200	4.07E+02	1.30E+01	7.98E+01	2.68E+00	2.43E-02	5.02E+02
250	2.05E+02	7.02E+00	3.88E+01	1.38E+00	1.99E-02	2.52E+02
300	1.11E+02	4.06E+00	1.95E+01	7.50E-01	1.67E-02	1.36E+02
350	6.35E+01	2.46E+00	1.01E+01	4.25E-01	1.38E-02	7.64E+01
400	3.77E+01	1.55E+00	5.33E+00	2.50E-01	1.13E-02	4.48E+01
450	2.30E+01	9.98E-01	2.86E+00	1.51E-01	9.17E-03	2.71E+01
500	1.45E+01	6.60E-01	1.56E+00	9.36E-02	7.30E-03	1.68E+01
550	9.32E+00	4.45E-01	8.63E-01	5.92E-02	5.71E-03	1.07E+01
600	6.12E+00	3.05E-01	4.83E-01	3.81E-02	4.42E-03	6.95E+00

Figure 5.8.4-16 Contour of the Controlled Area Boundary for the BWR 2×10 Cask Array

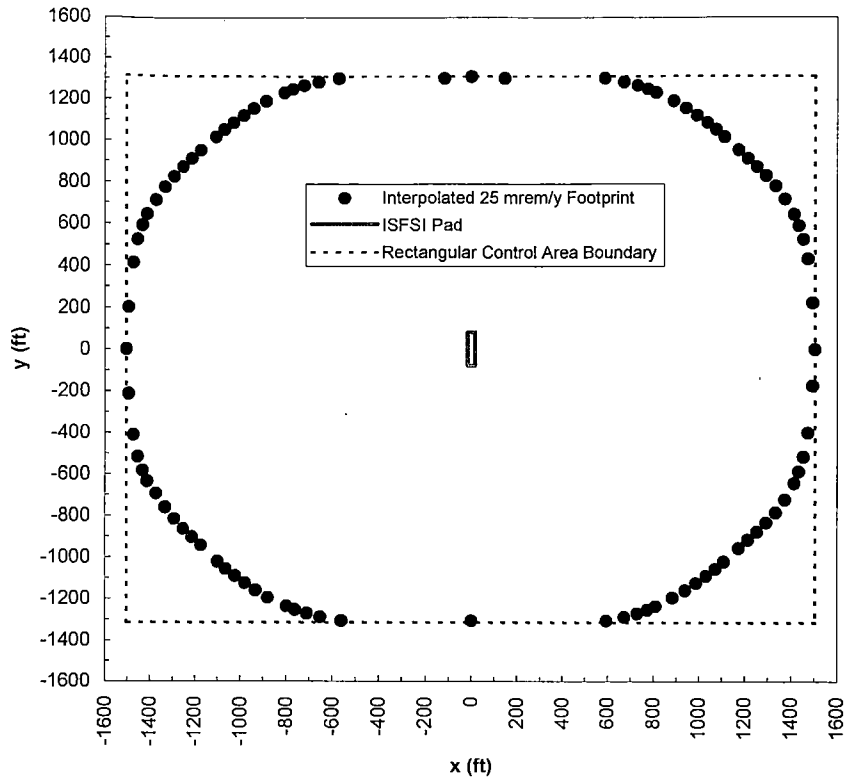


Table 5.8.4-1 BWR Fuel Region Homogenization Sample Calculation

Component	Area [cm²]	Area Fraction	Volume Fraction of Components		
			UO_2	Void	Clad
Fuel	5.6593E+01	2.8809E-01	2.8809E-01		
Gap	2.8033E+00	1.4271E-02		1.4271E-02	
Clad	1.8455E+01	9.3945E-02			9.3945E-02
Water Rods	4.6792E-01	2.3820E-03			2.3820E-03
Inside Water Rods	1.5024E+00	7.6484E-03		7.6484E-03	
Interstitial[a]	1.1662E+02	5.9366E-01		5.9366E-01	
Total	1.9644E+02	1.0000E+00	2.8809E-01	6.1558E-01	9.6327E-02

Table 5.8.4-2 BWR Nonfuel Hardware Homogenization Sample Calculation

Region	Assy Mass SS [kg/assy]	SS Volume [cm³/assy]	Modeled Dimensions		Volume Fraction
			Height [cm]	Volume [cm³/assy]	
Lower Nozzle	4.74	5.9698E+02	17.1704	3.3730E+03	1.7699E-01
Lower Plenum[b]	0.00	0.0000E+00	1.5875	3.1185E+02	0.0000E+00
Fuel Hardware	0.25	3.1033E+01	381.0000	7.4844E+04	4.1463E-04
Upper Plenum	1.71	2.1480E+02	28.6421	5.6265E+03	3.8177E-02
Upper Nozzle	2.08	2.6196E+02	19.0500	3.7422E+03	7.0003E-02

[a] Space in fuel assembly width envelope outside fuel rods and water rods(s).
[b] Represents fuel rod end-cap.

Table 5.8.4-3 Sample Fuel Region Homogenized Material Description (09b)

Material	Density [g/cm³]	Nuclide / Element	Density [atoms/b-cm]
Lower End-Fitting	1.3934	CHROMIUM	3.0662E-03
		MANGANESE	3.0548E-04
		IRON	1.0443E-02
		NICKEL	1.3582E-03
Lower Plenum	2.5369	CHROMIUM	2.9382E-05
		TIN	1.9304E-04
		IRON	3.4195E-05
		NITROGEN	5.4550E-05
		ZIRCONIUM	1.6450E-02
Active Fuel	3.5640	URANIUM-235	3.4157E-04
		URANIUM-238	6.4080E-03
		ZIRCONIUM	3.4959E-03
		CHROMIUM	6.2444E-06
		TIN	4.1026E-05
		NITROGEN	1.1593E-05
		OXYGEN	1.3496E-02
		IRON	7.2673E-06
Upper Plenum[a]	0.5758	CHROMIUM	1.0971E-03
		TIN	5.9100E-06
		MANGANESE	1.0920E-04
		IRON	3.7342E-03
		NITROGEN	1.6701E-06
		NICKEL	4.8554E-04
		ZIRCONIUM	5.0361E-04
Upper End-Fitting	0.5558	CHROMIUM	1.2230E-03
		MANGANESE	1.2185E-04
		IRON	4.1653E-03
		NICKEL	5.4175E-04

[a] Contains a zirconium alloy component due to the addition of the fuel rod end-plug material in the homogenization.

Table 5.8.4-4 Key BWR Basket Geometry Features

Feature	Material	Dimension
Tube	Carbon Steel	6.59 in outer width, 0.25 in thick 159.06/166.06 in long
Side Weldment	Carbon Steel	$^{5}/_{8}$ in thick 172.5/179.5 in long
Corner Weldment	Carbon Steel	$^{5}/_{16}$ in thick 172.5/179.5 in long
Bottom Spacer Pin	--	3.0 in long
Location of Drain/Vent Port	--	29.98 in radius

Table 5.8.4-5 09b Minimum Cool-time Solution, 45 GWd/MTU at 3.9 wt% ^{235}U

Cool Time	Heat Load (Watts)
5 yr	454.9
6 yr	401.1
Minimum Cool Time[a] (yr)	5.98
Rounded Limit (yr)	6.0
Heat Load at Limit	401.1

[a] Conservatively based on a linear interpolation of the exponential decay curve.

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	4.0	4.4	4.0	4.3	4.0	4.2	4.2
2.3 ≤ E < 2.5	4.0	4.3	4.0	4.2	4.0	4.2	4.1
2.5 ≤ E < 2.7	4.0	4.3	4.0	4.2	4.0	4.1	4.1
2.7 ≤ E < 2.9	4.0	4.2	4.0	4.1	4.0	4.1	4.0
2.9 ≤ E < 3.1	4.0	4.2	4.0	4.1	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.1	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.1	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.4	4.7	4.1	4.6	4.0	4.6	4.5
2.5 ≤ E < 2.7	4.3	4.6	4.0	4.5	4.0	4.5	4.4
2.7 ≤ E < 2.9	4.2	4.6	4.0	4.5	4.0	4.5	4.4
2.9 ≤ E < 3.1	4.2	4.5	4.0	4.4	4.0	4.4	4.3
3.1 ≤ E < 3.3	4.1	4.5	4.0	4.4	4.0	4.4	4.3
3.3 ≤ E < 3.5	4.1	4.4	4.0	4.3	4.0	4.3	4.2
3.5 ≤ E < 3.7	4.0	4.4	4.0	4.3	4.0	4.3	4.2
3.7 ≤ E < 3.9	4.0	4.3	4.0	4.3	4.0	4.2	4.1
3.9 ≤ E < 4.1	4.0	4.3	4.0	4.2	4.0	4.2	4.1
4.1 ≤ E < 4.3	4.0	4.3	4.0	4.2	4.0	4.1	4.1
4.3 ≤ E < 4.5	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.5 ≤ E < 4.7	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.7 ≤ E < 4.9	4.0	4.2	4.0	4.1	4.0	4.0	4.0
E ≥ 4.9	4.0	4.1	4.0	4.0	4.0	4.0	4.0

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.8	5.2	4.4	5.0	4.1	5.0	4.9
2.5 ≤ E < 2.7	4.7	5.1	4.4	4.9	4.0	4.9	4.8
2.7 ≤ E < 2.9	4.7	5.0	4.3	4.9	4.0	4.8	4.7
2.9 ≤ E < 3.1	4.6	5.0	4.2	4.8	4.0	4.8	4.7
3.1 ≤ E < 3.3	4.5	4.9	4.2	4.8	4.0	4.7	4.6
3.3 ≤ E < 3.5	4.5	4.8	4.1	4.7	4.0	4.7	4.6
3.5 ≤ E < 3.7	4.4	4.8	4.1	4.6	4.0	4.6	4.5
3.7 ≤ E < 3.9	4.4	4.7	4.0	4.6	4.0	4.6	4.5
3.9 ≤ E < 4.1	4.3	4.7	4.0	4.5	4.0	4.5	4.4
4.1 ≤ E < 4.3	4.3	4.6	4.0	4.5	4.0	4.5	4.4
4.3 ≤ E < 4.5	4.2	4.6	4.0	4.5	4.0	4.5	4.4
4.5 ≤ E < 4.7	4.2	4.6	4.0	4.5	4.0	4.4	4.3
4.7 ≤ E < 4.9	4.2	4.5	4.0	4.4	4.0	4.4	4.3
E ≥ 4.9	4.1	4.5	4.0	4.4	4.0	4.4	4.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.3	5.7	4.8	5.5	4.4	5.5	5.3
2.7 ≤ E < 2.9	5.2	5.6	4.7	5.4	4.3	5.4	5.2
2.9 ≤ E < 3.1	5.0	5.5	4.6	5.3	4.3	5.3	5.1
3.1 ≤ E < 3.3	5.0	5.4	4.6	5.3	4.2	5.2	5.0
3.3 ≤ E < 3.5	4.9	5.4	4.5	5.2	4.2	5.1	5.0
3.5 ≤ E < 3.7	4.9	5.3	4.5	5.1	4.1	5.0	4.9
3.7 ≤ E < 3.9	4.8	5.2	4.4	5.0	4.0	5.0	4.9
3.9 ≤ E < 4.1	4.7	5.2	4.4	5.0	4.0	5.0	4.8
4.1 ≤ E < 4.3	4.7	5.1	4.3	4.9	4.0	4.9	4.8
4.3 ≤ E < 4.5	4.6	5.0	4.3	4.9	4.0	4.9	4.8
4.5 ≤ E < 4.7	4.6	5.0	4.2	4.9	4.0	4.8	4.7
4.7 ≤ E < 4.9	4.6	5.0	4.2	4.8	4.0	4.8	4.7
E ≥ 4.9	4.5	4.9	4.2	4.8	4.0	4.7	4.6

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.5	5.9	5.0	5.7	4.5	5.7	5.5
2.7 ≤ E < 2.9	5.4	5.8	4.9	5.6	4.5	5.6	5.5
2.9 ≤ E < 3.1	5.3	5.7	4.8	5.6	4.4	5.5	5.4
3.1 ≤ E < 3.3	5.2	5.7	4.7	5.5	4.4	5.4	5.3
3.3 ≤ E < 3.5	5.1	5.6	4.7	5.4	4.3	5.4	5.2
3.5 ≤ E < 3.7	5.0	5.5	4.6	5.3	4.2	5.3	5.1
3.7 ≤ E < 3.9	5.0	5.5	4.5	5.3	4.2	5.2	5.0
3.9 ≤ E < 4.1	4.9	5.4	4.5	5.2	4.1	5.1	5.0
4.1 ≤ E < 4.3	4.9	5.3	4.5	5.1	4.1	5.1	5.0
4.3 ≤ E < 4.5	4.8	5.3	4.4	5.1	4.1	5.0	4.9
4.5 ≤ E < 4.7	4.8	5.2	4.4	5.0	4.0	5.0	4.9
4.7 ≤ E < 4.9	4.7	5.2	4.3	5.0	4.0	5.0	4.8
E ≥ 4.9	4.7	5.1	4.3	5.0	4.0	4.9	4.8

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.8	6.2	5.2	6.0	4.7	5.9	5.8
2.7 ≤ E < 2.9	5.7	6.1	5.1	5.9	4.6	5.8	5.7
2.9 ≤ E < 3.1	5.6	6.0	5.0	5.8	4.5	5.7	5.6
3.1 ≤ E < 3.3	5.5	5.9	4.9	5.7	4.5	5.7	5.5
3.3 ≤ E < 3.5	5.4	5.8	4.9	5.6	4.4	5.6	5.4
3.5 ≤ E < 3.7	5.3	5.8	4.8	5.6	4.4	5.5	5.3
3.7 ≤ E < 3.9	5.2	5.7	4.7	5.5	4.3	5.4	5.3
3.9 ≤ E < 4.1	5.1	5.6	4.7	5.4	4.3	5.4	5.2
4.1 ≤ E < 4.3	5.1	5.6	4.6	5.4	4.2	5.3	5.1
4.3 ≤ E < 4.5	5.0	5.5	4.6	5.3	4.2	5.3	5.1
4.5 ≤ E < 4.7	5.0	5.5	4.5	5.3	4.2	5.2	5.0
4.7 ≤ E < 4.9	4.9	5.4	4.5	5.2	4.1	5.1	5.0
E ≥ 4.9	4.9	5.4	4.4	5.2	4.1	5.1	5.0

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.0	6.5	5.4	6.2	4.9	6.2	6.0
2.7 ≤ E < 2.9	5.9	6.4	5.3	6.1	4.8	6.0	5.9
2.9 ≤ E < 3.1	5.8	6.3	5.2	6.0	4.7	5.9	5.8
3.1 ≤ E < 3.3	5.7	6.1	5.1	5.9	4.7	5.9	5.7
3.3 ≤ E < 3.5	5.6	6.0	5.0	5.9	4.6	5.8	5.6
3.5 ≤ E < 3.7	5.5	6.0	5.0	5.8	4.5	5.7	5.6
3.7 ≤ E < 3.9	5.5	5.9	4.9	5.7	4.5	5.7	5.5
3.9 ≤ E < 4.1	5.4	5.9	4.8	5.7	4.4	5.6	5.4
4.1 ≤ E < 4.3	5.3	5.8	4.8	5.6	4.4	5.5	5.4
4.3 ≤ E < 4.5	5.2	5.7	4.7	5.5	4.3	5.5	5.3
4.5 ≤ E < 4.7	5.2	5.7	4.7	5.5	4.3	5.4	5.3
4.7 ≤ E < 4.9	5.1	5.6	4.6	5.4	4.2	5.4	5.2
E ≥ 4.9	5.1	5.6	4.6	5.4	4.2	5.3	5.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.3	6.8	5.7	6.6	5.0	6.5	6.3
2.7 ≤ E < 2.9	6.2	6.7	5.6	6.4	5.0	6.3	6.1
2.9 ≤ E < 3.1	6.0	6.6	5.5	6.3	4.9	6.2	6.0
3.1 ≤ E < 3.3	6.0	6.5	5.4	6.2	4.8	6.1	5.9
3.3 ≤ E < 3.5	5.9	6.4	5.3	6.1	4.7	6.0	5.9
3.5 ≤ E < 3.7	5.8	6.3	5.2	6.0	4.7	5.9	5.8
3.7 ≤ E < 3.9	5.7	6.2	5.1	5.9	4.6	5.9	5.7
3.9 ≤ E < 4.1	5.6	6.1	5.0	5.9	4.6	5.8	5.7
4.1 ≤ E < 4.3	5.6	6.0	5.0	5.8	4.5	5.7	5.6
4.3 ≤ E < 4.5	5.5	5.9	4.9	5.8	4.5	5.7	5.5
4.5 ≤ E < 4.7	5.4	5.9	4.9	5.7	4.4	5.6	5.5
4.7 ≤ E < 4.9	5.4	5.9	4.8	5.7	4.4	5.6	5.4
E ≥ 4.9	5.3	5.8	4.8	5.6	4.3	5.5	5.4

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.5	7.0	5.8	6.8	5.2	6.7	6.4
2.9 ≤ E < 3.1	6.4	6.9	5.7	6.6	5.1	6.5	6.3
3.1 ≤ E < 3.3	6.3	6.8	5.6	6.5	5.0	6.4	6.2
3.3 ≤ E < 3.5	6.1	6.7	5.5	6.4	4.9	6.3	6.1
3.5 ≤ E < 3.7	6.0	6.6	5.4	6.3	4.9	6.2	6.0
3.7 ≤ E < 3.9	5.9	6.5	5.3	6.2	4.8	6.1	5.9
3.9 ≤ E < 4.1	5.9	6.4	5.3	6.1	4.7	6.0	5.9
4.1 ≤ E < 4.3	5.8	6.3	5.2	6.0	4.7	6.0	5.8
4.3 ≤ E < 4.5	5.7	6.2	5.1	6.0	4.6	5.9	5.8
4.5 ≤ E < 4.7	5.7	6.2	5.0	5.9	4.6	5.9	5.7
4.7 ≤ E < 4.9	5.6	6.1	5.0	5.9	4.5	5.8	5.6
E ≥ 4.9	5.6	6.0	4.9	5.8	4.5	5.8	5.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.9	7.5	6.0	7.0	5.4	7.0	6.8
2.9 ≤ E < 3.1	6.7	7.3	5.9	6.9	5.3	6.8	6.6
3.1 ≤ E < 3.3	6.6	7.1	5.8	6.8	5.2	6.7	6.5
3.3 ≤ E < 3.5	6.5	7.0	5.7	6.7	5.1	6.6	6.4
3.5 ≤ E < 3.7	6.4	6.9	5.6	6.6	5.0	6.5	6.3
3.7 ≤ E < 3.9	6.2	6.8	5.6	6.5	4.9	6.4	6.2
3.9 ≤ E < 4.1	6.1	6.7	5.5	6.4	4.9	6.3	6.1
4.1 ≤ E < 4.3	6.0	6.6	5.4	6.3	4.8	6.2	6.0
4.3 ≤ E < 4.5	6.0	6.5	5.3	6.2	4.8	6.1	6.0
4.5 ≤ E < 4.7	5.9	6.5	5.3	6.2	4.7	6.1	5.9
4.7 ≤ E < 4.9	5.8	6.4	5.2	6.1	4.7	6.0	5.9
E ≥ 4.9	5.8	6.3	5.1	6.0	4.6	6.0	5.8

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.2	7.9	6.3	7.5	5.6	7.4	7.0
2.9 ≤ E < 3.1	7.0	7.7	6.2	7.3	5.5	7.2	6.9
3.1 ≤ E < 3.3	6.9	7.5	6.0	7.1	5.4	7.0	6.8
3.3 ≤ E < 3.5	6.8	7.4	6.0	7.0	5.3	6.9	6.7
3.5 ≤ E < 3.7	6.7	7.2	5.9	6.9	5.2	6.8	6.6
3.7 ≤ E < 3.9	6.5	7.1	5.8	6.8	5.1	6.7	6.5
3.9 ≤ E < 4.1	6.5	7.0	5.7	6.7	5.1	6.6	6.4
4.1 ≤ E < 4.3	6.4	6.9	5.6	6.6	5.0	6.5	6.3
4.3 ≤ E < 4.5	6.2	6.8	5.6	6.5	4.9	6.5	6.2
4.5 ≤ E < 4.7	6.2	6.8	5.5	6.5	4.9	6.4	6.1
4.7 ≤ E < 4.9	6.1	6.7	5.4	6.4	4.8	6.3	6.0
E ≥ 4.9	6.0	6.6	5.4	6.3	4.8	6.2	6.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.7	8.3	6.7	7.9	5.8	7.8	7.5
2.9 ≤ E < 3.1	7.5	8.1	6.5	7.7	5.7	7.6	7.3
3.1 ≤ E < 3.3	7.3	8.0	6.4	7.6	5.6	7.4	7.1
3.3 ≤ E < 3.5	7.2	7.8	6.2	7.4	5.5	7.3	7.0
3.5 ≤ E < 3.7	7.0	7.7	6.1	7.3	5.5	7.2	6.9
3.7 ≤ E < 3.9	6.9	7.5	6.0	7.1	5.4	7.0	6.8
3.9 ≤ E < 4.1	6.8	7.4	5.9	7.0	5.3	6.9	6.7
4.1 ≤ E < 4.3	6.7	7.3	5.9	6.9	5.2	6.8	6.6
4.3 ≤ E < 4.5	6.6	7.2	5.8	6.8	5.1	6.8	6.5
4.5 ≤ E < 4.7	6.5	7.1	5.7	6.8	5.0	6.7	6.4
4.7 ≤ E < 4.9	6.4	7.0	5.7	6.7	5.0	6.6	6.4
E ≥ 4.9	6.3	6.9	5.6	6.6	4.9	6.5	6.3

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	8.1	8.9	7.0	8.3	6.0	8.2	7.9
2.9 ≤ E < 3.1	7.9	8.6	6.8	8.1	6.0	8.0	7.7
3.1 ≤ E < 3.3	7.7	8.4	6.7	7.9	5.9	7.8	7.5
3.3 ≤ E < 3.5	7.6	8.2	6.6	7.8	5.8	7.7	7.4
3.5 ≤ E < 3.7	7.4	8.1	6.4	7.7	5.7	7.5	7.2
3.7 ≤ E < 3.9	7.3	7.9	6.3	7.5	5.6	7.4	7.1
3.9 ≤ E < 4.1	7.1	7.8	6.2	7.4	5.5	7.3	7.0
4.1 ≤ E < 4.3	7.0	7.7	6.1	7.3	5.4	7.2	6.9
4.3 ≤ E < 4.5	6.9	7.6	6.0	7.2	5.3	7.1	6.8
4.5 ≤ E < 4.7	6.8	7.5	5.9	7.1	5.3	7.0	6.7
4.7 ≤ E < 4.9	6.7	7.4	5.9	7.0	5.2	6.9	6.7
E ≥ 4.9	6.7	7.3	5.8	6.9	5.1	6.8	6.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.4	9.2	7.1	8.6	6.2	8.5	8.1
3.1 ≤ E < 3.3	8.2	9.0	7.0	8.4	6.1	8.3	7.9
3.3 ≤ E < 3.5	8.0	8.8	6.9	8.2	6.0	8.1	7.8
3.5 ≤ E < 3.7	7.8	8.6	6.7	8.0	5.9	7.9	7.6
3.7 ≤ E < 3.9	7.7	8.4	6.6	7.9	5.8	7.8	7.5
3.9 ≤ E < 4.1	7.5	8.2	6.5	7.8	5.7	7.7	7.4
4.1 ≤ E < 4.3	7.4	8.1	6.4	7.7	5.6	7.6	7.2
4.3 ≤ E < 4.5	7.3	8.0	6.3	7.6	5.6	7.4	7.1
4.5 ≤ E < 4.7	7.2	7.9	6.2	7.5	5.5	7.3	7.0
4.7 ≤ E < 4.9	7.1	7.8	6.1	7.4	5.4	7.2	7.0
E ≥ 4.9	7.0	7.7	6.0	7.3	5.3	7.1	6.9

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.9	9.8	7.6	9.2	6.5	9.0	8.6
3.1 ≤ E < 3.3	8.7	9.6	7.4	8.9	6.4	8.8	8.4
3.3 ≤ E < 3.5	8.5	9.3	7.2	8.7	6.3	8.6	8.2
3.5 ≤ E < 3.7	8.3	9.1	7.0	8.5	6.1	8.4	8.0
3.7 ≤ E < 3.9	8.1	8.9	6.9	8.4	6.0	8.2	7.9
3.9 ≤ E < 4.1	8.0	8.7	6.8	8.2	5.9	8.0	7.7
4.1 ≤ E < 4.3	7.8	8.6	6.7	8.0	5.8	7.9	7.6
4.3 ≤ E < 4.5	7.7	8.4	6.6	8.0	5.8	7.8	7.5
4.5 ≤ E < 4.7	7.6	8.3	6.5	7.8	5.7	7.7	7.4
4.7 ≤ E < 4.9	7.5	8.2	6.4	7.7	5.6	7.6	7.3
E ≥ 4.9	7.4	8.1	6.3	7.6	5.6	7.5	7.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.5	10.5	8.0	9.8	6.8	9.6	9.1
3.1 ≤ E < 3.3	9.3	10.2	7.8	9.5	6.7	9.3	8.9
3.3 ≤ E < 3.5	9.0	9.9	7.6	9.3	6.5	9.0	8.6
3.5 ≤ E < 3.7	8.8	9.7	7.4	9.1	6.4	8.9	8.5
3.7 ≤ E < 3.9	8.6	9.5	7.3	8.9	6.3	8.7	8.3
3.9 ≤ E < 4.1	8.4	9.3	7.1	8.7	6.1	8.6	8.1
4.1 ≤ E < 4.3	8.3	9.1	7.0	8.5	6.0	8.4	8.0
4.3 ≤ E < 4.5	8.1	8.9	6.9	8.4	6.0	8.2	7.9
4.5 ≤ E < 4.7	8.0	8.8	6.8	8.3	5.9	8.1	7.8
4.7 ≤ E < 4.9	7.9	8.7	6.7	8.1	5.8	8.0	7.7
E ≥ 4.9	7.8	8.6	6.6	8.0	5.8	7.9	7.6

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.1	11.2	8.5	10.4	7.1	10.2	9.7
3.1 ≤ E < 3.3	9.9	10.9	8.2	10.1	7.0	9.9	9.4
3.3 ≤ E < 3.5	9.6	10.6	8.0	9.8	6.8	9.7	9.2
3.5 ≤ E < 3.7	9.4	10.4	7.8	9.6	6.7	9.4	9.0
3.7 ≤ E < 3.9	9.1	10.1	7.7	9.4	6.6	9.2	8.8
3.9 ≤ E < 4.1	9.0	9.9	7.5	9.2	6.5	9.0	8.6
4.1 ≤ E < 4.3	8.8	9.7	7.4	9.0	6.3	8.9	8.4
4.3 ≤ E < 4.5	8.6	9.6	7.3	8.9	6.2	8.7	8.3
4.5 ≤ E < 4.7	8.5	9.3	7.1	8.7	6.1	8.6	8.2
4.7 ≤ E < 4.9	8.4	9.2	7.0	8.6	6.0	8.5	8.0
E ≥ 4.9	8.2	9.1	6.9	8.5	6.0	8.4	8.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.9	12.0	9.0	11.2	7.5	11.0	10.3
3.1 ≤ E < 3.3	10.6	11.7	8.7	10.9	7.3	10.6	10.0
3.3 ≤ E < 3.5	10.3	11.3	8.5	10.5	7.1	10.3	9.8
3.5 ≤ E < 3.7	9.9	11.1	8.3	10.2	7.0	10.0	9.5
3.7 ≤ E < 3.9	9.7	10.8	8.1	10.0	6.9	9.9	9.3
3.9 ≤ E < 4.1	9.5	10.5	7.9	9.8	6.7	9.6	9.1
4.1 ≤ E < 4.3	9.3	10.3	7.8	9.6	6.6	9.4	8.9
4.3 ≤ E < 4.5	9.1	10.1	7.7	9.4	6.5	9.2	8.8
4.5 ≤ E < 4.7	9.0	9.9	7.5	9.3	6.4	9.1	8.6
4.7 ≤ E < 4.9	8.8	9.8	7.4	9.1	6.3	8.9	8.5
E ≥ 4.9	8.7	9.6	7.3	9.0	6.2	8.8	8.4

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.3	12.4	9.2	11.5	7.7	11.3	10.7
3.3 ≤ E < 3.5	11.0	12.1	9.0	11.3	7.5	11.1	10.4
3.5 ≤ E < 3.7	10.7	11.8	8.8	10.9	7.4	10.7	10.1
3.7 ≤ E < 3.9	10.4	11.5	8.6	10.7	7.2	10.5	9.8
3.9 ≤ E < 4.1	10.2	11.3	8.4	10.5	7.0	10.2	9.7
4.1 ≤ E < 4.3	9.9	11.1	8.2	10.2	6.9	10.0	9.4
4.3 ≤ E < 4.5	9.8	10.8	8.1	10.0	6.8	9.9	9.3
4.5 ≤ E < 4.7	9.5	10.6	7.9	9.9	6.7	9.7	9.1
4.7 ≤ E < 4.9	9.4	10.4	7.8	9.6	6.6	9.5	8.9
E ≥ 4.9	9.2	10.2	7.7	9.5	6.5	9.3	8.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.0	13.3	9.8	12.3	8.1	12.0	11.4
3.3 ≤ E < 3.5	11.6	12.9	9.6	11.9	7.9	11.7	11.1
3.5 ≤ E < 3.7	11.3	12.6	9.3	11.6	7.7	11.4	10.8
3.7 ≤ E < 3.9	11.0	12.2	9.1	11.4	7.5	11.2	10.5
3.9 ≤ E < 4.1	10.8	11.9	8.9	11.2	7.4	10.9	10.2
4.1 ≤ E < 4.3	10.5	11.7	8.7	10.9	7.3	10.7	10.0
4.3 ≤ E < 4.5	10.3	11.5	8.5	10.7	7.1	10.5	9.9
4.5 ≤ E < 4.7	10.0	11.3	8.3	10.5	7.0	10.2	9.7
4.7 ≤ E < 4.9	9.9	11.1	8.2	10.3	6.9	10.0	9.5
E ≥ 4.9	9.8	10.9	8.0	10.0	6.8	9.9	9.4

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.7	14.1	10.5	13.1	8.6	12.8	12.0
3.3 ≤ E < 3.5	12.4	13.7	10.1	12.8	8.3	12.5	11.8
3.5 ≤ E < 3.7	12.0	13.4	9.9	12.4	8.1	12.1	11.5
3.7 ≤ E < 3.9	11.7	13.1	9.6	12.1	7.9	11.9	11.2
3.9 ≤ E < 4.1	11.5	12.8	9.4	11.8	7.8	11.6	10.9
4.1 ≤ E < 4.3	11.2	12.5	9.2	11.5	7.6	11.3	10.7
4.3 ≤ E < 4.5	11.0	12.3	9.0	11.4	7.5	11.1	10.5
4.5 ≤ E < 4.7	10.8	12.0	8.8	11.1	7.3	10.9	10.2
4.7 ≤ E < 4.9	10.5	11.8	8.7	11.0	7.2	10.8	10.0
E ≥ 4.9	10.4	11.6	8.5	10.8	7.1	10.6	9.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	13.6	15.0	11.2	13.9	9.1	13.7	12.9
3.3 ≤ E < 3.5	13.2	14.7	10.9	13.6	8.8	13.3	12.5
3.5 ≤ E < 3.7	12.8	14.2	10.6	13.2	8.6	13.0	12.2
3.7 ≤ E < 3.9	12.5	13.9	10.2	12.9	8.3	12.6	11.8
3.9 ≤ E < 4.1	12.2	13.6	9.9	12.6	8.1	12.4	11.6
4.1 ≤ E < 4.3	11.9	13.3	9.7	12.3	8.0	12.0	11.4
4.3 ≤ E < 4.5	11.7	13.0	9.5	12.0	7.8	11.8	11.2
4.5 ≤ E < 4.7	11.5	12.8	9.3	11.8	7.7	11.6	10.9
4.7 ≤ E < 4.9	11.2	12.6	9.2	11.6	7.6	11.4	10.7
E ≥ 4.9	11.0	12.3	9.0	11.4	7.4	11.2	10.5

Table 5.8.4-6 Loading Table for BWR Fuel – 402 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	14.4	15.9	11.9	14.8	9.6	14.6	13.7
3.3 ≤ E < 3.5	14.0	15.6	11.6	14.4	9.3	14.1	13.3
3.5 ≤ E < 3.7	13.6	15.1	11.2	14.0	9.0	13.7	13.0
3.7 ≤ E < 3.9	13.3	14.7	11.0	13.7	8.8	13.4	12.6
3.9 ≤ E < 4.1	13.0	14.4	10.6	13.3	8.6	13.1	12.3
4.1 ≤ E < 4.3	12.7	14.2	10.3	13.1	8.4	12.9	12.0
4.3 ≤ E < 4.5	12.4	13.8	10.1	12.8	8.2	12.6	11.8
4.5 ≤ E < 4.7	12.1	13.6	9.9	12.5	8.0	12.3	11.6
4.7 ≤ E < 4.9	11.9	13.4	9.7	12.3	7.9	12.1	11.4
E ≥ 4.9	11.7	13.2	9.5	12.1	7.8	11.9	11.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)**						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	14.9	16.4	12.1	15.3	9.8	15.0	14.1
3.5 ≤ E < 3.7	14.5	16.0	11.8	14.9	9.6	14.7	13.8
3.7 ≤ E < 3.9	14.1	15.6	11.5	14.5	9.3	14.2	13.5
3.9 ≤ E < 4.1	13.8	15.4	11.2	14.2	9.0	13.9	13.1
4.1 ≤ E < 4.3	13.4	15.0	10.9	13.8	8.9	13.6	12.8
4.3 ≤ E < 4.5	13.2	14.7	10.7	13.6	8.7	13.3	12.5
4.5 ≤ E < 4.7	12.9	14.4	10.4	13.3	8.5	13.1	12.2
4.7 ≤ E < 4.9	12.6	14.1	10.2	13.1	8.3	12.8	12.0
E ≥ 4.9	12.4	13.9	10.0	12.9	8.2	12.6	11.8

Table 5.8.4-7 Maximum Transfer Cask Radial, Top, and Bottom Surface Dose Rates

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	09a	9.6	59	3.1	1,504	895
Top	08b	4.3	32.5	2.1	676	250
Bottom	09a	5.0	44	2.5	4,836	2,643

Table 5.8.4-8 Maximum Concrete Cask Dose Rates

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	09a	4.0	37.5	2.5	77	53
Top	08b	4.3	32.5	2.1	430	104
Air Inlet	09a	5.0	44	2.5	364	--
Air Outlet	08b	4.3	32.5	2.1	59	--

Table 5.8.4-9 BWR Bounding Surface Current Input Data[a]

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Cask Surface Neutron Source (n/sec)	Cask Surface Gamma Source (γ/sec)
Radial	09a	4.0	40	2.5	3.885E+07	2.434E+10
Top	08b	4.6	37.5	2.3	1.750E+07	1.511E+10

Table 5.8.4-10 Rectangular Controlled Area Boundary for the 2×10 BWR Cask Array

Direction Basis	Distance From the Center of the Array [ft]	Distance from the Center of the Array [m]
x direction (Perpendicular to Long Side of the Array)	1504	458
y direction (Perpendicular to the Short Side of the Array)	1315	401

[a] Based on 38 kW heat load.

5.8.5 PWR Nonfuel Hardware Components - BPRA and Thimble Plug

The PWR fuel assembly basket is designed to store nonfuel components inside the fuel assembly. Nonfuel components that may be stored include the following:

- BPRAs (Burnable Poison Rod Assemblies)

  Burnable poison rods are employed in the majority of PWR cores as either replacement rods for fuel rods, typical of CE cores, or as BPRAs in Westinghouse and B&W cores. Common types of BPRAs are Westinghouse Pyrex BPRAs, Westinghouse WABA, and B&W/Framatome Al_2O_3-B_4C zirconium alloy rods. BPRAs are composed of a set of rods made from an absorber material suspended from a spider structure located on the top-end fitting of the assembly. BPRAs are designed to reduce reactivity in fresh fuel, but may remain in a fuel assembly for more than one cycle. Potential BPRA source regions are the top-end fitting, top plenum, and active fuel regions. The amount of activated material depends on the number of absorber (poison) rods attached to the BPRA and the material of the BPRA. Guide tube locations not occupied by absorber rods are typically occupied by short plug rods extending into the upper plenum region of the assembly. BPRA rods may be composed of activated material such as steel or a relatively inert material such as zirconium alloy. Table 5.8.5-1 provides a summary of Westinghouse 15×15 core BPRA types and the maximum regional masses chosen for the analysis. BPRAs for the remaining Westinghouse and B&W cores are treated similarly. A summary of BPRA characteristics for fuel placed into the transfer and storage systems is listed in Table 5.8.5-2. Poison rods replacing fuel rods are enveloped in the shielding analysis since they are typically constructed with a zirconium alloy clad and do not contain a significant amount of activated material, in particular compared to the fuel rod that they replace.

- Thimble Plugs

  Thimble plugs are similar to BPRAs in that they are attached to a spider resting on the end-fitting tie plate. Thimble plugs extend into the upper plenum region of the fuel assembly and block flow through the guide tubes during in-core operations. Thimble plug components do not extend into the active fuel region. They may be reused in multiple cycles and can experience significantly higher burnup than BPRAs. Thimble plug masses evaluated for each core are shown in Table 5.8.5-2.

5.8.5.1 Modeling Detail

Dose rates for BPRA and thimble plug components are estimated using fuel assembly response functions for the hardware source regions of interest. Credit is taken for the increased region masses and the associated increase in self-shielding. The BPRA and thimble plug activated hardware is primarily composed of stainless steel. A 0.8 g/kg ^{59}Co impurity is applied against this material. Full cask loads containing up to 37 nonfuel hardware components (i.e., one in each assembly) are evaluated and allowed for storage. There are no restrictions on the number of components per TSC, location of component within the TSC, or mixture of BPRA and thimble plug components with other nonfuel hardware within a TSC.

5.8.5.2 Dose Rate and Heat Load Impact

To minimize impact of off-site boundary and occupational dose evaluations, the maximum dose rate contribution of the nonfuel assembly hardware on the radial surface of the concrete cask is limited to 7.5 mrem/hr. This limit is reduced for the B&W BPRAs that do not contain activated hardware in the active fuel region. BPRAs are evaluated to a maximum burnup of 70 GWd/MTU, with thimble plug burnup being limited to an equivalent 180 GWd/MTU. The BPRAs and thimble plugs for each core configuration are independently evaluated.

5.8.5.2.1 BPRA

Table 5.8.5-3 lists the allowed BPRA loading configurations expressed in burnup and cool-time limits or curie limits. The radiation source for the BPRAs is dominated by ^{60}Co gammas. Therefore, the spectrum of the activated BPRAs is not decay time sensitive. As a result of the dominant ^{60}Co contribution, the burnup/cool-time loading table reflects the cool-time increase required to decay to a limiting ^{60}Co curie content for each assembly type at each burnup level. System users may choose to directly implement the burnup/cool-time tables on a generic fuel type basis or to determine site-specific minimum BPRA cool times based on the ^{60}Co curie limit in Table 5.8.5-3.

Maximum and average dose rate contributions from BPRAs on the concrete and transfer cask surfaces are listed in Table 5.8.5-4. The BPRA radial profile from the cask configuration and fuel assembly which produces maximum radial dose rates (CC4 with Westinghouse 14 × 14 assembly) is shown in Figure 5.8.5-1. The addition of the BPRA increases the maximum reported dose rates, as demonstrated in Figure 5.8.5-2 for a Westinghouse 14×14 assembly.

The maximum decay heat produced by a full cask load of BPRAs (37) is 0.44 kW. For any of the fuel assemblies evaluated, an increase in cool time, shown in Table 5.8.5-7, is necessary to accommodate loading the BPRAs. An increase in cool time will also decrease the fuel source

term. Therefore, the strict application of increased fuel assembly minimum cool time without considering the corresponding reduction in fuel dose rates is conservative.

5.8.5.2.2 Thimble Plugs

Table 5.8.5-5 lists the allowed thimble plug loading configurations expressed in burnup and cool-time limits or curie limits. The radiation source for the thimble plugs is dominated by ^{60}Co gammas. Therefore, the spectrum of the activated thimble plugs is not decay time sensitive. As a result of the dominant ^{60}Co contribution, the burnup/cool-time loading table reflects the cool time increase required to decay to a limiting ^{60}Co curie content for each assembly type at each burnup level. System users may choose to directly implement the burnup/cool-time tables on a generic fuel type basis or to determine site-specific minimum thimble plug cool times based on the ^{60}Co curie limit in Table 5.8.5-5.

Maximum and average dose rate contributions from thimble plugs on the concrete and transfer cask surfaces are listed in Table 5.8.5-6. The concrete cask axial profile for the thimble plugs is shown in Figure 5.8.5-3. The addition of the thimble plugs does not increase the maximum reported dose rates, as demonstrated in Figure 5.8.5-4 for a Westinghouse 14×14 assembly.

The maximum decay heat produced by a full cask load of thimble plugs (37) is 0.04 kW. For any of the fuel assemblies evaluated, an increase in cool time, shown in Table 5.8.5-7, is necessary to accommodate loading the thimble plugs. An increase in cool time will also decrease the fuel source term. Therefore, the strict application of increased fuel assembly minimum cool time without considering the corresponding reduction in fuel dose rates is conservative.

5.8.5.2.3 Combination of Fuel, BPRA, and Thimble Plug Dose Rates

Maximum PWR system dose rates are reported for the conservative combination of fuel, BPRA, and thimble plug dose rates. At each cask/detector surface combination, with the exception of the concrete and transfer cask sides, this combination is straightforward based on the hardware sources being the dominant contributor to the total. On the sides of the casks, the fuel sources comprise most of the total, and the elevation of the maximum dose rate due to fuel, BPRA, and thimble plug may not coincide. As shown in the previous sections, BPRA loading affects the maximum dose rate while thimble plugs do not.

The combined maxima are listed as follows.

Cask / Dose Location	Fuel		Combined	
	Assembly	Max. Dose Rate (mrem/hr)	Assembly	Max. Dose Rate (mrem/hr)
Standard Shield Concrete Cask Top	CE 16×16	378	CE 16×16	378
Standard Shield Concrete Cask Radial	CE 14×14	76.7	WE 14×14	79.3
Standard Shield Concrete Cask Inlet	WE 14×14	425	WE 14×14	434
Standard Shield Concrete Cask Outlet	CE 16×16	38.3	CE 16×16	38.3
Carbon Steel Transfer Cask Top	WE 14×14	451	WE 14×14	546
Carbon Steel Transfer Cask Radial	CE 14×14	939	WE 14×14	942
Carbon Steel Transfer Cask Bottom	WE 14×14	5,824	WE 14×14	5,908
Augmented Shield Concrete Cask Top	WE 14×14	350	WE 14×14	408
Augmented Shield Concrete Cask Radial	CE 14×14	36.5	WE 14×14	37.1
Augmented Shield Concrete Cask Inlet	WE 14x14	117	WE 14×14	119
Augmented Shield Concrete Cask Outlet	B&W 17×17	21.8	WE 14×14	26.2
Stainless Steel Transfer Cask Top	B&W 17×17	505	WE 14×14	568
Stainless Steel Transfer Cask Radial	CE 14×14	922	WE 14×14	945
Stainless Steel Transfer Cask Bottom	WE 14×14	5,239	WE 14×14	5,326
CC4 Top	WE 14×14	316	WE 14×14	365
CC4 Radial	CE 14×14	76.8	WE 14×14	79.5
CC4 Inlet	WE 14×14	112.4	WE 14×14	115
CC4 Outlet	B&W 17×17	36.8	B&W 17×17	42.8

Figure 5.8.5-1 BPRA Concrete Cask Axial Dose Profile (CC4)

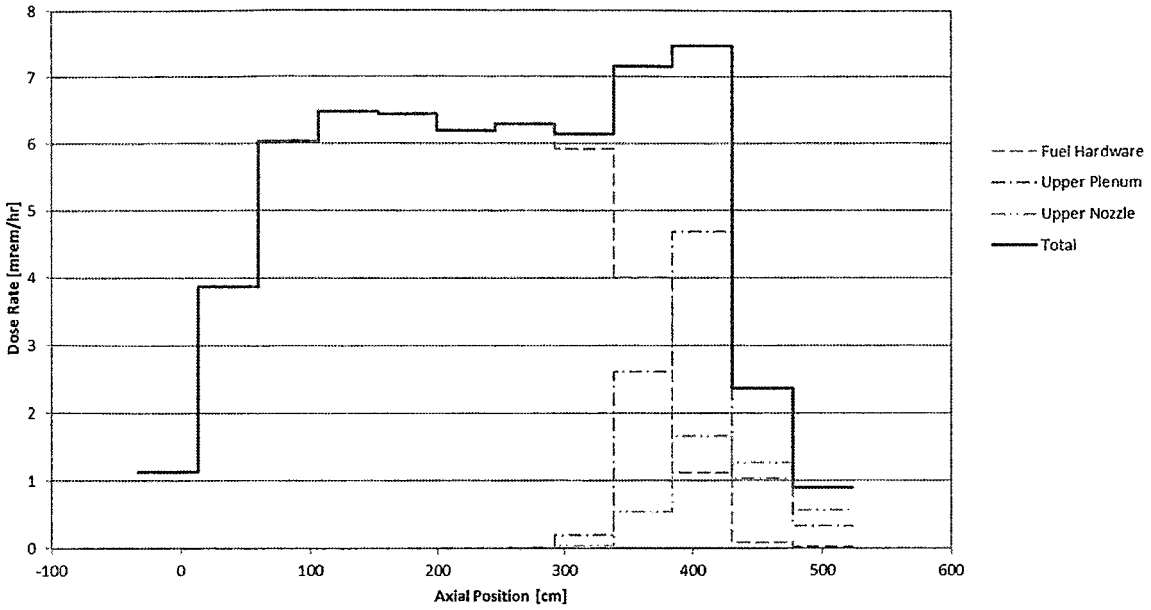


Figure 5.8.5-2 Combined Fuel Assembly and BPRA Concrete Cask Axial Dose Profile (CC4)

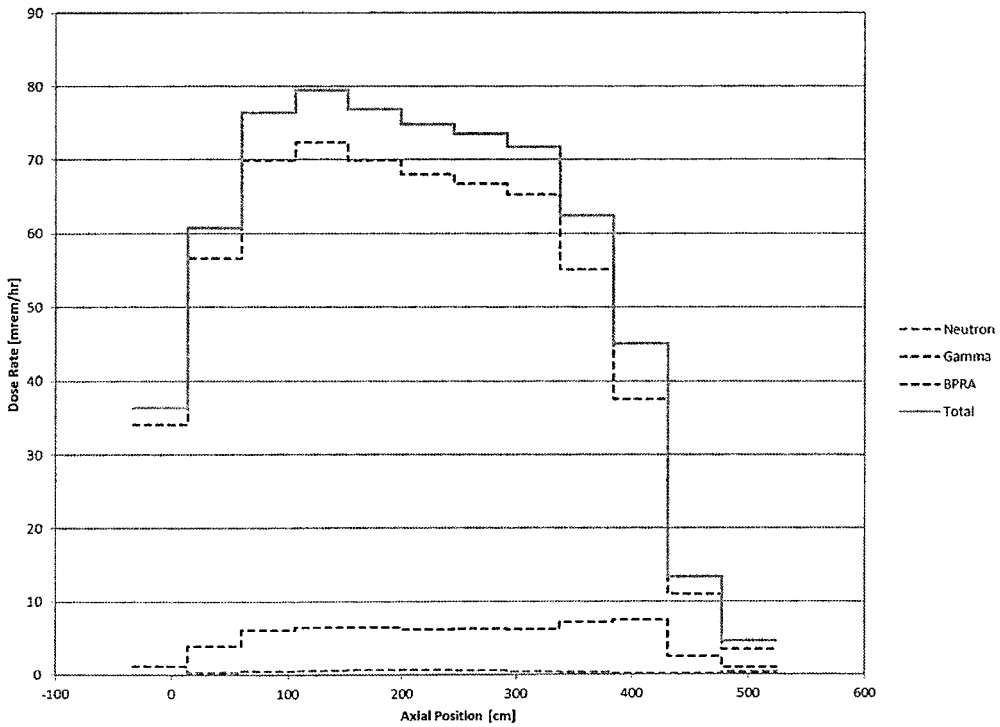


Figure 5.8.5-3 Thimble Plug Concrete Cask Side Dose Profile (CC4)

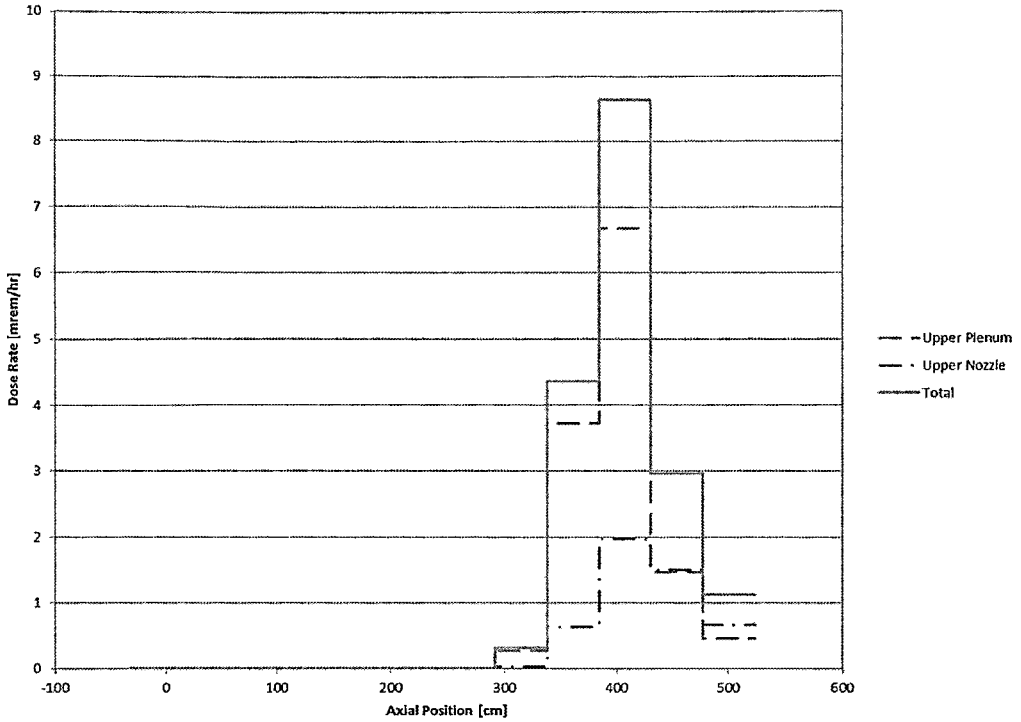


Figure 5.8.5-4 Combined Fuel Assembly & Thimble Plug Cask Axial Dose Profile (CC4)

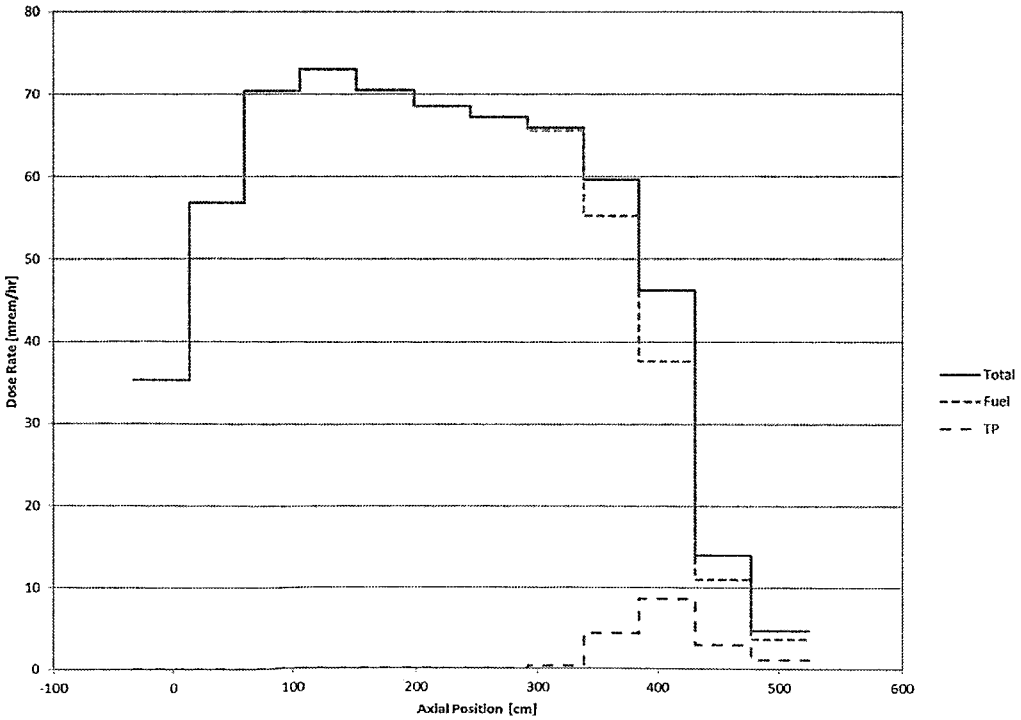


Table 5.8.5-1 Sample Core Type BPRA Hardware Summary – Westinghouse 15×15 Core

Absorber Type	Regional Stainless Steel/Inconel Mass (kg)		
	Upper End-Fitting	Upper Plenum	Active Fuel
Pyrex (4 rods)	2.14	1.78	2.28
Pyrex (5 rods)	2.16	1.68	2.85
Pyrex (6 rods)	2.18	1.58	3.42
Pyrex (13 rods)	2.33	0.88	7.48
Pyrex (16 rods)	2.39	0.58	9.11
Pyrex (20 rods)	2.47	0.18	11.39
WABA (4 rods)	2.23	2.18	0.00
WABA (6 rods)	2.24	1.91	0.00
WABA (8 rods)	2.26	1.63	0.00
WABA (12 rods)	2.30	1.09	0.00
WABA (16 rods)	2.33	0.54	0.00
Maximum	2.47	2.18	11.39

Table 5.8.5-2 Bounding Regional Nonfuel Hardware Masses

Assembly	Component	Regional Mass (kg)		
		Upper Nozzle	Upper Plenum	Active Fuel
Westinghouse 14×14	Thimble Plug	2.12	2.18	0
	BPRA	2.41	2.07	9.22
Westinghouse 15×15	Thimble Plug	2.19	2.72	0
	BPRA	2.47	2.18	11.39
Westinghouse 17×17	Thimble Plug	2.73	3.16	0
	BPRA	3.04	2.85	10.995
B&W 15×15	Thimble Plug	3.641	3.41	0
	BPRA	3.602	0	0
B&W 17×17	Thimble Plug	3.641	3.41	0
	BPRA	3.602	0	0

Table 5.8.5-3 Allowed BPRA Burnup and Cool-time Combinations

Burnup (GWd/MTU)	Cool Time (yrs)				
	WE 14×14	WE 15×15	B&W 15×15	WE 17×17	B&W 17×17
10	0.5	0.5	0.5	0.5	0.5
15	0.5	0.5	0.5	0.5	0.5
20	0.5	1.0	2.0	2.0	0.5
25	1.0	2.5	3.5	3.5	1.0
30	2.5	4.0	5.0	5.0	2.5
32.5	3.0	4.5	6.0	6.0	3.0
35	3.5	5.0	6.0	6.0	3.5
37.5	4.0	6.0	7.0	7.0	4.0
40	4.5	6.0	7.0	7.0	4.5
45	5.0	7.0	8.0	8.0	6.0
50	6.0	8.0	9.0	9.0	7.0
55	7.0	8.0	10.0	9.0	7.0
60	7.0	9.0	10.0	10.0	8.0
65	8.0	10.0	12.0	12.0	8.0
70	8.0	10.0	12.0	12.0	9.0
^{60}Co Activity (Ci)	718	733	19	637	26

Table 5.8.5-4 BPRA Dose Rate Contributions – Westinghouse 14×14

Cask / Dose Location	Maximum Dose (mrem/hr)	Average Dose (mrem/hr)
Standard Shield Concrete Cask Top	39	9.6
Standard Shield Concrete Cask Radial	7.8	4.9
Standard Shield Concrete Cask Inlet	8.7	--
Standard Shield Concrete Cask Outlet	2.8	--
Carbon Steel Transfer Cask Top	77	23
Carbon Steel Transfer Cask Radial	118	57
Carbon Steel Transfer Cask Bottom	86	47
Augmented Shield Concrete Cask Top	52	8.8
Augmented Shield Concrete Cask Radial	3.4	2.3
Augmented Shield Concrete Cask Inlet	2.2	--
Augmented Shield Concrete Cask Outlet	3.3	--
Stainless Steel Transfer Cask Top	83	31
Stainless Steel Transfer Cask Radial	121	57
Stainless Steel Transfer Cask Bottom	86	44
CC4 Top	44.8	9.5
CC4 Radial	7.5	5.0
CC4 Inlet	2.6	--
CC4 Outlet	6.0	--

Table 5.8.5-5 Allowed Thimble Plug Burnup and Cool-time Combinations

Burnup (GWd/MTU)	Cool Time (yrs)				
	WE 14×14	WE 15×15	B&W 15×15	WE 17×17	B&W 17×17
45	2.0	3.5	7.0	5.0	6.0
90	6.0	7.0	10.0	9.0	10.0
135	7.0	9.0	12.0	10.0	12.0
180	8.0	9.0	14.0	12.0	12.0
^{60}Co Activity (Ci)	63.5	64.1	56.9	64.0	63.6

Table 5.8.5-6 Thimble Plug Dose Rate Contributions – Westinghouse 14×14

Cask / Dose Location	Maximum Dose (mrem/hr)	Average Dose (mrem/hr)
Standard Shield Concrete Cask Top	42	11
Standard Shield Concrete Cask Radial	7.3	1.4
Standard Shield Concrete Cask Outlet	3.4	--
Carbon Steel Transfer Cask Top	95	28
Carbon Steel Transfer Cask Radial	152	16
Augmented Shield Concrete Cask Top	57	9.9
Augmented Shield Concrete Cask Radial	4.0	0.7
Augmented Shield Concrete Cask Outlet	4.1	--
Stainless Steel Transfer Cask Top	102	38
Stainless Steel Transfer Cask Radial	154	16
CC4 Top	48.9	10.8
CC4 Radial	8.6	10.8
CC4 Outlet	7.3	--

Table 5.8.5-7 Additional Assembly Cool Time (Years) Required to Load BPRA or TP (Uniform Loading)

	BPRA	TP
CE 14x14[a]	--	--
WE 14x14	0.5	0.1
WE 15x15	0.5	0.1
B&W 15x15	0.1	0.1
CE 16x16[a]	--	--
WE 17x17	0.5	0.1
B&W 17x17	0.1	0.1

[a] BPRAs and TPs are not evaluated for CE fuel.

5.8.6 Nonfuel Hardware Component – Reactor Control Elements

Reactor control element (e.g., CEAs and RCCAs) material quantities and the core region in which the material was exposed to the neutron activation flux were obtained from the DOE characteristics database [30]. Bounding mass quantities activated in the assembly top and gas plenum regions are listed in Table 5.8.6-1 for the seven analyzed assembly configurations. Similar to the fuel assembly hardware evaluation, the plenum material is activated at a 0.2 flux factor, with top material activation at a 0.1 flux factor (0.05 for the CE 16×16 fuel). Material above the top is not considered to be activated to a significant extent and is, therefore, not modeled. In the shielding evaluation, the source material activated in the plenum region of the fuel assembly is located at the bottom of the active fuel region. This is the result of the full insertion of the CEA into the assembly under storage conditions. The CEA material classified as that in the top assembly region is modeled directly above the active fuel region. To minimize the increased dose due to loading of CEAs, only the center nine basket locations are allowed to contain the added source.

CEA response functions are evaluated in groups 11 through 15 based on the significant energy lines of the Ag-In-Cd, inconel, and stainless steel light element spectra. CEAs may also contain hafnium as the primary absorber nuclide. As seen in table 5.8.6-3, the source for hafnium components of the absorber is not significant when compared to the source of steel/inconel or Ag-In-Cd based absorbers. The minimum cool time for CEAs is set uniformly at 10 years, with a maximum exposure of 180 GWd/MTU to assess dose effects on the system.

Maximum CEA dose rates are calculated for the Westinghouse 17×17 bounding CEA description due to the significant amount of Ag-In-Cd and steel/inconel activated in the assembly upper plenum region. Results are shown in Table 5.8.6-2. On the sides of the concrete and transfer casks, the additive dose rate does not affect the maximum dose rates. At the concrete cask inlets and transfer cask bottom, loading of CEAs significantly increases the maximum dose rates.

The maximum decay heat produced by a loading of nine CEAs is 0.62 kW. For any of the fuel assemblies evaluated, an increase in cool time, shown in Table 5.8.6-6, is necessary to accommodate loading a CEA. As an increase in cool time will also decrease the fuel source term, the strict application of increased cool time without a recalculation of fuel dose rates is conservative.

The cask system is evaluated for higher CEA burnup/exposure than the 180,000 MWd/MTU, 10-year-cooled case used to establish baseline dose rate effects. The effects of higher burnup/exposure on steel/inconel absorber and the steel hardware of other absorbers is evaluated by reviewing the source spectrum in Table 5.8.6-3 that demonstrates that the overwhelming majority of the source is in energy groups 12 and 13, which correspond to the ^{60}Co energy lines.

Figure 5.8.6-1 is then used to compare the source strength in groups 12 and 13 with higher exposures at a cool time of 12 years. The figure demonstrates that the increase in cool time is enough to reduce the source to less than the 180 GWd/MTU and 10-year-cooled source. A similar comparison is made in Figure 5.8.6-2 for group 15 of the Ag-In-Cd absorber. Group 15 was chosen for the comparison as it represents the group producing maximum energy and source magnitude. As shown in Figure 5.8.6-2, due to the longer half life of the isotopes producing these gamma rays, additional cool time is required. The complete source spectrum is, therefore, used to determine dose rate effects on the system with minimum cool times of 14 and 20 years for maximum exposures of 270 and 360 GWd/MTU, respectively. As shown in Table 5.8.6-4, these exposure/cool time combinations are bounded by the baseline 180,000 MWd/MTU, 10-year cool time state point.

Table 5.8.6-5 lists the exposure cool time combinations applicable to all CEA types.

Figure 5.8.6-1 CEA Stainless Steel/Inconel Spectrum Comparison

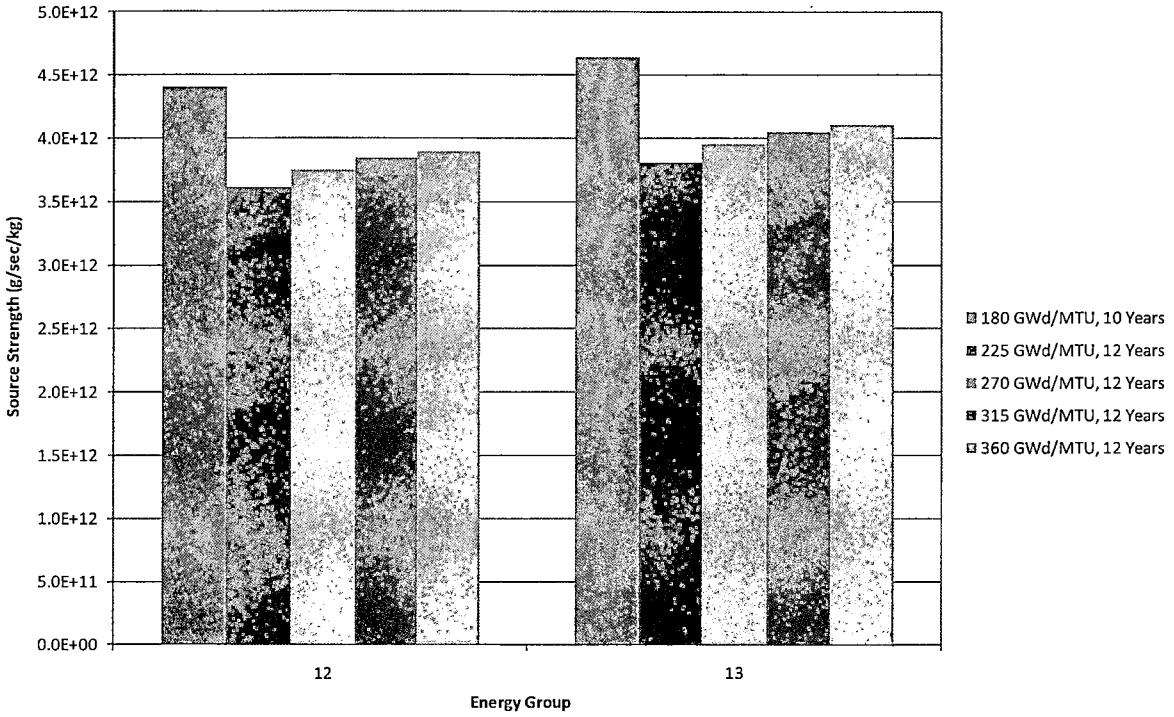


Figure 5.8.6-2 CEA Ag-In-Cd Spectrum Comparison

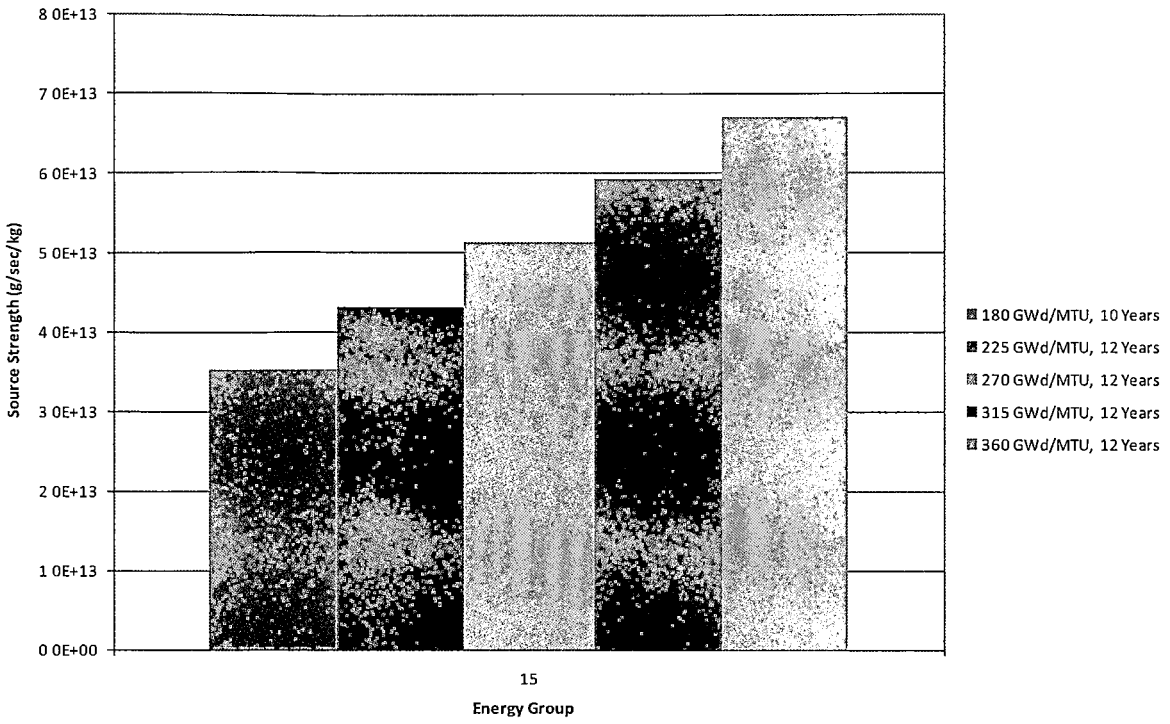


Table 5.8.6-1 Bounding CEA Descriptions

Material	Neutron Zone	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
Steel/Inconel	Top	2.495	10.39	0.88	0.488	2.857	14.87	0.488
Ag-In-Cd	Top	0	0	0	1.581	1.089	0	1.581
Steel/Inconel	Gas Plenum	2.495	12.4	16.30	0.488	2.857	23.60	0.488
Ag-In-Cd	Gas Plenum	2.767	45.4	58.70	1.581	2.812	51.80	1.581

Table 5.8.6-2 CEA Dose Rate Contributions – Westinghouse 17×17

Cask / Dose Location	Maximum Dose (mrem/hr)	Average Dose (mrem/hr)
Standard Shield Concrete Cask Radial	3.6	0.3
Standard Shield Concrete Cask Inlet	32	--
Carbon Steel Transfer Cask Radial	0.9	< 0.1
Carbon Steel Transfer Cask Bottom	2,527	848
Augmented Shield Concrete Cask Radial	0.9	< 0.1
Augmented Shield Concrete Cask Inlet	6.7	--
Stainless Steel Transfer Cask Radial	0.9	< 0.1
Stainless Steel Transfer Cask Bottom	2,304	790
CC4 Radial	0.8	< 0.1
CC4 Inlet	6.3	--

Table 5.8.6-3 Gamma Source Comparison for CEA Primary Absorber Materials

Group	Steel/Inconel 180 GWd/MTU 10-yr cooled (gamma/sec/kg)	Ag-In-Cd 180 GWd/MTU 10-yr cooled (gamma/sec/kg)	Hafnium 360 GWd/MTU 10-yr cooled (gamma/sec/kg)
1	0.000E+00	0.000E+00	0.000E+00
2	0.000E+00	0.000E+00	0.000E+00
3	0.000E+00	0.000E+00	0.000E+00
4	0.000E+00	0.000E+00	0.000E+00
5	0.000E+00	0.000E+00	0.000E+00
6	0.000E+00	0.000E+00	0.000E+00
7	6.508E-16	1.351E-09	0.000E+00
8	7.212E+04	7.637E+02	0.000E+00
9	4.651E+07	2.810E+05	1.739E-17
10	6.989E-06	1.370E+07	3.596E-05
11	1.236E+01	7.785E+09	3.438E+03
12	4.406E+12	1.120E+10	2.294E+06
13	4.644E+12	7.394E+08	5.918E+06
14	1.126E+09	5.100E+10	1.873E+05
15	8.200E+06	3.525E+13	2.442E+01
16	2.361E+07	1.589E+13	9.747E+01
17	3.736E+08	2.023E+10	1.976E+03
18	2.847E+08	3.069E+10	1.216E+06
19	5.734E+09	1.013E+11	2.178E+06
20	2.377E+10	1.607E+12	7.323E+06
21	6.830E+10	8.541E+12	3.077E+05
22	8.206E+10	2.695E+11	2.777E+05
Total	9.232E+12	6.179E+13	1.971E+07

Note: B_4C absorbers do not produce significant sources in the storage and transfer systems.

Table 5.8.6-4 Dose Rates from Ag-In-Cd Based CEAs as a Function of Exposure and Cool Time

Cask / Dose Location	180 GWd/MTU, 10 Years		270 GWd/MTU, 14 Years		360 GWd/MTU, 20 Years	
	Maximum	Average	Maximum	Average	Maximum	Average
Concrete Cask Radial	3.6	0.3	3.6	0.3	3.6	0.3
Concrete Cask Inlet	32	--	32	--	32	--
Transfer Cask Radial	0.9	<0.1	0.7	<0.1	0.4	<0.1
Transfer Cask Bottom	2527	848	2193	739	1849	625

Table 5.8.6-5 CEA Maximum Exposure and Minimum Cool Time Summary

Maximum Exposure (GWd/MTU)	Minimum Cool Time (yrs)
180	10
270	14
360	20

Table 5.8.6-6 Additional Assembly Cool Time (Years) Required to Load a CEA (Uniform Loading)

Assembly	Cool Time
CE 14x14	0.2
WE 14x14	2.0
WE 15x15	3.1
B&W 15x15	0.2
CE 16x16	0.2
WE 17x17	2.9
B&W 17x17	0.2

5.8.7 Preferential Loading of PWR Fuel

In order to envelop fuel assemblies with heat loads higher than 959 kW, a three-zone preferential loading pattern is proposed as follows.

Zone Description	Designator	Heat Load [W/assy]	# Assemblies
Inner Ring	A	922	9
Middle Ring	B	1,200	12
Outer Ring	C	800	16

Preferential and uniform loading patterns limit total cask heat load to 37 kW. As will be seen in the results section, the maximum dose rate for the preferential loading pattern is less than that calculated for a uniform pattern.

A sketch of the PWR basket and loading pattern is shown in Figure 5.8.7-1.

Minimum cool time tables for the preferential heat load pattern are included in Section 5.8.9. The method and models for the preferential loading pattern shielding evaluations are identical to those of the uniform loading pattern with the exception of requiring three sets of response functions, one for each zone. Source spectrum varies as a result of changes in burnup, initial enrichment and minimum cool time and, therefore, requires cask dose responses (dose per unit source in each spectrum energy group) for each of the zones. The dose responses from each ring, accounting for the differences in the number of assemblies per zone, are added to arrive at the dose rate for a fully loaded cask.

5.8.7.1 Input File Setup

Based on a three-zone pattern, the source and tally descriptions are modified in the MCNP models to consider the sources in the appropriate basket locations with the proper scaling on the tally cards. For each cask/detector combination, three sets of runs (A, B and C) are needed to characterize the dose rate response.

5.8.7.2 Results

Maximum and average surface dose rates for the preferential pattern are shown in Table 5.8.7-1, with the corresponding limiting results for the uniform pattern. The maximum dose rates for the analyzed preferential loading pattern are less than or statistically unchanged from those calculated for a uniform pattern at each detector surface for both casks.

The concrete cask radial and top axial average dose rates are less than or statistically unchanged in the preferential pattern. Therefore, using the uniform pattern to characterize the restricted area

and controlled area boundaries is acceptable. Although the transfer cask top and bottom average dose rates are slightly higher for the preferential pattern, the maximum dose rates on the top of the cask, which are higher for the uniform pattern, are the dominant contributor to occupational exposures. Bottom dose rates do not contribute to occupational exposures. As such, the occupational exposure evaluations for TSC transfer are also conservative.

5.8.7.3 Cool-time Tables

Cool times for the three preferential loading pattern heat loads are shown in Table 5.8.9-3 through Table 5.8.9-5. Results are not shown for burnups of $\leq$ 30 GWd/MTU. The minimum enrichments and cool times (as a function of burnup) for $\leq$ 30 GWd/MTU fuel are listed in Table 5.8.9-1.

Figure 5.8.7-1 Schematic of PWR Fuel Preferential Loading Pattern

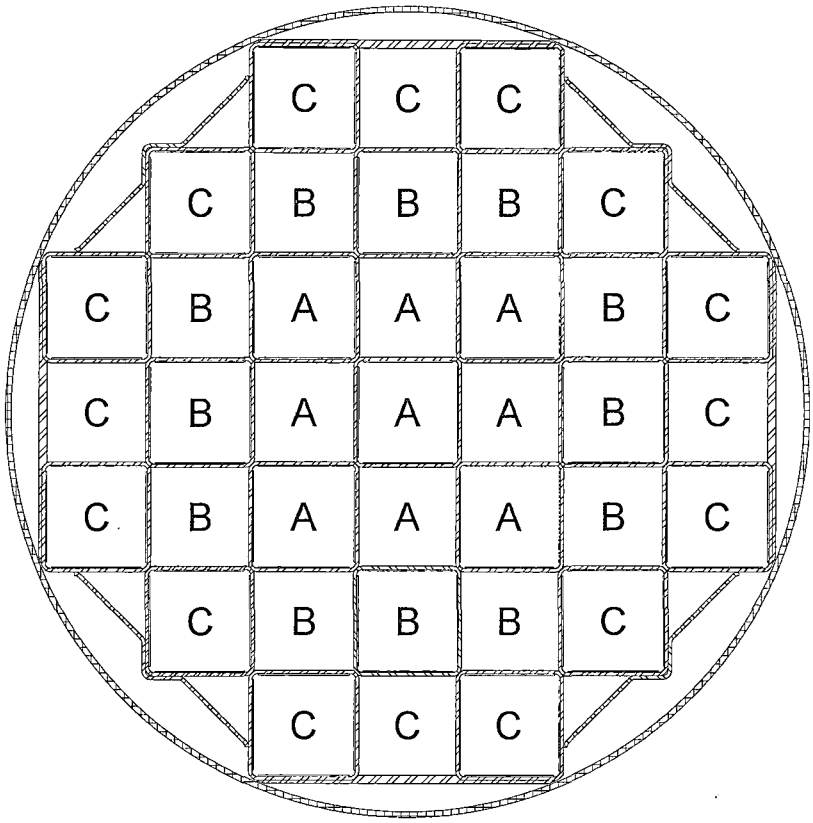


Table 5.8.7-1 Preferential Pattern Dose Rate Results

Cask / Dose Location	Uniform		Preferential	
	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)
Augmented Shield Concrete Cask Radial	24.7	35.5	22.5	31.9
Augmented Shield Concrete Cask Top	56.2	350	50.0	294
Augmented Shield Concrete Cask Inlet	--	116.8	--	110.4
Augmented Shield Concrete Cask Outlet	--	21.8	--	20.8
Stainless Steel Transfer Cask Radial	683	969	651	899
Stainless Steel Transfer Cask Top	225	509	239	500
Stainless Steel Transfer Cask Bottom	3,034	5,880	2,982	5,964
Standard Shield Concrete Cask Radial	54.4	76.7	47.8	70.6
Standard Shield Concrete Cask Top	82.3	378	77.3	350
Standard Shield Concrete Cask Inlet	--	425	--	410
Standard Shield Concrete Cask Outlet	--	38.3	--	38.8
Carbon Steel Transfer Cask Radial	650	939	615	904
Carbon Steel Transfer Cask Top	172	451	180	433
Carbon Steel Transfer Cask Bottom	2,953	5,824	2,976	5,899
CC4 Radial	52.9	76.8	53.0	77.4
CC4 Top	61.5	315	60.7	308
CC4 Inlet	--	112.4	--	111.4
CC4 Outlet	--	36.8	--	37.3

5.8.8 Sample Input Files

This section contains sample input files for the source term and shielding evaluations.

5.8.8.1 Sample Source Term Input Files

Figure 5.8.8-1 contains a sample PWR SAS2H input file. Figure 5.8.8-2 contains a sample input for the BWR model. The ORIGEN-S decay calculation section of the input file is removed from the BWR input file. The input data is identical to the PWR file.

5.8.8.2 Undamaged Fuel Basket Transfer Cask Sample Shielding Input Files

PWR and BWR sample MCNP5 input files for the carbon steel transfer cask are shown in Figure 5.8.8-3 and Figure 5.8.8-4, respectively. As indicated previously in this chapter, shielding evaluations are performed using the response function method. Only one energy line is therefore defined in the source description. A sample input file for the PWR stainless steel transfer cask, including a full source spectrum, is shown in Figure 5.8.8-9.

5.8.8.3 Undamaged Fuel Basket Concrete Cask Sample Shielding Input Files

PWR and BWR sample MCNP5 input files for the standard shield concrete cask are shown in Figure 5.8.8-5 and Figure 5.8.8-6, respectively. A sample input file for the PWR augmented shield concrete cask, including a full source spectrum, is shown in Figure 5.8.8-10.

5.8.8.4 Sample NAC-CASC Input Files

Figure 5.8.8-7 contains a sample PWR NAC-CASC model input file. Figure 5.8.8-8 contains a sample input file for the BWR NAC-CASC model. Detector locations are truncated in the sample files.

5.8.8.5 Damaged Fuel Basket Sample Shielding Input Files

Figure 5.8.8-11 and Figure 5.8.8-12 contain sample PWR damaged fuel basket input files for the transfer cask and the concrete cask, respectively.

Figure 5.8.8-1 PWR Fuel Assembly Source Term Sample Input File

```
=SAS2H       PARM=(HALT03,SKIPSHIPDATA)
17a - 3.7 w/o U235, 45000 MWD/MTU, 5 - 16 years cool time
44GROUPNDF5 LATTICECELL
UO2        1 0.950 900 92235 3.7 92238 96.3 END
ZR 2 1.0 620. END
H2O        3 DEN=0.725 1.0 580 END
ARBM-BORMOD 0.725 1 1 0 0 5000 100 3 550.0E-6 580 END
ZR  4 1.0 580 END
H2O        5 DEN=0.725 0.9751 580 END
ZR  5 0.0249 580 END
END COMP
SQUAREPITCH 1.2598 0.8192 1 3 0.9500 2 0.8357 0 END
NPIN=264 FUEL=365.760 NCYC=3 NLIB=1 PRIN=6 LIGH=5
INPL=1 NUMH=24 NUMI=1 MXTUBE=4 ORTU=0.6121 SRTU=0.5740 END
' Path B not used
POWER=18.5535 BURN=377.6050 DOWN=60 END
POWER=18.5535 BURN=377.6050 DOWN=60 END
POWER=18.5535 BURN=377.6050 DOWN=1461 END
' Cycle not used
' Cycle not used
FE 0.6738 CR 0.1900 NI 0.1150 MN 0.0200 CO 0.0012
END
=ORIGENS
0$$  A4 21 A8 26 A10 51 71  E
1$$  1 1T
COOLING 5 - 16 YEARS AND FISSION PRODUCT GAMMA REBIN
3$$  21 0 1 28 A33 22 E
54$$  A8 1 E T
35$$  0 T
56$$  0 9 A13 -2 5 3 E
57**  4.0 E T
COOLING 5 - 16 YEARS AND FISSION PRODUCT GAMMA REBIN
SINGLE REACTOR ASSEMBLY
60** 5.0 6.0 7.0 8.0 9.0 10.0 12.0 14.0 16.0
65$$  A4 1 A7 1 A10 1 A25 1 A28 1 A31 1 A46 1 A49 1 A52 1 E
61**  F.00000001
81$$  2 51 26 1 E
82$$  F6
83**  1.40e+7  1.20e+7  1.00e+7  8.00e+6   6.50e+6  5.00e+6
      4.00e+6  3.00e+6  2.50e+6  2.00e+6   1.66e+6  1.44e+6
      1.22e+6  1.00e+6  0.80e+6  0.60e+6   0.40e+6  0.30e+6
      0.20e+6  0.10e+6  0.05e+6  0.02e+6   0.01e+6
84**  1.46e+7  1.36e+7  1.25e+7  1.125e+7  1.00e+7
      8.25e+6  7.00e+6  6.07e+6  4.72e+6   3.68e+6
      2.87e+6  1.74e+6  0.64e+6  0.39e+6   0.11e+6
      6.74e+4  2.48e+4  9.12e+3  2.95e+3   9.61e+2
      3.54e+2  1.66e+2  4.81e+1  1.60e+1   4.00e+0
      1.50e+0  5.50e-1  7.09e-2  1.00e-5   T
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
FISSION PRODUCT GAMMA SPECTRA IN AEA GROUPS
56$$ F0  T
END
=ORIGENS
0$$  A4 21 A8 26 A10 51 71  E
1$$  1 1T
COOLING 5 - 16 YEARS AND ACTINIDE GAMMA REBIN
3$$  21 0 1 28 A33 22 E
54$$  A8 1 E T
35$$  0 T
56$$  0 9 A13 -2 5 3 E
57**  4.0 E T
COOLING 5 - 16 YEARS AND ACTINIDE GAMMA REBIN
SINGLE REACTOR ASSEMBLY
```

Figure 5.8.8-1 PWR Fuel Assembly Source Term Sample Input File (cont'd)

```
60** 5.0 6.0 7.0 8.0 9.0 10.0 12.0 14.0 16.0
65$$  A4 1 A7 1 A10 1 A25 1 A28 1 A31 1 A46 1 A49 1 A52 1 E
61**  F.00000001
81$$  2 51 26 1 E
82$$  F5
83**  1.40e+7  1.20e+7  1.00e+7  8.00e+6   6.50e+6  5.00e+6
      4.00e+6  3.00e+6  2.50e+6  2.00e+6   1.66e+6  1.44e+6
      1.22e+6  1.00e+6  0.80e+6  0.60e+6   0.40e+6  0.30e+6
      0.20e+6  0.10e+6  0.05e+6  0.02e+6   0.01e+6
84**  1.46e+7  1.36e+7  1.25e+7  1.125e+7  1.00e+7
      8.25e+6  7.00e+6  6.07e+6  4.72e+6   3.68e+6
      2.87e+6  1.74e+6  0.64e+6  0.39e+6   0.11e+6
      6.74e+4  2.48e+4  9.12e+3  2.95e+3   9.61e+2
      3.54e+2  1.66e+2  4.81e+1  1.60e+1   4.00e+0
      1.50e+0  5.50e-1  7.09e-2  1.00e-5   T
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
ACTINIDE GAMMA SPECTRA IN AEA GROUPS
56$$ F0  T
END
=ORIGENS
0$$  A4 21 A8 26 A10 51 71  E
1$$  1 1T
COOLING 5 - 16 YEARS AND LIGHT ELEMENT GAMMA REBIN
3$$  21 0 1 28 A33 22 E
54$$  A8 1 E T
35$$  0 T
56$$  0 9 A13 -2 5 3 E
57**  4.0 E T
COOLING 5 - 16 YEARS AND LIGHT ELEMENT GAMMA REBIN
SINGLE REACTOR ASSEMBLY
60** 5.0 6.0 7.0 8.0 9.0 10.0 12.0 14.0 16.0
65$$  A4 1 A7 1 A10 1 A25 1 A28 1 A31 1 A46 1 A49 1 A52 1 E
61**  F.00000001
81$$  2 51 26 1 E
82$$  F4
83**  1.40e+7  1.20e+7  1.00e+7  8.00e+6   6.50e+6  5.00e+6
      4.00e+6  3.00e+6  2.50e+6  2.00e+6   1.66e+6  1.44e+6
      1.22e+6  1.00e+6  0.80e+6  0.60e+6   0.40e+6  0.30e+6
      0.20e+6  0.10e+6  0.05e+6  0.02e+6   0.01e+6
84**  1.46e+7  1.36e+7  1.25e+7  1.125e+7  1.00e+7
      8.25e+6  7.00e+6  6.07e+6  4.72e+6   3.68e+6
      2.87e+6  1.74e+6  0.64e+6  0.39e+6   0.11e+6
      6.74e+4  2.48e+4  9.12e+3  2.95e+3   9.61e+2
      3.54e+2  1.66e+2  4.81e+1  1.60e+1   4.00e+0
      1.50e+0  5.50e-1  7.09e-2  1.00e-5   T
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
LIGHT ELEMENT AEA GROUP STRUCTURE
56$$ F0  T
END
```

Figure 5.8.8-2 BWR Fuel Assembly Source Term Sample Input File

```
=SAS2H      PARM=(HALT06,SKIPSHIPDATA)
ng09b - 3.7 w/o U235, 45000 MWD/MTU, 5 - 16 years cool time
44GROUPNDF5 LATTICECELL
UO2        1 0.950 840 92235 3.7 92238 96.3 END
ZR 2 1.0 620. END
H2O 3 DEN=0.446 1.0 562 END
H2O 4 DEN=0.743 1.0 553 END
ZR 5 1.0 553 END
H2O 6 DEN=0.446 1.0 562 END
END COMP
SQUAREPITCH 1.4376 0.9550 1 3 1.1201 2 0.9784 0 END
NPIN=79 FUEL=381.000 NCYC=3 NLIB=2 PRIN=6 LIGH=5
INPL=2 NUMZ=7 END
4 0.6916 5 0.7920 6 1.1471 500 7.2999 6 7.5636 5 7.7929 4 8.5982
POWER=4.7250 BURN=628.2464 DOWN=60 END
POWER=4.7250 BURN=628.2464 DOWN=60 END
POWER=4.7250 BURN=628.2464 DOWN=1461 END
' Cycle not used
' Cycle not used
FE 0.6738 CR 0.1900 NI 0.1150 MN 0.0200 CO 0.0012
END
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC

```
MAGNASTOR Transfer Cask - trfShwDryRadFg_ng17a_11g
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng17a - v1.1
1 1 -1.8782 -1      u=6 $ Lower Nozzle
2 2 -2.6798 -2 +1     u=6 $ Lower Plenum
3 3 -3.8195 -3 +2     u=6 $ Fuel
4 4 -0.7412 -4 +3     u=6 $ Upper Plenum
5 5 -1.8385 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube  v1.3
7 8 -7.8212 -8 +7     u=5 $ Tube
8 9 -2.6336 -9 : -10 : -11 : -12      u=5 $ Poison
9 0          #7  #8  -6   u=5 $ Outside below PFE
10 0          #7  #8  +6   u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
11 0          -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )     u=4 $ Assy loc 1
12 like 11 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )     u=4 $ Assy loc 3
13 like 11 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )     u=4 $ Assy loc 4
14 like 11 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )     u=4 $ Assy loc 6
15 like 11 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )     u=4 $ Assy loc 8
16 like 11 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )     u=4 $ Assy loc 9
17 like 11 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )     u=4 $ Assy loc 11
18 like 11 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )     u=4 $ Assy loc 13
19 like 11 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )     u=4 $ Assy loc 15
20 like 11 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )     u=4 $ Assy loc 17
21 like 11 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )     u=4 $ Assy loc 19
22 like 11 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )     u=4 $ Assy loc 21
23 like 11 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 23
24 like 11 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 25
25 like 11 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 27
26 like 11 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 29
27 like 11 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 30
28 like 11 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )     u=4 $ Assy loc 32
29 like 11 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 34
30 like 11 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 35
31 like 11 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 37
32 8 -7.8212 -15 #19 #26      u=4 $ Side support +x
33 8 -7.8212 -16 #16 #23      u=4 $ Side support -x
34 8 -7.8212 -17 #11 #12      u=4 $ Side support +y
35 8 -7.8212 -18 #30 #31      u=4 $ Side support -y
36 8 -7.8212 -19 +20 +21      u=4 $ Corner
37 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #11 #12 #16 #19 #23 #26 #30 #31       u=4 $ Corner diagonal
38 0         -6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
                #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
                #32 #33 #34 #35 #36 #37      u=4 $ Basket below PFE
39 0         +6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
               #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
               #32 #33 #34 #35 #36 #37      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
40 0         -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )     u=3 $ Assy loc 1
41 like 40 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )     u=3 $ Assy loc 2
42 like 40 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )     u=3 $ Assy loc 3
43 like 40 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )     u=3 $ Assy loc 4
44 like 40 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )     u=3 $ Assy loc 5
45 like 40 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )     u=3 $ Assy loc 6
46 like 40 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )     u=3 $ Assy loc 7
47 like 40 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )     u=3 $ Assy loc 8
48 like 40 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )     u=3 $ Assy loc 9
49 like 40 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )     u=3 $ Assy loc 10
50 like 40 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )     u=3 $ Assy loc 11
51 like 40 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )     u=3 $ Assy loc 12
52 like 40 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )     u=3 $ Assy loc 13
53 like 40 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )     u=3 $ Assy loc 14
54 like 40 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )     u=3 $ Assy loc 15
55 like 40 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )     u=3 $ Assy loc 16
56 like 40 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )     u=3 $ Assy loc 17
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
57 like 40 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
58 like 40 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
59 like 40 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
60 like 40 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
61 like 40 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
62 like 40 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
63 like 40 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
64 like 40 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
65 like 40 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
66 like 40 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
67 like 40 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
68 like 40 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
69 like 40 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
70 like 40 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
71 like 40 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
72 like 40 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
73 like 40 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
74 like 40 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
75 like 40 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
76 like 40 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
77 0         #40 #41 #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52
#53 #54 #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65
#66 #67 #68 #69 #70 #71 #72 #73 #74 #75 #76      fill=4 u=3 $ Cavity
C Cells - Canister w/Weld Shield v1.3
78 0         -24 #90  #91  fill=3    u=2 $ Cavity
79 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
80 0         -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Bottom Drain Port
81 14 -3.9700 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Middle Drain Port
82 0         -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Top Drain Port
83 like 80 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Bottom Vent Port
84 like 81 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Middle Vent Port
85 like 82 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Top Vent Port
86 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
87 8 -7.8212 -31 -24.1 +24.2 -29 #80 #81  #83 #84   u=2 $ Lower lid
88 7 -7.9400 -31 -24.1 +29 #81 #82  #84 #85    u=2 $ Upper lid
89 7 -7.9400 (-32 +35 +36) : (-33 +35 +36) : (-34 +35 +36)       u=2 $ Weld Shield
90 7 -7.9400 -39 +38 +37 -24.2 trcl = ( 61.7220 44.7040 0.0000 )   u=2 $ Drain port
shield
91 7 -7.9400 -39 +38 +37 -24.2 trcl = ( -61.7220 -44.7040 0.0000 )   u=2 $ Vent port
shield
92 6 -0.9982 +31 #89  -40     u=2 $ Outside water
93 0         +31 #89  +40     u=2 $ Outside void
C Transfer Cask Cells - v1.3.0_ng17a
94 6 -0.9982 -41 -42 #104  fill=2 ( 0.0000 0.0000 6.9850 )   u=1 $ Cavity
95 8 -7.8212 -41 +42 -47    u=1 $ Bottom forging
96 8 -7.8212 -43 +42 +47 -48   u=1 $ Inner shell
97 0         -44 +43 +47 -48   u=1 $ Gap
98 11 -11.344 -45 +44 +47 -48   u=1 $ Lead shell
99 12 -1.6316 -46 +45 +47 -48   u=1 $ NS4FR shell
100 8 -7.8212 -41 +46 +47 -48   u=1 $ Outer shell
101 8 -7.8212 -41 +42 +48    u=1 $ Top forging
102 8 -7.8212 (-49 +50 -55) : (-49 -51 -55)      u=1 $ Door rail
103 8 -7.8212 -54 -52 +53 -55   u=1 $ Door steel
104 8 -7.8212 -57 +56     u=1 $ Weld bar
105 0         +41 #102  #103     u=1 $ Void
C Detector Cells - Radial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ 1ft
600  0  -600  +400  +500  $ 1m
700  0  -700  +400  +500  +600  $ 2m
800  0  -800  +400  +500  +600  +700  $ 4m
900  0  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng17a - v1.1
1 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 6.8580  $ Lower Nozzle
2 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 8.5979  $ Lower Plenum
3 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 374.3579  $ Fuel
4 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 396.5702  $ Upper Plenum
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
5 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 405.8920  $ Upper Nozzle
6 PZ 252.4379        $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 8 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 8 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 8 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.5
23 RPP -10.7015 10.7015 -10.7015 10.7015 0.0000 405.8921   $ Assy opening
C Surfaces - Canister w/Weld Shield v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1962         $ Lower/upper lid
30 PZ 459.5114         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
32 RCC 0.0000 0.0000 462.3562 0.0000 0.0000 5.0800 78.1050   $ Weld shield bot
33 RCC 0.0000 0.0000 467.4362 0.0000 0.0000 5.0800 71.7550   $ Weld shield mid
34 RCC 0.0000 0.0000 472.5162 0.0000 0.0000 5.0800 66.6750   $ Weld shield top
35 RCC 61.7220 44.7040 462.3562 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout +x+y
36 RCC -61.7220 -44.7040 462.3562 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout -x-
y
37 PZ 433.1462         $ Port shield elevation
38 CZ 2.6924         $ Port shield ID
39 CZ 5.0800         $ Port shield OD
40 RCC 0.0000 0.0000 -3.0748 0.0000 0.0000 459.4098 99.0000   $ Water jacket
C Transfer Cask Surfaces - v1.3.0_ng17a
41 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 488.9500 111.7600  $ Cask
42 CZ 92.7100        $ Cavity
43 CZ 94.6150        $ Inner shell
44 CZ 94.7420        $ Gap
45 CZ 102.8700        $ Lead shell
46 CZ 108.5850        $ NS4FR shell
47 PZ 30.4800        $ Bottom forging
48 PZ 453.3900        $ Top forging
49 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door container
50 PY 97.0026        $ Inside rail +y
51 PY -97.0026        $ Inside rail -y
52 PY 96.5200        $ Door +y
53 PY -96.5200        $ Door -y
54 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000   $ Door prism
       108.4699 0.0000 0.0000 89.7374 -73.7172 0.0000
       -89.7374 -73.7172 0.0000
55 RCC 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000 111.7600  $ Door container
56 RCC 0.0000 0.0000 469.3412 0.0000 0.0000 1.9050 90.8049  $ Weld bar inner
57 RCC 0.0000 0.0000 469.3412 0.0000 0.0000 1.9050 92.7100  $ Weld bar outer
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  501.8500  111.8600
401  PZ  20.6567
402  PZ  54.1133
403  PZ  87.5700
404  PZ  121.0267
405  PZ  154.4833
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
406  PZ  187.9400
407  PZ  221.3967  408  PZ  254.8533
409  PZ  288.3100
410  PZ  321.7667
411  PZ  355.2233
412  PZ  388.6800
413  PZ  422.1367
414  PZ  455.5933
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -43.2800  0.0000  0.0000  562.8100  142.3400
501  PZ  -5.7593
502  PZ  31.7613
503  PZ  69.2820
504  PZ  106.8027
505  PZ  144.3233
506  PZ  181.8440
507  PZ  219.3647
508  PZ  256.8853
509  PZ  294.4060
510  PZ  331.9267
511  PZ  369.4473
512  PZ  406.9680
513  PZ  444.4887
514  PZ  482.0093
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -112.8000  0.0000  0.0000  701.8500  211.8600
601  PZ  -77.7075
602  PZ  -42.6150
603  PZ  -7.5225
604  PZ  27.5700
605  PZ  62.6625
606  PZ  97.7550
607  PZ  132.8475
608  PZ  167.9400
609  PZ  203.0325
610  PZ  238.1250
611  PZ  273.2175
612  PZ  308.3100
613  PZ  343.4025
614  PZ  378.4950
615  PZ  413.5875
616  PZ  448.6800
617  PZ  483.7725
618  PZ  518.8650
619  PZ  553.9575
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -212.8000  0.0000  0.0000  901.8500  311.8600
701  PZ  -167.7075
702  PZ  -122.6150
703  PZ  -77.5225
704  PZ  -32.4300
705  PZ  12.6625
706  PZ  57.7550
707  PZ  102.8475
708  PZ  147.9400
709  PZ  193.0325
710  PZ  238.1250
711  PZ  283.2175
712  PZ  328.3100
713  PZ  373.4025
714  PZ  418.4950
715  PZ  463.5875
716  PZ  508.6800
717  PZ  553.7725
718  PZ  598.8650
719  PZ  643.9575
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -412.8000  0.0000  0.0000  1301.8500  511.8600
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
801  PZ  -347.7075
802  PZ  -282.6150
803  PZ  -217.5225
804  PZ  -152.4300
805  PZ  -87.3375
806  PZ  -22.2450
807  PZ  42.8475
808  PZ  107.9400
809  PZ  173.0325
810  PZ  238.1250
811  PZ  303.2175
812  PZ  368.3100
813  PZ  433.4025
814  PZ  498.4950
815  PZ  563.5875
816  PZ  628.6800
817  PZ  693.7725
818  PZ  758.8650
819  PZ  823.9575

C
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6495E-02 40000 -1.6893E-01 24000 -1.7199E-04
      92238 -6.9340E-01 50000 -2.5798E-03  7014 -8.5993E-05
       8016 -9.8121E-02 26000 -2.1498E-04
C Homogenized Upper Plenum
m4    24000 -1.3648E-01 50000 -4.2477E-03 25055 -1.4336E-02
      26000 -4.9854E-01  7014 -1.4159E-04 28000 -6.8098E-02
      40000 -2.7816E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Neutron Poison
m9    13027 -0.6605 5010 -0.0478 5011 -0.2179
      6012 -0.0737
C Aluminum
m10   13027 -1.0
C Lead
m11   82000 -1.0
C NS-4-FR
m12   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m13   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Balsa
m15   6012 6 1001 10 8016 5
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
 C NS-4-FR (Accident)
m16   5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
      5011 -7.7389E-03
C Copper
m17   29063 -6.8499E-01 29065 -3.1501E-01  C Damaged Fuel
m18   92235 -4.4075E-02 92238 -8.3742E-01  8016 -1.1850E-01
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:p 1 109r 0
C
C PWR Source Definition - Fuel Gamma Response to Group 11
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=400:94:78:d5:3
si1   -10.70102 10.70102
sp1   0 1
si2   -10.70102 10.70102
sp2   0 1
si3 a 8.5979 17.7419 26.8859 36.0299 45.1739 54.3179 63.4619
      319.4939 328.6379 337.7819 346.9259 356.0699 365.2139 374.3579
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
si4   1.440E+00 1.660E+00
sp4   0 1
C Source Information
si5 l       40 41 42
         43 44 45 46 47
      48 49 50 51 52 53 54
      55 56 57 58 59 60 61
      62 63 64 65 66 67 68
         69 70 71 72 73
            74 75 76
C Source Probability
sp5           1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
            1.0 1.0 1.0
mode p
nps 400000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=89 0 198 origin=0.1 0.1 -513
     imesh 90.2 91.4 92.7 94.6 102.9 108.6 111.8 611.8
     iints 5 1 1 1 3 1 1 1
     jmesh 500 513 520 527 528 894 916 926 959 997 1497
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
     jints 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
C wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +400.1
fm2 3.7000E+01
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  -412
     -413  -414  T
tf2
fc12 Radial 1ft Tally
f12:p +500.1
fm12 3.7000E+01
fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  -512
     -513  -514  T
tf12
fc22 Radial 1m Tally
f22:p +600.1
fm22 3.7000E+01
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  -615  -616  -617  -618
     -619  T
tf22
fc32 Radial 2m Tally
f32:p +700.1
fm32 3.7000E+01
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf32
fc42 Radial 4m Tally
f42:p +800.1
fm42 3.7000E+01
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 5.625 degree rotation around z-axis
*TR1 0.0 0.0 0.0 5.625 95.625 90 -84.375 5.625 90 90 90 0
C 11.25 degree rotation around z-axis
*TR2 0.0 0.0 0.0 11.250 101.250 90 -78.750 11.250 90 90 90 0
C 16.875 degree rotation around z-axis
*TR3 0.0 0.0 0.0 16.875 106.875 90 -73.125 16.875 90 90 90 0
C 22.5 degree rotation around z-axis
*TR4 0.0 0.0 0.0 22.500 112.500 90 -67.500 22.500 90 90 90 0
C 28.125 degree rotation around z-axis
*TR5 0.0 0.0 0.0 28.125 118.125 90 -61.875 28.125 90 90 90 0
C 33.75 degree rotation around z-axis
*TR6 0.0 0.0 0.0 33.750 123.750 90 -56.250 33.750 90 90 90 0
C 39.375 degree rotation around z-axis
```

Figure 5.8.8-3 Transfer Cask Sample Input File – PWR TSC (cont'd)

```
*TR7 0.0 0.0 0.0 39.375 129.375 90 -50.625 39.375 90 90 90 0
C 45 degree rotation around z-axis
*TR8 0.0 0.0 0.0 45.000 135.000 90 -45.000 45.000 90 90 90 0
C 50.625 degree rotation around z-axis
*TR9 0.0 0.0 0.0 50.625 140.625 90 -39.375 50.625 90 90 90 0
C 56.25 degree rotation around z-axis
*TR10 0.0 0.0 0.0 56.250 146.250 90 -33.750 56.250 90 90 90 0
C 61.875 degree rotation around z-axis    *
TR11 0.0 0.0 0.0 61.875 151.875 90 -28.125 61.875 90 90 90 0
C 67.5 degree rotation around z-axis
*TR12 0.0 0.0 0.0 67.500 157.500 90 -22.500 67.500 90 90 90 0
C 73.125 degree rotation around z-axis
*TR13 0.0 0.0 0.0 73.125 163.125 90 -16.875 73.125 90 90 90 0
C 78.75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 78.750 168.750 90 -11.250 78.750 90 90 90 0
C 84.375 degree rotation around z-axis
*TR15 0.0 0.0 0.0 84.375 174.375 90 -5.625 84.375 90 90 90 0
C 95.625 degree rotation around z-axis
*TR16 0.0 0.0 0.0 95.625 185.625 90 5.625 95.625 90 90 90 0
C 101.25 degree rotation around z-axis
*TR17 0.0 0.0 0.0 101.250 191.250 90 11.250 101.250 90 90 90 0
C 106.875 degree rotation around z-axis
*TR18 0.0 0.0 0.0 106.875 196.875 90 16.875 106.875 90 90 90 0
C 112.5 degree rotation around z-axis
*TR19 0.0 0.0 0.0 112.500 202.500 90 22.500 112.500 90 90 90 0
C 118.125 degree rotation around z-axis
*TR20 0.0 0.0 0.0 118.125 208.125 90 28.125 118.125 90 90 90 0
C 123.75 degree rotation around z-axis
*TR21 0.0 0.0 0.0 123.750 213.750 90 33.750 123.750 90 90 90 0
C 129.375 degree rotation around z-axis
*TR22 0.0 0.0 0.0 129.375 219.375 90 39.375 129.375 90 90 90 0
C 135 degree rotation around z-axis
*TR23 0.0 0.0 0.0 135.000 225.000 90 45.000 135.000 90 90 90 0
C 140.625 degree rotation around z-axis
*TR24 0.0 0.0 0.0 140.625 230.625 90 50.625 140.625 90 90 90 0
C 146.25 degree rotation around z-axis
*TR25 0.0 0.0 0.0 146.250 236.250 90 56.250 146.250 90 90 90 0
C 151.875 degree rotation around z-axis
*TR26 0.0 0.0 0.0 151.875 241.875 90 61.875 151.875 90 90 90 0
C 157.5 degree rotation around z-axis
*TR27 0.0 0.0 0.0 157.500 247.500 90 67.500 157.500 90 90 90 0
C 163.125 degree rotation around z-axis
*TR28 0.0 0.0 0.0 163.125 253.125 90 73.125 163.125 90 90 90 0
C 168.75 degree rotation around z-axis
*TR29 0.0 0.0 0.0 168.750 258.750 90 78.750 168.750 90 90 90 0
C 174.375 degree rotation around z-axis
*TR30 0.0 0.0 0.0 174.375 264.375 90 84.375 174.375 90 90 90 0
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC

```
MAGNASTOR Transfer Cask - trfShwDryTopUf_ng08b_12g
C Top Axial Biasing - Upper Nozzle Source
C Fuel Assembly Cells - ng08b - v1.0
1 1 -1.3934 -1     u=6 $ Lower Nozzle
2 2 -2.5369 -2 +1    u=6 $ Lower Plenum
3 3 -3.5640 -3 +2    u=6 $ Fuel
4 4 -0.5758 -4 +3    u=6 $ Upper Plenum
5 5 -0.5558 -5 +4    u=6 $ Upper Nozzle
6 0         +5     u=6 $ Outside
C Cells - Fuel Tube w/Poison v1.2
7 8 -7.8212 -7 +6    u=5 $ Tube
8 9 -2.6379 -8 : -9 : -10 : -11     u=5 $ Poison
9 0         #7 #8      u=5 $ Void
C Cells - BWR Basket v1.3
10 0         -12 -13 fill=5 trcl = ( -15.7009 78.5045 0.0000 )    u=4 $ Assy loc 1
11 like 10 but fill=5 trcl = ( 15.7009 78.5045 0.0000 )    u=4 $ Assy loc 3
12 like 10 but fill=5 trcl = ( -31.4018 62.8036 0.0000 )    u=4 $ Assy loc 5
13 like 10 but fill=5 trcl = ( 0.0000 62.8036 0.0000 )    u=4 $ Assy loc 7
14 like 10 but fill=5 trcl = ( 31.4018 62.8036 0.0000 )    u=4 $ Assy loc 9
15 like 10 but fill=5 trcl = ( -47.1027 47.1027 0.0000 )    u=4 $ Assy loc 12
16 like 10 but fill=5 trcl = ( -15.7009 47.1027 0.0000 )    u=4 $ Assy loc 14
17 like 10 but fill=5 trcl = ( 15.7009 47.1027 0.0000 )    u=4 $ Assy loc 16
18 like 10 but fill=5 trcl = ( 47.1027 47.1027 0.0000 )    u=4 $ Assy loc 18
19 like 10 but fill=5 trcl = ( -62.8036 31.4018 0.0000 )    u=4 $ Assy loc 20
20 like 10 but fill=5 trcl = ( -31.4018 31.4018 0.0000 )    u=4 $ Assy loc 22
21 like 10 but fill=5 trcl = ( 0.0000 31.4018 0.0000 )    u=4 $ Assy loc 24
22 like 10 but fill=5 trcl = ( 31.4018 31.4018 0.0000 )    u=4 $ Assy loc 26
23 like 10 but fill=5 trcl = ( 62.8036 31.4018 0.0000 )    u=4 $ Assy loc 28
24 like 10 but fill=5 trcl = ( -78.5045 15.7009 0.0000 )    u=4 $ Assy loc 29
25 like 10 but fill=5 trcl = ( -47.1027 15.7009 0.0000 )    u=4 $ Assy loc 31
26 like 10 but fill=5 trcl = ( -15.7009 15.7009 0.0000 )    u=4 $ Assy loc 33
27 like 10 but fill=5 trcl = ( 15.7009 15.7009 0.0000 )    u=4 $ Assy loc 35
28 like 10 but fill=5 trcl = ( 47.1027 15.7009 0.0000 )    u=4 $ Assy loc 37
29 like 10 but fill=5 trcl = ( 78.5045 15.7009 0.0000 )    u=4 $ Assy loc 39
30 like 10 but fill=5 trcl = ( -62.8036 0.0000 0.0000 )    u=4 $ Assy loc 41
31 like 10 but fill=5 trcl = ( -31.4018 0.0000 0.0000 )    u=4 $ Assy loc 43
32 like 10 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 45
33 like 10 but fill=5 trcl = ( 31.4018 0.0000 0.0000 )    u=4 $ Assy loc 47
34 like 10 but fill=5 trcl = ( 62.8036 0.0000 0.0000 )    u=4 $ Assy loc 49
35 like 10 but fill=5 trcl = ( -78.5045 -15.7009 0.0000 )    u=4 $ Assy loc 51
36 like 10 but fill=5 trcl = ( -47.1027 -15.7009 0.0000 )    u=4 $ Assy loc 53
37 like 10 but fill=5 trcl = ( -15.7009 -15.7009 0.0000 )    u=4 $ Assy loc 55
38 like 10 but fill=5 trcl = ( 15.7009 -15.7009 0.0000 )    u=4 $ Assy loc 57
39 like 10 but fill=5 trcl = ( 47.1027 -15.7009 0.0000 )    u=4 $ Assy loc 59
40 like 10 but fill=5 trcl = ( 78.5045 -15.7009 0.0000 )    u=4 $ Assy loc 61
41 like 10 but fill=5 trcl = ( -62.8036 -31.4018 0.0000 )    u=4 $ Assy loc 62
42 like 10 but fill=5 trcl = ( -31.4018 -31.4018 0.0000 )    u=4 $ Assy loc 64
43 like 10 but fill=5 trcl = ( 0.0000 -31.4018 0.0000 )    u=4 $ Assy loc 66
44 like 10 but fill=5 trcl = ( 31.4018 -31.4018 0.0000 )    u=4 $ Assy loc 68
45 like 10 but fill=5 trcl = ( 62.8036 -31.4018 0.0000 )    u=4 $ Assy loc 70
46 like 10 but fill=5 trcl = ( -47.1027 -47.1027 0.0000 )    u=4 $ Assy loc 72
47 like 10 but fill=5 trcl = ( -15.7009 -47.1027 0.0000 )    u=4 $ Assy loc 74
48 like 10 but fill=5 trcl = ( 15.7009 -47.1027 0.0000 )    u=4 $ Assy loc 76
49 like 10 but fill=5 trcl = ( 47.1027 -47.1027 0.0000 )    u=4 $ Assy loc 78
50 like 10 but fill=5 trcl = ( -31.4018 -62.8036 0.0000 )    u=4 $ Assy loc 81
51 like 10 but fill=5 trcl = ( 0.0000 -62.8036 0.0000 )    u=4 $ Assy loc 83
52 like 10 but fill=5 trcl = ( 31.4018 -62.8036 0.0000 )    u=4 $ Assy loc 85
53 like 10 but fill=5 trcl = ( -15.7009 -78.5045 0.0000 )    u=4 $ Assy loc 87
54 like 10 but fill=5 trcl = ( 15.7009 -78.5045 0.0000 )    u=4 $ Assy loc 89
55 8 -7.8212 -14 #29  #40     u=4 $ Thick side support +x
56 8 -7.8212 -15 #24  #35     u=4 $ Thick side support -x
57 8 -7.8212 -16 #10  #11     u=4 $ Thick side support +y
58 8 -7.8212 -17 #53  #54     u=4 $ Thick side support -y
59 8 -7.8212 -18 +14 #29  #40    u=4 $ Thin side support +x
60 8 -7.8212 -19 +15 #24  #35    u=4 $ Thin side support -x
61 8 -7.8212 -20 +16 #10  #11    u=4 $ Thin side support +y
62 8 -7.8212 -21 +17 #53  #54    u=4 $ Thin side support -y
63 8 -7.8212 -24 +25 +22 +27  #15 #18 #46 #49     u=4 $ Corner part 1
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
64 8 -7.8212 -22 +23 +27  #15 #18 #46 #49     u=4 $ Corner part 2
65 8 -7.8212 -26 +27 +22 +24  +14.2 +15.1 +16.4 +17.3
             #10 #11 #12 #14 #19 #23 #24 #29
             #35 #40 #41 #45 #50 #52 #53 #54       u=4 $ Corner diagonal
66 0         +28 +29
             #11 #13 #14 #17 #18 #21 #22
             #23 #27 #28 #29 #32 #33 #34
             #55 #57 #59 #61 #63 #64 #65       u=4 $ Basket +x+y
67 0         +28 -29
             #32 #33 #34 #38 #39 #40 #43
             #44 #45 #48 #49 #51 #52 #54
             #55 #58 #59 #62 #63 #64 #65       u=4 $ Basket +x-y
68 0         -28 +29
             #10 #12 #13 #15 #16 #19 #20
             #21 #24 #25 #26 #30 #31 #32
             #56 #57 #60 #61 #63 #64 #65       u=4 $ Basket -x+y
69 0         -28 -29
             #30 #31 #32 #35 #36 #37 #41
             #42 #43 #46 #47 #50 #51 #53
             #56 #58 #60 #62 #63 #64 #65       u=4 $ Basket -x+y
C Cells - BWR Canister Cavity v1.3
70 0         -30 fill=6 trcl = ( -15.7009 78.5045 0.0000 )    u=3 $ Assy loc 1
71 like 70 but fill=6 trcl = ( 0.0000 78.5045 0.0000 )    u=3 $ Assy loc 2
72 like 70 but fill=6 trcl = ( 15.7009 78.5045 0.0000 )    u=3 $ Assy loc 3
73 like 70 but fill=6 trcl = ( -47.1027 62.8036 0.0000 )    u=3 $ Assy loc 4
74 like 70 but fill=6 trcl = ( -31.4018 62.8036 0.0000 )    u=3 $ Assy loc 5
75 like 70 but fill=6 trcl = ( -15.7009 62.8036 0.0000 )    u=3 $ Assy loc 6
76 like 70 but fill=6 trcl = ( 0.0000 62.8036 0.0000 )    u=3 $ Assy loc 7
77 like 70 but fill=6 trcl = ( 15.7009 62.8036 0.0000 )    u=3 $ Assy loc 8
78 like 70 but fill=6 trcl = ( 31.4018 62.8036 0.0000 )    u=3 $ Assy loc 9
79 like 70 but fill=6 trcl = ( 47.1027 62.8036 0.0000 )    u=3 $ Assy loc 10
80 like 70 but fill=6 trcl = ( -62.8036 47.1027 0.0000 )    u=3 $ Assy loc 11
81 like 70 but fill=6 trcl = ( -47.1027 47.1027 0.0000 )    u=3 $ Assy loc 12
82 like 70 but fill=6 trcl = ( -31.4018 47.1027 0.0000 )    u=3 $ Assy loc 13
83 like 70 but fill=6 trcl = ( -15.7009 47.1027 0.0000 )    u=3 $ Assy loc 14
84 like 70 but fill=6 trcl = ( 0.0000 47.1027 0.0000 )    u=3 $ Assy loc 15
85 like 70 but fill=6 trcl = ( 15.7009 47.1027 0.0000 )    u=3 $ Assy loc 16
86 like 70 but fill=6 trcl = ( 31.4018 47.1027 0.0000 )    u=3 $ Assy loc 17
87 like 70 but fill=6 trcl = ( 47.1027 47.1027 0.0000 )    u=3 $ Assy loc 18
88 0         -30  trcl = ( 62.8036 47.1027 0.0000 )    u=3 $ Assy loc 19
89 like 70 but fill=6 trcl = ( -62.8036 31.4018 0.0000 )    u=3 $ Assy loc 20
90 like 70 but fill=6 trcl = ( -47.1027 31.4018 0.0000 )    u=3 $ Assy loc 21
91 like 70 but fill=6 trcl = ( -31.4018 31.4018 0.0000 )    u=3 $ Assy loc 22
92 like 70 but fill=6 trcl = ( -15.7009 31.4018 0.0000 )    u=3 $ Assy loc 23
93 like 70 but fill=6 trcl = ( 0.0000 31.4018 0.0000 )    u=3 $ Assy loc 24
94 like 70 but fill=6 trcl = ( 15.7009 31.4018 0.0000 )    u=3 $ Assy loc 25
95 like 70 but fill=6 trcl = ( 31.4018 31.4018 0.0000 )    u=3 $ Assy loc 26
96 like 70 but fill=6 trcl = ( 47.1027 31.4018 0.0000 )    u=3 $ Assy loc 27
97 like 70 but fill=6 trcl = ( 62.8036 31.4018 0.0000 )    u=3 $ Assy loc 28
98 like 70 but fill=6 trcl = ( -78.5045 15.7009 0.0000 )    u=3 $ Assy loc 29
99 like 70 but fill=6 trcl = ( -62.8036 15.7009 0.0000 )    u=3 $ Assy loc 30
100 like 70 but fill=6 trcl = ( -47.1027 15.7009 0.0000 )    u=3 $ Assy loc 31
101 like 70 but fill=6 trcl = ( -31.4018 15.7009 0.0000 )    u=3 $ Assy loc 32
102 like 70 but fill=6 trcl = ( -15.7009 15.7009 0.0000 )    u=3 $ Assy loc 33
103 like 70 but fill=6 trcl = ( 0.0000 15.7009 0.0000 )    u=3 $ Assy loc 34
104 like 70 but fill=6 trcl = ( 15.7009 15.7009 0.0000 )    u=3 $ Assy loc 35
105 like 70 but fill=6 trcl = ( 31.4018 15.7009 0.0000 )    u=3 $ Assy loc 36
106 like 70 but fill=6 trcl = ( 47.1027 15.7009 0.0000 )    u=3 $ Assy loc 37
107 like 70 but fill=6 trcl = ( 62.8036 15.7009 0.0000 )    u=3 $ Assy loc 38
108 like 70 but fill=6 trcl = ( 78.5045 15.7009 0.0000 )    u=3 $ Assy loc 39
109 like 70 but fill=6 trcl = ( -78.5045 0.0000 0.0000 )    u=3 $ Assy loc 40
110 like 70 but fill=6 trcl = ( -62.8036 0.0000 0.0000 )    u=3 $ Assy loc 41
111 like 70 but fill=6 trcl = ( -47.1027 0.0000 0.0000 )    u=3 $ Assy loc 42
112 like 70 but fill=6 trcl = ( -31.4018 0.0000 0.0000 )    u=3 $ Assy loc 43
113 like 70 but fill=6 trcl = ( -15.7009 0.0000 0.0000 )    u=3 $ Assy loc 44
114 like 70 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 45
115 like 70 but fill=6 trcl = ( 15.7009 0.0000 0.0000 )    u=3 $ Assy loc 46
116 like 70 but fill=6 trcl = ( 31.4018 0.0000 0.0000 )    u=3 $ Assy loc 47
117 like 70 but fill=6 trcl = ( 47.1027 0.0000 0.0000 )    u=3 $ Assy loc 48
118 like 70 but fill=6 trcl = ( 62.8036 0.0000 0.0000 )    u=3 $ Assy loc 49
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
119 like 70 but fill=6 trcl = ( 78.5045 0.0000 0.0000 )    u=3 $ Assy loc 50
120 like 70 but fill=6 trcl = ( -78.5045 -15.7009 0.0000 )    u=3 $ Assy loc 51
121 like 70 but fill=6 trcl = ( -62.8036 -15.7009 0.0000 )    u=3 $ Assy loc 52
122 like 70 but fill=6 trcl = ( -47.1027 -15.7009 0.0000 )    u=3 $ Assy loc 53
123 like 70 but fill=6 trcl = ( -31.4018 -15.7009 0.0000 )    u=3 $ Assy loc 54
124 like 70 but fill=6 trcl = ( -15.7009 -15.7009 0.0000 )    u=3 $ Assy loc 55
125 like 70 but fill=6 trcl = ( 0.0000 -15.7009 0.0000 )    u=3 $ Assy loc 56
126 like 70 but fill=6 trcl = ( 15.7009 -15.7009 0.0000 )    u=3 $ Assy loc 57
127 like 70 but fill=6 trcl = ( 31.4018 -15.7009 0.0000 )    u=3 $ Assy loc 58
128 like 70 but fill=6 trcl = ( 47.1027 -15.7009 0.0000 )    u=3 $ Assy loc 59
129 like 70 but fill=6 trcl = ( 62.8036 -15.7009 0.0000 )    u=3 $ Assy loc 60
130 like 70 but fill=6 trcl = ( 78.5045 -15.7009 0.0000 )    u=3 $ Assy loc 61
131 like 70 but fill=6 trcl = ( -62.8036 -31.4018 0.0000 )    u=3 $ Assy loc 62
132 like 70 but fill=6 trcl = ( -47.1027 -31.4018 0.0000 )    u=3 $ Assy loc 63
133 like 70 but fill=6 trcl = ( -31.4018 -31.4018 0.0000 )    u=3 $ Assy loc 64
134 like 70 but fill=6 trcl = ( -15.7009 -31.4018 0.0000 )    u=3 $ Assy loc 65
135 like 70 but fill=6 trcl = ( 0.0000 -31.4018 0.0000 )    u=3 $ Assy loc 66
136 like 70 but fill=6 trcl = ( 15.7009 -31.4018 0.0000 )    u=3 $ Assy loc 67
137 like 70 but fill=6 trcl = ( 31.4018 -31.4018 0.0000 )    u=3 $ Assy loc 68
138 like 70 but fill=6 trcl = ( 47.1027 -31.4018 0.0000 )    u=3 $ Assy loc 69
139 like 70 but fill=6 trcl = ( 62.8036 -31.4018 0.0000 )    u=3 $ Assy loc 70
140 0         -30  trcl = ( -62.8036 -47.1027 0.0000 )    u=3 $ Assy loc 71
141 like 70 but fill=6 trcl = ( -47.1027 -47.1027 0.0000 )    u=3 $ Assy loc 72
142 like 70 but fill=6 trcl = ( -31.4018 -47.1027 0.0000 )    u=3 $ Assy loc 73
143 like 70 but fill=6 trcl = ( -15.7009 -47.1027 0.0000 )    u=3 $ Assy loc 74
144 like 70 but fill=6 trcl = ( 0.0000 -47.1027 0.0000 )    u=3 $ Assy loc 75
145 like 70 but fill=6 trcl = ( 15.7009 -47.1027 0.0000 )    u=3 $ Assy loc 76
146 like 70 but fill=6 trcl = ( 31.4018 -47.1027 0.0000 )    u=3 $ Assy loc 77
147 like 70 but fill=6 trcl = ( 47.1027 -47.1027 0.0000 )    u=3 $ Assy loc 78
148 like 70 but fill=6 trcl = ( 62.8036 -47.1027 0.0000 )    u=3 $ Assy loc 79
149 like 70 but fill=6 trcl = ( -47.1027 -62.8036 0.0000 )    u=3 $ Assy loc 80
150 like 70 but fill=6 trcl = ( -31.4018 -62.8036 0.0000 )    u=3 $ Assy loc 81
151 like 70 but fill=6 trcl = ( -15.7009 -62.8036 0.0000 )    u=3 $ Assy loc 82
152 like 70 but fill=6 trcl = ( 0.0000 -62.8036 0.0000 )    u=3 $ Assy loc 83
153 like 70 but fill=6 trcl = ( 15.7009 -62.8036 0.0000 )    u=3 $ Assy loc 84
154 like 70 but fill=6 trcl = ( 31.4018 -62.8036 0.0000 )    u=3 $ Assy loc 85
155 like 70 but fill=6 trcl = ( 47.1027 -62.8036 0.0000 )    u=3 $ Assy loc 86
156 like 70 but fill=6 trcl = ( -15.7009 -78.5045 0.0000 )    u=3 $ Assy loc 87
157 like 70 but fill=6 trcl = ( 0.0000 -78.5045 0.0000 )    u=3 $ Assy loc 88
158 like 70 but fill=6 trcl = ( 15.7009 -78.5045 0.0000 )    u=3 $ Assy loc 89
159 0         +31
              #70 #71 #72 #73 #74 #75 #76 #77 #78 #79
              #80 #81 #82 #83 #84 #85 #86 #87 #88 #89
              #90 #91 #92 #93 #94 #95 #96 #97 #98 #99
              #100 #101 #102 #103 #104 #105 #106 #107 #108 #109
              #110 #111 #112 #113 #114 #115 #116 #117 #118 #119      fill=4 u=3 $ Cavity
+y
160 0         -31
              #109 #110 #111 #112 #113 #114 #115 #116 #117 #118
              #119 #120 #121 #122 #123 #124 #125 #126 #127 #128
              #129 #130 #131 #132 #133 #134 #135 #136 #137 #138
              #139 #140 #141 #142 #143 #144 #145 #146 #147 #148
              #149 #150 #151 #152 #153 #154 #155 #156 #157 #158      fill=4 u=3 $ Cavity
-y
C Cells - Canister w/Weld Shield v1.2
161 0         -32 #172  #173  fill=3    u=2 $ Cavity
162 7 -7.9400 -38 +32.3      u=2 $ Canister Bottom
163 0         -33 +32.2 -36 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Bottom Drain Port
164 14 -3.9700 -34 +36 -37 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Middle Drain Port
165 0         -35 +37 -38.2 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Top Drain Port
166 like 163 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Bottom Vent Port
167 like 164 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Middle Vent Port
168 like 165 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Top Vent Port
169 7 -7.9400 -38 -32.3 +32.1     u=2 $ Canister Shell
170 7 -7.9400 -38 -32.1 +32.2 #163 #164 #165 #166 #167 #168     u=2 $ Lid
171 7 -7.9400 (-39 +42 +43) : (-40 +42 +43) : (-41 +42 +43)       u=2 $ Weld Shield
172 7 -7.9400 -46 +45 +44 -32.2 trcl = ( 62.7565 43.1314 0.0000 )   u=2 $ Drain port
shield
173 7 -7.9400 -46 +45 +44 -32.2 trcl = ( -62.7565 -43.1314 0.0000 )   u=2 $ Vent port
shield
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
174 6 -0.9982 +38 #171  -47     u=2 $ Outside water
175 0         +38 #171  +47     u=2 $ Outside void
C Transfer Cask Cells - v1.1.2
176 6 -0.9982 -65 -49 #186  fill=2 ( 0.0000 0.0000 6.9850 )   u=1 $ Cavity
177 8 -7.8212 -48 +49 -54    u=1 $ Bottom forging
178 8 -7.8212 -50 +49 +54 -55   u=1 $ Inner shell
179 0         -51 +50 +54 -55   u=1 $ Gap
180 11 -11.344 -52 +51 +54 -55   u=1 $ Lead shell
181 12 -1.6316 -53 +52 +54 -55   u=1 $ NS4FR shell
182 8 -7.8212 -48 +53 +54 -55   u=1 $ Outer shell
183 8 -7.8212 -48 +49 +55    u=1 $ Top forging
184 8 -7.8212 (-56 +57 -62) : (-56 -58 -62)      u=1 $ Door rail
185 8 -7.8212 -61 -59 +60 -62   u=1 $ Door steel
186 8 -7.8212 -64 +63     u=1 $ Weld bar
187 0         +48 #184  #185  #176    u=1 $ Void
C
C Detector Cells - Axial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ PortAzi
600  0  -600  +400  +500  $ AnnulusAzi
700  0  -700  +400  +500  +600  $ 1ft
800  0  -800  +400  +500  +600  +700  $ 1m
900  0  -900  +400  +500  +600  +700  +800  $ 2m
1000  0  -1000  +400  +500  +600  +700  +800  +900  $ 4m
1100  0  +400  +500  +600  +700  +800  +900  +1000  $ Exterior

C Fuel Assembly Surfaces - ng08b - v1.0
1 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 17.1704  $ Lower Nozzle
2 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 18.7579  $ Lower Plenum
3 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 399.7579  $ Fuel
4 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 428.4980  $ Upper Plenum
5 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 447.5480  $ Upper Nozzle
C Surfaces - Fuel Tube w/Poison v1.2
6 RPP -7.7343 7.7343 -7.7343 7.7343 7.6200 429.4124  $ Tube void
7 RPP -8.3693 8.3693 -8.3693 8.3693 7.6200 429.4124  $ Tube
8 RPP -7.7343 -7.4803 -6.7310 6.7310 9.2075 427.8249  $ Poison left
9 RPP 7.4803 7.7343 -6.7310 6.7310 9.2075 427.8249  $ Poison right
10 RPP -6.7310 6.7310 7.4803 7.7343 9.2075 427.8249  $ Poison top
11 RPP -6.7310 6.7310 -7.7343 -7.4803 9.2075 427.8249  $ Poison bottom
C Surfaces - BWR Basket v1.3
12  RPP -8.3693 8.3693 -8.3693 8.3693 7.6200 455.9300  $ Tube opening
13 8 RPP -11.0998 11.0998 -11.0998 11.0998 7.6200 455.9300  $ Tube radius
14  RPP 85.9213 87.5088 -8.3693 8.3693 7.6200 455.9300  $ Thick side support +x
15  RPP -87.5088 -85.9213 -8.3693 8.3693 7.6200 455.9300  $ Thick side support -x
16  RPP -8.3693 8.3693 85.9213 87.5088 7.6200 455.9300  $ Thick side support +y
17  RPP -8.3693 8.3693 -87.5088 -85.9213 7.6200 455.9300  $ Thick side support -y
18  RPP 86.8738 87.5088 -22.2250 22.2250 7.6200 429.4124  $ Thin side support +x
19  RPP -87.5088 -86.8738 -22.2250 22.2250 7.6200 429.4124  $ Thin side support -x
20  RPP -22.2250 22.2250 86.8738 87.5088 7.6200 429.4124  $ Thin side support +y
21  RPP -22.2250 22.2250 -87.5088 -86.8738 7.6200 429.4124  $ Thin side support -y
22  RPP -71.9667 71.9667 -55.4720 55.4720 7.6200 448.3100  $ Corner outer
23  RPP -71.1729 71.1729 -54.6783 54.6783 7.6200 448.3100  $ Corner inner
24  RPP -55.4720 55.4720 -71.9667 71.9667 7.6200 448.3100  $ Corner outer
25  RPP -54.6783 54.6783 -71.1729 71.1729 7.6200 448.3100  $ Corner inner
26 8 RPP -76.2402 76.2402 -76.2402 76.2402 7.6200 448.3100  $ Corner dia. outer
27 8 RPP -75.4465 75.4465 -75.4465 75.4465 7.6200 448.3100  $ Corner dia. inner
28  PX 0.0000       $ Cut plane
29  PY 0.0000       $ Cut plane
C Surfaces - BWR Canister Cavity v1.3
30 RPP -7.0084 7.0084 -7.0084 7.0084 0.0000 447.5481   $ Assy opening
31 PY 0.0000        $ Cut plane
C Surfaces - Canister w/Weld Shield v1.2
32 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 457.2000 90.1700   $ Cavity
33 CZ 2.6924         $ Bot Cylinder Radius
34 CZ 6.7691         $ Mid Cyclinder Radius
35 CZ 7.4041         $ Top Cylinder Radius
36 PZ 468.5538         $ Port plane bot/mid
37 PZ 477.2152         $ Port plane mid/top
38 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 487.0450 91.4400   $ Canister
39 RCC 0.0000 0.0000 480.0600 0.0000 0.0000 5.0800 78.1050   $ Weld shield bot
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
40 RCC 0.0000 0.0000 485.1400 0.0000 0.0000 5.0800 71.7550   $ Weld shield mid
41 RCC 0.0000 0.0000 490.2200 0.0000 0.0000 5.0800 66.6750   $ Weld shield top
42 RCC 62.7565 43.1314 480.0600 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout +x+y
43 RCC -62.7565 -43.1314 480.0600 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout -x-
y
44 PZ 450.8500          $ Port shield elevation
45 CZ 2.7051          $ Port shield ID
46 CZ 5.0800          $ Port shield OD
47 RCC 0.0000 0.0000 2.2338 0.0000 0.0000 471.8812 99.0000   $ Water jacket
C Transfer Cask Surfaces - v1.1.2
48 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 488.9500 111.6330  $ Cask
49 CZ 92.7100         $ Cavity
50 CZ 94.6150         $ Inner shell
51 CZ 94.7420         $ Gap
52 CZ 102.8700         $ Lead shell
53 CZ 108.4580         $ NS4FR shell
54 PZ 30.4800         $ Bottom forging
55 PZ 453.3900         $ Top forging
56 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door container
57 PY 97.0026         $ Inside rail +y
58 PY -97.0026         $ Inside rail -y
59 PY 96.5200         $ Door +y
60 PY -96.5200         $ Door -y
61 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000   $ Door prism
       108.4699 0.0000 0.0000 89.7374 -73.7172 0.0000
       -89.7374 -73.7172 0.0000
62 RCC 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000 111.6330  $ Door container
63 RCC 0.0000 0.0000 487.0450 0.0000 0.0000 1.9050 90.8049  $ Weld bar inner
64 RCC 0.0000 0.0000 487.0450 0.0000 0.0000 1.9050 92.7100  $ Weld bar outer
65 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 502.2850 111.6330  $ Container
C Axial Detector DTA (Surface)
400  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  515.1850  111.8600
401  CZ  9.3217
402  CZ  18.6433
403  CZ  27.9650
404  CZ  37.2867
405  CZ  46.6083
406  CZ  55.9300
407  CZ  65.2517
408  CZ  74.5733
409  CZ  83.8950
410  CZ  93.2167
411  CZ  102.5383
C Axial Detector DTAA (PortAzi)
500  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  515.2850  83.5533
501  CZ  68.7451
502     PX  0.0000
503  1  PX  0.0000
504  2  PX  0.0000
505  3  PX  0.0000
506  4  PX  0.0000
507  5  PX  0.0000
508  6  PX  0.0000
509  7  PX  0.0000
510  8  PX  0.0000
511  9  PX  0.0000
512  10  PX  0.0000
513  11  PX  0.0000
514  12  PX  0.0000
515  13  PX  0.0000
516  14  PX  0.0000
517  15  PX  0.0000
518     PY  0.0000
519  16  PX  0.0000
520  17  PX  0.0000
521  18  PX  0.0000
522  19  PX  0.0000
523  20  PX  0.0000
524  21  PX  0.0000
525  22  PX  0.0000
526  23  PX  0.0000
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
527  24  PX  0.0000
528  25  PX  0.0000
529  26  PX  0.0000
530  27  PX  0.0000
531  28  PX  0.0000
532  29  PX  0.0000
533  30  PX  0.0000
C Axial Detector DTAB (AnnulusAzi)
600  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  515.3850  92.7100
601  CZ  83.5533
602     PX  0.0000
603  8  PX  0.0000
604     PY  0.0000
605  23  PX  0.0000
C Axial Detector DTB (1ft)
700  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  545.6650  142.3400
701  CZ  11.8617
702  CZ  23.7233
703  CZ  35.5850
704  CZ  47.4467
705  CZ  59.3083
706  CZ  71.1700
707  CZ  83.0317
708  CZ  94.8933
709  CZ  106.7550
710  CZ  118.6167
711  CZ  130.4783
C Axial Detector DTC (1m)
800  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  615.1850  211.8600
801  CZ  17.6550
802  CZ  35.3100
803  CZ  52.9650
804  CZ  70.6200
805  CZ  88.2750
806  CZ  105.9300
807  CZ  123.5850
808  CZ  141.2400
809  CZ  158.8950
810  CZ  176.5500
811  CZ  194.2050
C Axial Detector DTD (2m)
900  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  715.1850  311.8600
901  CZ  25.9883
902  CZ  51.9767
903  CZ  77.9650
904  CZ  103.9533
905  CZ  129.9417
906  CZ  155.9300
907  CZ  181.9183
908  CZ  207.9067
909  CZ  233.8950
910  CZ  259.8833
911  CZ  285.8717
C Axial Detector DTE (4m)
1000  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  915.1850  511.8600
1001  CZ  42.6550
1002  CZ  85.3100
1003  CZ  127.9650
1004  CZ  170.6200
1005  CZ  213.2750
1006  CZ  255.9300
1007  CZ  298.5850
1008  CZ  341.2400
1009  CZ  383.8950
1010  CZ  426.5500
1011  CZ  469.2050

C
C Materials List - Common Materials - v1.4
C
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
C Homogenized Lower Nozzle
m1    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03 7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel
m3    92235 -3.7407E-02 40000 -1.4859E-01 24000 -1.5128E-04
      92238 -7.1074E-01 50000 -2.2692E-03 7014 -7.5639E-05
      8016 -1.0058E-01 26000 -1.8910E-04
C Homogenized Upper Plenum
m4    24000 -1.6451E-01 50000 -2.0233E-03 25055 -1.7302E-02
      26000 -6.0142E-01 7014 -6.7444E-05 28000 -8.2186E-02
      40000 -1.3249E-01
C Homogenized Upper Nozzle
m5    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99 6012 -0.01
C Neutron Poison
m9    13027 -0.6822 5010 -0.0448 5011 -0.2040
      6012 -0.0690
C Aluminum
m10   13027 -1.0
C Lead
m11   82000 -1.0
C NS-4-FR
m12   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m13   26000 -0.014 20000 -0.044 14000 -0.337
      1001 -0.010 8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Balsa
m15   6012 6 1001 10 8016 5
nonu $ No subcritical multiplication
C
C Cell Importances
C
imp:p 1 193r 0
C
C BWR Source Definition - Upper Nozzle Response to Group 12
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=400:176:161:d5:5
si1   -7.00786 7.00786
sp1   0 1
si2   -7.00786 7.00786
sp2   0 1
si3   428.4980 447.5480
sp3   0 1
si4   1.220E+00 1.440E+00
sp4   0 1
C Source Information
si5 1                 70  71  72
              73  74  75  76  77  78  79
          80  81  82  83  84  85  86  87
          89  90  91  92  93  94  95  96  97
      98  99 100 101 102 103 104 105 106 107 108
     109 110 111 112 113 114 115 116 117 118 119
     120 121 122 123 124 125 126 127 128 129 130
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
          131 132 133 134 135 136 137 138 139
              141 142 143 144 145 146 147 148
              149 150 151 152 153 154 155
                      156 157 158
C Source Probability
sp5                   1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0
                      1.0 1.0 1.0
C Source Biasing
sb5                           1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                              1E+00 1E+00 1E+00
mode p
nps 8000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Top Axial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=0 0 454 origin=0.1 0.1 -14
     imesh 90.2 91.4 92.7 94.6 102.7 108.5 111.6 611.6
     iints 1 1 1 1 1 1 1 1
     jmesh 1 14 21 38 39 420 449 468 478 516 1016
     jints 1 3 2 1 1 10 1 1 1 7 1
     kmesh 1
     kints 1
C wwge:p  1e-3 1 20
fc2 Axial Surface Tally
f2:p +400.2
fm2 8.7000E+01
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Axial PortAzi Tally Q1 (+x+y)
f12:p +500.2
fm12 8.7000E+01
fs12 -501  -502  -518
     -503  -504  -505  -506  -507  -508
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
     -509  -510  -511  -512  -513  -514
     -515  -516  -517  T
sd12 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf12
fc22 Axial PortAzi Tally Q2 (-x+y)
f22:p +500.2
fm22 8.7000E+01
fs22 -501  +502  -518
     +519  +520  +521  +522  +523  +524
     +525  +526  +527  +528  +529  +530
     +531  +532  +533  T
sd22 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf22
fc32 Axial PortAzi Tally Q3 (-x-y)
f32:p +500.2
fm32 8.7000E+01
fs32 -501  +502  +518
     +503  +504  +505  +506  +507  +508
     +509  +510  +511  +512  +513  +514
     +515  +516  +517  T
sd32 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf32
fc42 Axial PortAzi Tally Q4 (+x-y)
f42:p +500.2
fm42 8.7000E+01
fs42 -501  -502  +518
     -519  -520  -521  -522  -523  -524
     -525  -526  -527  -528  -529  -530
     -531  -532  -533  T
sd42 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf42
fc52 Axial AnnulusAzi Tally Q1 (+x+y)
f52:p +600.2
fm52 8.7000E+01
fs52 -601  -602  -604
     -603  T
sd52 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf52
fc62 Axial AnnulusAzi Tally Q2 (-x+y)
f62:p +600.2
fm62 8.7000E+01
fs62 -601  +602  -604
     +605  T
sd62 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf62
fc72 Axial AnnulusAzi Tally Q3 (-x-y)
f72:p +600.2
fm72 8.7000E+01
fs72 -601  +602  +604
     +603  T
sd72 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf72
fc82 Axial AnnulusAzi Tally Q4 (+x-y)
f82:p +600.2
fm82 8.7000E+01
fs82 -601  -602  +604
     -605  T
sd82 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf82
fc92 Axial 1ft Tally
f92:p +700.2
fm92 8.7000E+01
fs92  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  T
tf92
fc102 Axial 1m Tally
f102:p +800.2
fm102 8.7000E+01
fs102  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  T
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
tf102
fc112 Axial 2m Tally
f112:p +900.2
fm112 8.7000E+01
fs112  -901  -902  -903  -904  -905  -906
     -907  -908  -909  -910  -911  T
tf112
fc122 Axial 4m Tally
f122:p +1000.2
fm122 8.7000E+01
fs122  -1001  -1002  -1003  -1004  -1005  -1006
     -1007  -1008  -1009  -1010  -1011  T
tf122
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 5.625 degree rotation around z-axis
*TR1 0.0 0.0 0.0 5.625 95.625 90 -84.375 5.625 90 90 90 0
C 11.25 degree rotation around z-axis
*TR2 0.0 0.0 0.0 11.250 101.250 90 -78.750 11.250 90 90 90 0
C 16.875 degree rotation around z-axis
*TR3 0.0 0.0 0.0 16.875 106.875 90 -73.125 16.875 90 90 90 0
C 22.5 degree rotation around z-axis
*TR4 0.0 0.0 0.0 22.500 112.500 90 -67.500 22.500 90 90 90 0
C 28.125 degree rotation around z-axis
*TR5 0.0 0.0 0.0 28.125 118.125 90 -61.875 28.125 90 90 90 0
C 33.75 degree rotation around z-axis
*TR6 0.0 0.0 0.0 33.750 123.750 90 -56.250 33.750 90 90 90 0
C 39.375 degree rotation around z-axis
*TR7 0.0 0.0 0.0 39.375 129.375 90 -50.625 39.375 90 90 90 0
C 45 degree rotation around z-axis
*TR8 0.0 0.0 0.0 45.000 135.000 90 -45.000 45.000 90 90 90 0
C 50.625 degree rotation around z-axis
*TR9 0.0 0.0 0.0 50.625 140.625 90 -39.375 50.625 90 90 90 0
C 56.25 degree rotation around z-axis
*TR10 0.0 0.0 0.0 56.250 146.250 90 -33.750 56.250 90 90 90 0
C 61.875 degree rotation around z-axis
*TR11 0.0 0.0 0.0 61.875 151.875 90 -28.125 61.875 90 90 90 0
C 67.5 degree rotation around z-axis
*TR12 0.0 0.0 0.0 67.500 157.500 90 -22.500 67.500 90 90 90 0
C 73.125 degree rotation around z-axis
*TR13 0.0 0.0 0.0 73.125 163.125 90 -16.875 73.125 90 90 90 0
C 78.75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 78.750 168.750 90 -11.250 78.750 90 90 90 0
C 84.375 degree rotation around z-axis
*TR15 0.0 0.0 0.0 84.375 174.375 90 -5.625 84.375 90 90 90 0
C 95.625 degree rotation around z-axis
*TR16 0.0 0.0 0.0 95.625 185.625 90 5.625 95.625 90 90 90 0
C 101.25 degree rotation around z-axis
*TR17 0.0 0.0 0.0 101.250 191.250 90 11.250 101.250 90 90 90 0
C 106.875 degree rotation around z-axis
*TR18 0.0 0.0 0.0 106.875 196.875 90 16.875 106.875 90 90 90 0
C 112.5 degree rotation around z-axis
*TR19 0.0 0.0 0.0 112.500 202.500 90 22.500 112.500 90 90 90 0
C 118.125 degree rotation around z-axis
*TR20 0.0 0.0 0.0 118.125 208.125 90 28.125 118.125 90 90 90 0
C 123.75 degree rotation around z-axis
*TR21 0.0 0.0 0.0 123.750 213.750 90 33.750 123.750 90 90 90 0
C 129.375 degree rotation around z-axis
*TR22 0.0 0.0 0.0 129.375 219.375 90 39.375 129.375 90 90 90 0
```

Figure 5.8.8-4 Transfer Cask Sample Input File – BWR TSC (cont'd)

```
C 135 degree rotation around z-axis
*TR23 0.0 0.0 0.0 135.000 225.000 90 45.000 135.000 90 90 90 0
C 140.625 degree rotation around z-axis
*TR24 0.0 0.0 0.0 140.625 230.625 90 50.625 140.625 90 90 90 0
C 146.25 degree rotation around z-axis
*TR25 0.0 0.0 0.0 146.250 236.250 90 56.250 146.250 90 90 90 0
C 151.875 degree rotation around z-axis
*TR26 0.0 0.0 0.0 151.875 241.875 90 61.875 151.875 90 90 90 0
C 157.5 degree rotation around z-axis
*TR27 0.0 0.0 0.0 157.500 247.500 90 67.500 157.500 90 90 90 0
C 163.125 degree rotation around z-axis
*TR28 0.0 0.0 0.0 163.125 253.125 90 73.125 163.125 90 90 90 0
C 168.75 degree rotation around z-axis
*TR29 0.0 0.0 0.0 168.750 258.750 90 78.750 168.750 90 90 90 0
C 174.375 degree rotation around z-axis
*TR30 0.0 0.0 0.0 174.375 264.375 90 84.375 174.375 90 90 90 0
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC

```
MAGNASTOR VCC - strShlDryRadFn_17a_07g
C Radial Biasing - Fuel Neutron Source
C Fuel Assembly Cells - 17a - v1.1
1 1 -1.8782 -1      u=6 $ Lower Nozzle
2 2 -2.6798 -2 +1     u=6 $ Lower Plenum
3 3 -3.8195 -3 +2     u=6 $ Fuel
4 4 -0.7412 -4 +3     u=6 $ Upper Plenum
5 5 -1.8385 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube  v1.3
7 8 -7.8212 -8 +7     u=5 $ Tube
8 9 -2.6336 -9 : -10 : -11 : -12      u=5 $ Poison
9 0          #7  #8  -6   u=5 $ Outside below PFE
10 0          #7  #8  +6   u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
11 0          -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )     u=4 $ Assy loc 1
12 like 11 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )     u=4 $ Assy loc 3
13 like 11 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )     u=4 $ Assy loc 4
14 like 11 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )     u=4 $ Assy loc 6
15 like 11 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )     u=4 $ Assy loc 8
16 like 11 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )     u=4 $ Assy loc 9
17 like 11 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )     u=4 $ Assy loc 11
18 like 11 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )     u=4 $ Assy loc 13
19 like 11 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )     u=4 $ Assy loc 15
20 like 11 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )     u=4 $ Assy loc 17
21 like 11 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )     u=4 $ Assy loc 19
22 like 11 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )     u=4 $ Assy loc 21
23 like 11 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 23
24 like 11 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 25
25 like 11 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 27
26 like 11 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 29
27 like 11 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 30
28 like 11 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )     u=4 $ Assy loc 32
29 like 11 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 34
30 like 11 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 35
31 like 11 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 37
32 8 -7.8212 -15 #19 #26      u=4 $ Side support +x
33 8 -7.8212 -16 #16 #23      u=4 $ Side support -x
34 8 -7.8212 -17 #11 #12      u=4 $ Side support +y
35 8 -7.8212 -18 #30 #31      u=4 $ Side support -y
36 8 -7.8212 -19 +20 +21      u=4 $ Corner
37 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
#11 #12 #16 #19 #23 #26 #30 #31       u=4 $ Corner diagonal
38 0          -6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
#22 #23 #24 #25 #26 #27 #28 #29 #30 #31
#32 #33 #34 #35 #36 #37      u=4 $ Basket below PFE
39 0          +6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
#22 #23 #24 #25 #26 #27 #28 #29 #30 #31
#32 #33 #34 #35 #36 #37      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
40 0          -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )     u=3 $ Assy loc 1
41 like 40 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )     u=3 $ Assy loc 2
42 like 40 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )     u=3 $ Assy loc 3
43 like 40 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )     u=3 $ Assy loc 4
44 like 40 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )     u=3 $ Assy loc 5
45 like 40 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )     u=3 $ Assy loc 6
46 like 40 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )     u=3 $ Assy loc 7
47 like 40 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )     u=3 $ Assy loc 8
48 like 40 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )     u=3 $ Assy loc 9
49 like 40 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )     u=3 $ Assy loc 10
50 like 40 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )     u=3 $ Assy loc 11
51 like 40 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )     u=3 $ Assy loc 12
52 like 40 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )     u=3 $ Assy loc 13
53 like 40 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )     u=3 $ Assy loc 14
54 like 40 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )     u=3 $ Assy loc 15
55 like 40 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )     u=3 $ Assy loc 16
56 like 40 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )     u=3 $ Assy loc 17
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
57 like 40 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
58 like 40 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
59 like 40 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
60 like 40 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
61 like 40 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
62 like 40 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
63 like 40 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
64 like 40 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
65 like 40 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
66 like 40 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
67 like 40 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
68 like 40 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
69 like 40 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
70 like 40 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
71 like 40 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
72 like 40 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
73 like 40 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
74 like 40 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
75 like 40 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
76 like 40 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
77 0         #40 #41 #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52
#53 #54 #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65
#66 #67 #68 #69 #70 #71 #72 #73 #74 #75 #76      fill=4 u=3 $ Cavity
C Cells - Canister v1.3
78 0         -24 fill=3      u=2 $ Cavity
79 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
80 7 -7.9400 -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Bottom Drain Port
81 7 -7.9400 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Middle Drain Port
82 7 -7.9400 -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Top Drain Port
83 like 80 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Bottom Vent Port
84 like 81 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Middle Vent Port
85 like 82 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Top Vent Port
86 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
87 8 -7.8212 -31 -24.1 +24.2 -29 #80 #81  #83 #84   u=2 $ Lower lid
88 7 -7.9400 -31 -24.1 +29 #81 #82  #84 #85    u=2 $ Upper lid
89 0         +31       u=2 $ Outside
C VCC Cells - v1.3.0_ng17a
90 8 -7.8212 -32       u=1 $ Pedestal plate
91 8 -7.8212 -33 +34      u=1 $ Stand
92 8 -7.8212 -39 +40 +46 +47    u=1 $ Bottom plate outer
93 8 -7.8212 (-40 +41 -35) : (-40 +41 -36)       u=1 $ Bottom plate connector
94 8 -7.8212 -41       u=1 $ Bottom plate inner
95 8 -7.8212 (-34 -56 +57 -43) : (-34 -54 +55 +56 -43)   u=1 $ Support rail inside stand
96 8 -7.8212 (+33 -56 +57 -43) : (+33 -54 +55 +56 -43)   u=1 $ Support rail outside stand
97 8 -7.8212 (-51 +53 +35 +36 -44) :
(-52 +53 +35 +36 -44 +51)       u=1 $ Air inlet top
98 8 -7.8212 (-48 +46 +50 -44 +35 +36 +39) :
(-49 +47 +50 -44 +35 +36 +39)       u=1 $ Air inlet wall
99 8 -7.8212 (-35 +37 +33 -44 +39) : (-36 +38 +33 -44 +39) u=1 $ Air inlet angular wall
100 8 -7.8212 (-50 -48 +46 +35 +36 +47 +39) :
(-50 -49 +47 +35 +36 +46 +39)       u=1 $ Air inlet remaining wall
101 13 -2.3234 -44 +42 +35 +36 +39 +51 +52 +48 +49 +45      fill=7 u=1 $ Concrete
102 13 -2.3234 -45       u=1 $ Concrete pad
103 8 -7.8212 -42 +43      u=1 $ Liner
104 13 -2.3234 -58 +42      u=1 $ Top flange
105 8 -7.8212 (-59 +71 -43) :
(-60 +72 -43) :
(-61 +73 -43) :
(-62 +74 -43) :
(-63 +75 -43) :
(-64 +76 -43) :
(-65 +77 -43) :
(-66 +78 -43) :
(-67 +79 -43) :
(-68 +80 -43) :
(-69 +81 -43) :
              (-70 +82 -43)       u=1 $ Standoffs
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
106 0          (-39 +40 -46 +84 +87 +89 +92) :
(-39 +40 -47 +94 +97 +99 +102)       u=1 $ Bottom plate outer void
107 0          -40 +41 +35 +36    u=1 $ Bottom plate connector void
108 0          (-34 -57 -43) : (-34 -55 +56 -43)    u=1 $ Support rail inside stand void
109 0          (+33 -57 -43) : (+33 -55 +56 -43)    u=1 $ Support rail outside stand void
110 0          (-46 +33 +35 +36 -44 +39) :
(-47 +33 +35 +36 -44 +39 +46)       u=1 $ Air inlet void
111 0          -53 +33 +35 +36       u=1 $ Air inlet top void
112 0          (-37 +39 +33) : (-38 +39 +33)       u=1 $ Connector void
113 0          -34 +54 +56       u=1 $ Stand void
114 0          -43 +32 +33 +54 +56 #105
fill=2 ( 0.0000 0.0000 6.9850 )       u=1 $ Cavity
115 0          +44 +42 +58 fill=9 ( 0.0000 0.0000 485.4702 )   u=1 $ Outside
C VCC Rebar Cells - v1.3.0_ng17a
116 8 -7.8212 -83       u=7 $ Outer hoop 1
117 8 -7.8212 -84       u=7 $ Outer hoop 2
118 8 -7.8212 -85       u=7 $ Outer hoop 3
119 8 -7.8212 -86       u=7 $ Outer hoop 4
120 8 -7.8212 -87       u=7 $ Outer hoop 5
121 8 -7.8212 -88       u=7 $ Outer hoop 6
122 8 -7.8212 -89       u=7 $ Outer hoop 7
123 8 -7.8212 -90       u=7 $ Outer hoop 8
124 8 -7.8212 -91       u=7 $ Outer hoop 9
125 8 -7.8212 -92       u=7 $ Outer hoop 10
126 8 -7.8212 -93       u=7 $ Outer hoop 11
127 8 -7.8212 -94       u=7 $ Outer hoop 12
128 8 -7.8212 -95       u=7 $ Outer hoop 13
129 8 -7.8212 -96       u=7 $ Outer hoop 14
130 8 -7.8212 -97       u=7 $ Outer hoop 15
131 8 -7.8212 -98       u=7 $ Outer hoop 16
132 8 -7.8212 -99       u=7 $ Outer hoop 17
133 8 -7.8212 -100       u=7 $ Outer hoop 18
134 8 -7.8212 -101       u=7 $ Outer hoop 19
135 8 -7.8212 -102       u=7 $ Outer hoop 20
136 8 -7.8212 -103       u=7 $ Outer hoop 21
137 8 -7.8212 -104       u=7 $ Outer hoop 22
138 8 -7.8212 -105       u=7 $ Outer hoop 23
139 8 -7.8212 -106       u=7 $ Outer hoop 24
140 8 -7.8212 -107       u=7 $ Outer hoop 25
141 8 -7.8212 -108       u=7 $ Outer hoop 26
142 8 -7.8212 -109       u=7 $ Outer hoop 27
143 8 -7.8212 -110       u=7 $ Outer hoop 28
144 8 -7.8212 -111       u=7 $ Outer hoop 29
145 8 -7.8212 -112       u=7 $ Outer hoop 30
146 8 -7.8212 -113       u=7 $ Outer hoop 31
147 8 -7.8212 -114       u=7 $ Outer hoop 32
148 8 -7.8212 -115       u=7 $ Outer hoop 33
149 8 -7.8212 -116       u=7 $ Outer hoop 34
150 8 -7.8212 -117       u=7 $ Outer hoop 35
151 8 -7.8212 -118       u=7 $ Outer hoop 36
152 8 -7.8212 -119       u=7 $ Outer hoop 37
153 8 -7.8212 -120       u=7 $ Outer hoop 38
154 8 -7.8212 -121       u=7 $ Outer hoop 39
155 8 -7.8212 -122       u=7 $ Outer hoop 40
156 8 -7.8212 -123       u=7 $ Outer hoop 41
157 8 -7.8212 -124       u=7 $ Outer hoop 42
158 8 -7.8212 -125       u=7 $ Outer hoop 43
159 8 -7.8212 -126       u=7 $ Outer hoop 44
160 8 -7.8212 -127       u=7 $ Outer hoop 45
161 8 -7.8212 -128       u=7 $ Outer hoop 46
162 8 -7.8212 -129       u=7 $ Outer hoop 47
163 8 -7.8212 -130       u=7 $ Outer hoop 48
164 13 -2.3234 #116 #117 #118 #119 #120 #121 #122
#123 #124 #125 #126 #127 #128 #129 #130 #131 #132
#133 #134 #135 #136 #137 #138 #139 #140 #141 #142
#143 #144 #145 #146 #147 #148 #149 #150 #151 #152
#153 #154 #155 #156 #157 #158 #159 #160 #161 #162
#163       fill=8 u=7
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
165 8 -7.8212 -131   trcl = ( 160.3375 0.0000 0.0000 )    u=8 $ Outer bar 1
166 like 165 but   trcl = ( 159.3293 17.9521 0.0000 )    u=8 $ Outer bar 2
167 like 165 but   trcl = ( 156.3175 35.6785 0.0000 )    u=8 $ Outer bar 3
168 like 165 but   trcl = ( 151.3399 52.9561 0.0000 )    u=8 $ Outer bar 4
169 like 165 but   trcl = ( 144.4591 69.5678 0.0000 )    u=8 $ Outer bar 5
170 like 165 but   trcl = ( 135.7616 85.3047 0.0000 )    u=8 $ Outer bar 6
171 like 165 but   trcl = ( 125.3569 99.9688 0.0000 )    u=8 $ Outer bar 7
172 like 165 but   trcl = ( 113.3757 113.3757 0.0000 )    u=8 $ Outer bar 8
173 like 165 but   trcl = ( 99.9688 125.3569 0.0000 )    u=8 $ Outer bar 9
174 like 165 but   trcl = ( 85.3047 135.7616 0.0000 )    u=8 $ Outer bar 10
175 like 165 but   trcl = ( 69.5678 144.4591 0.0000 )    u=8 $ Outer bar 11
176 like 165 but   trcl = ( 52.9561 151.3399 0.0000 )    u=8 $ Outer bar 12
177 like 165 but   trcl = ( 35.6785 156.3175 0.0000 )    u=8 $ Outer bar 13
178 like 165 but   trcl = ( 17.9521 159.3293 0.0000 )    u=8 $ Outer bar 14
179 like 165 but   trcl = ( 0.0000 160.3375 0.0000 )    u=8 $ Outer bar 15
180 like 165 but   trcl = ( -17.9521 159.3293 0.0000 )    u=8 $ Outer bar 16
181 like 165 but   trcl = ( -35.6785 156.3175 0.0000 )    u=8 $ Outer bar 17
182 like 165 but   trcl = ( -52.9561 151.3399 0.0000 )    u=8 $ Outer bar 18
183 like 165 but   trcl = ( -69.5678 144.4591 0.0000 )    u=8 $ Outer bar 19
184 like 165 but   trcl = ( -85.3047 135.7616 0.0000 )    u=8 $ Outer bar 20
185 like 165 but   trcl = ( -99.9688 125.3569 0.0000 )    u=8 $ Outer bar 21
186 like 165 but   trcl = ( -113.3757 113.3757 0.0000 )    u=8 $ Outer bar 22
187 like 165 but   trcl = ( -125.3569 99.9688 0.0000 )    u=8 $ Outer bar 23
188 like 165 but   trcl = ( -135.7616 85.3047 0.0000 )    u=8 $ Outer bar 24
189 like 165 but   trcl = ( -144.4591 69.5678 0.0000 )    u=8 $ Outer bar 25
190 like 165 but   trcl = ( -151.3399 52.9561 0.0000 )    u=8 $ Outer bar 26
191 like 165 but   trcl = ( -156.3175 35.6785 0.0000 )    u=8 $ Outer bar 27
192 like 165 but   trcl = ( -159.3293 17.9521 0.0000 )    u=8 $ Outer bar 28
193 like 165 but   trcl = ( -160.3375 0.0000 0.0000 )    u=8 $ Outer bar 29
194 like 165 but   trcl = ( -159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 30
195 like 165 but   trcl = ( -156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 31
196 like 165 but   trcl = ( -151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 32
197 like 165 but   trcl = ( -144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 33
198 like 165 but   trcl = ( -135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 34
199 like 165 but   trcl = ( -125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 35
200 like 165 but   trcl = ( -113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 36
201 like 165 but   trcl = ( -99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 37
202 like 165 but   trcl = ( -85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 38
203 like 165 but   trcl = ( -69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 39
204 like 165 but   trcl = ( -52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 40
205 like 165 but   trcl = ( -35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 41
206 like 165 but   trcl = ( -17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 42
207 like 165 but   trcl = ( 0.0000 -160.3375 0.0000 )    u=8 $ Outer bar 43
208 like 165 but   trcl = ( 17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 44
209 like 165 but   trcl = ( 35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 45
210 like 165 but   trcl = ( 52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 46
211 like 165 but   trcl = ( 69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 47
212 like 165 but   trcl = ( 85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 48
213 like 165 but   trcl = ( 99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 49
214 like 165 but   trcl = ( 113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 50
215 like 165 but   trcl = ( 125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 51
216 like 165 but   trcl = ( 135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 52
217 like 165 but   trcl = ( 144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 53
218 like 165 but   trcl = ( 151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 54
219 like 165 but   trcl = ( 156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 55
220 like 165 but   trcl = ( 159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 56
221 13 -2.3234 #165 #166 #167
        #168 #169 #170 #171 #172 #173 #174 #175 #176 #177
        #178 #179 #180 #181 #182 #183 #184 #185 #186 #187
        #188 #189 #190 #191 #192 #193 #194 #195 #196 #197
        #198 #199 #200 #201 #202 #203 #204 #205 #206 #207
        #208 #209 #210 #211 #212 #213 #214 #215 #216 #217
        #218 #219 #220          u=8
C VCC Lid Cells - v1.3.0_ng17a
222 13 -2.3234 -133 +132      u=9 $ Lid base
223 13 -2.3234 -135 +136      u=9 $ Lid base disk
224 8 -7.8212 -136 +137 +145 +146    u=9 $ Lid liner
225 8 -7.8212 -139 +140      u=9 $ Anchor steel -x-y
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
226 8 -7.8212 -141 +142      u=9 $ Anchor steel +x+y
227 8 -7.8212 -134 +133 -143 trcl = ( 71.1200 123.1835 0.0000 )    u=9 $ Lift support
228 like 227 but   trcl = ( -123.1835 71.1200 0.0000 )    u=9 $ Lift support
229 like 227 but   trcl = ( -71.1200 -123.1835 0.0000 )    u=9 $ Lift support
230 like 227 but   trcl = ( 123.1835 -71.1200 0.0000 )    u=9 $ Lift support
231 8 -7.8212 -149 +137 +136     u=9 $ Sectional flange
232 8 -7.8212 (-145 +146 +147 -134 +144) : (-146 +145 +148 -134 +144)   u=9 $ Outlet
steel
233 8 -7.8212 -150       u=9 $ Lid top
234 8 -7.8212 -151 +152      u=9 $ Lid shell
235 13 -2.2432 -152       u=9 $ Lid concrete
236 13 -2.3234 -134 +133 +145 +146 +136 +139 +141 +137
        #227 #228 #229 #230 #231 #233        u=9 $ Concrete
237 13 -2.3234 -132 +135 +138     u=9 $ Lid base void 1
238 8 -7.8212 -132 +135 -138 +137    u=9 $ Lid base void 2
239 0         (-147 +148 -134 +144) : (-148 +147 -134 +144)       u=9 $ Outlet void
240 0         #222 #223 #224 #225 #226 #227 #228 #229 #230
              #231 #232 #233 #234 #235 #236 #237 #238 #239        u=9 $ Outside
C Detector Cells - Radial Biasing
399  0  -399  fill=1  $ Cask
400  0  -400  +399  $ Surface
500  0  -500  +399  +400  $ 1ft
600  0  -600  +399  +400  +500  $ 1m
700  0  -700  +399  +400  +500  +600  $ 2m
800  0  -800  +399  +400  +500  +600  +700  $ 4m
900  0  +399  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - 17a - v1.1
1 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 6.8580  $ Lower Nozzle
2 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 8.5979  $ Lower Plenum
3 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 374.3579  $ Fuel
4 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 396.5702  $ Upper Plenum
5 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 405.8920  $ Upper Nozzle
6 PZ 252.4379       $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 9 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 9 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 9 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.5
23 RPP -10.7015 10.7015 -10.7015 10.7015 0.0000 405.8921   $ Assy opening
C Surfaces - Canister v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1962         $ Lower/upper lid
30 PZ 459.5114         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
C VCC Surfaces - v1.3.0_ng17a
32  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
33  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 63.4999  $ Stand outer
34  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 62.3888  $ Stand inner
35 9 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate A
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
36 10 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate B
37 9 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall A
38 10 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall B
39  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
40  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 100.3300  $ Connector radius
41  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
42  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 105.41  $ VCC liner outer
43  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 100.965  $ VCC liner inner
44  RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 618.2362 172.7200  $ Concrete
45  RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
46  RPP -172.7200 172.7200 -63.5000 63.5000 -32.7660 -21.4630   $ Air inlet void X
47  RPP -63.5000 63.5000 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet void Y
48  RPP -172.7200 172.7200 -64.7700 64.7700 -32.7660 -21.4630   $ Air inlet wall X
49  RPP -64.7700 64.7700 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet wall Y
50  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 11.3030 100.3300  $ Air inlet divider
51  RPP -172.7200 172.7200 -64.7700 64.7700 -21.4630 -16.3830   $ Air inlet top X
52  RPP -64.7700 64.7700 -172.7200 172.7200 -21.4630 -16.3830   $ Air inlet top Y
53  RCC 0.0000 0.0000 -21.4630 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
54  RPP -106.6800 106.6800 -5.7150 5.7150 -16.3830 -5.0800   $ Support rail exterior X
55  RPP -106.6800 106.6800 -4.4450 4.4450 -16.3830 -5.0800   $ Support rail interior X
56  RPP -5.7150 5.7150 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail exterior Y
57  RPP -4.4450 4.4450 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail interior Y
58  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 2.5400 115.5700  $ Top flange
59  RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 1
60 11 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 2
61 12 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 3
62 9 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 4
63 13 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 5
64 14 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 6
65  RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 7
66 11 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 8
67 12 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 9
68 9 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 10
69 13 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 11
70 14 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 12
71  RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 1
72 11 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 2
73 12 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 3
74 9 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 4
75 13 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 5
76 14 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 6
77  RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 7
78 11 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 8
79 12 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 9
80 9 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 10
81 13 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 11
82 14 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 12
C VCC Rebar Surfaces - v1.3.0_ng17a
83  TZ 0.0000 0.0000 -1.4022 162.2425 0.9525 0.9525   $ Outer hoop 1
84  TZ 0.0000 0.0000 8.4986 162.2425 0.9525 0.9525   $ Outer hoop 2
85  TZ 0.0000 0.0000 18.3994 162.2425 0.9525 0.9525   $ Outer hoop 3
86  TZ 0.0000 0.0000 28.3003 162.2425 0.9525 0.9525   $ Outer hoop 4
87  TZ 0.0000 0.0000 38.2011 162.2425 0.9525 0.9525   $ Outer hoop 5
88  TZ 0.0000 0.0000 48.1019 162.2425 0.9525 0.9525   $ Outer hoop 6
89  TZ 0.0000 0.0000 58.0027 162.2425 0.9525 0.9525   $ Outer hoop 7
90  TZ 0.0000 0.0000 67.9035 162.2425 0.9525 0.9525   $ Outer hoop 8
91  TZ 0.0000 0.0000 77.8043 162.2425 0.9525 0.9525   $ Outer hoop 9
92  TZ 0.0000 0.0000 87.7052 162.2425 0.9525 0.9525   $ Outer hoop 10
93  TZ 0.0000 0.0000 97.6060 162.2425 0.9525 0.9525   $ Outer hoop 11
94  TZ 0.0000 0.0000 107.5068 162.2425 0.9525 0.9525   $ Outer hoop 12
95  TZ 0.0000 0.0000 117.4076 162.2425 0.9525 0.9525   $ Outer hoop 13
96  TZ 0.0000 0.0000 127.3084 162.2425 0.9525 0.9525   $ Outer hoop 14
97  TZ 0.0000 0.0000 137.2092 162.2425 0.9525 0.9525   $ Outer hoop 15
98  TZ 0.0000 0.0000 147.1101 162.2425 0.9525 0.9525   $ Outer hoop 16
99  TZ 0.0000 0.0000 157.0109 162.2425 0.9525 0.9525   $ Outer hoop 17
100  TZ 0.0000 0.0000 166.9117 162.2425 0.9525 0.9525   $ Outer hoop 18
101  TZ 0.0000 0.0000 176.8125 162.2425 0.9525 0.9525   $ Outer hoop 19
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
102  TZ 0.0000 0.0000 186.7133 162.2425 0.9525 0.9525   $ Outer hoop 20
103  TZ 0.0000 0.0000 196.6141 162.2425 0.9525 0.9525   $ Outer hoop 21
104  TZ 0.0000 0.0000 206.5150 162.2425 0.9525 0.9525   $ Outer hoop 22
105  TZ 0.0000 0.0000 216.4158 162.2425 0.9525 0.9525   $ Outer hoop 23
106  TZ 0.0000 0.0000 226.3166 162.2425 0.9525 0.9525   $ Outer hoop 24
107  TZ 0.0000 0.0000 236.2174 162.2425 0.9525 0.9525   $ Outer hoop 25
108  TZ 0.0000 0.0000 246.1182 162.2425 0.9525 0.9525   $ Outer hoop 26
109  TZ 0.0000 0.0000 256.0190 162.2425 0.9525 0.9525   $ Outer hoop 27
110  TZ 0.0000 0.0000 265.9199 162.2425 0.9525 0.9525   $ Outer hoop 28
111  TZ 0.0000 0.0000 275.8207 162.2425 0.9525 0.9525   $ Outer hoop 29
112  TZ 0.0000 0.0000 285.7215 162.2425 0.9525 0.9525   $ Outer hoop 30
113  TZ 0.0000 0.0000 295.6223 162.2425 0.9525 0.9525   $ Outer hoop 31
114  TZ 0.0000 0.0000 305.5231 162.2425 0.9525 0.9525   $ Outer hoop 32
115  TZ 0.0000 0.0000 315.4239 162.2425 0.9525 0.9525   $ Outer hoop 33
116  TZ 0.0000 0.0000 325.3248 162.2425 0.9525 0.9525   $ Outer hoop 34
117  TZ 0.0000 0.0000 335.2256 162.2425 0.9525 0.9525   $ Outer hoop 35
118  TZ 0.0000 0.0000 345.1264 162.2425 0.9525 0.9525   $ Outer hoop 36
119  TZ 0.0000 0.0000 355.0272 162.2425 0.9525 0.9525   $ Outer hoop 37
120  TZ 0.0000 0.0000 364.9280 162.2425 0.9525 0.9525   $ Outer hoop 38
121  TZ 0.0000 0.0000 374.8288 162.2425 0.9525 0.9525   $ Outer hoop 39
122  TZ 0.0000 0.0000 384.7297 162.2425 0.9525 0.9525   $ Outer hoop 40
123  TZ 0.0000 0.0000 394.6305 162.2425 0.9525 0.9525   $ Outer hoop 41
124  TZ 0.0000 0.0000 404.5313 162.2425 0.9525 0.9525   $ Outer hoop 42
125  TZ 0.0000 0.0000 414.4321 162.2425 0.9525 0.9525   $ Outer hoop 43
126  TZ 0.0000 0.0000 424.3329 162.2425 0.9525 0.9525   $ Outer hoop 44
127  TZ 0.0000 0.0000 434.2337 162.2425 0.9525 0.9525   $ Outer hoop 45
128  TZ 0.0000 0.0000 444.1346 162.2425 0.9525 0.9525   $ Outer hoop 46
129  TZ 0.0000 0.0000 454.0354 162.2425 0.9525 0.9525   $ Outer hoop 47
130  TZ 0.0000 0.0000 463.9362 162.2425 0.9525 0.9525   $ Outer hoop 48
131  RCC 0.0000 0.0000 -11.3030 0.0000 0.0000 485.1400 0.9525  $ Bar
C VCC Lid Surfaces - v1.3.0_ng17a
132  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 116.459  $ Lid base
133  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 172.7199  $ Lid base outer
134  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 54.1020 172.7199  $ Lid container
135  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 0.9525 116.4590  $ Lid base disk
136  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 48.7045 101.6  $ Lid liner
137  CZ 100.965        $ Lid liner inner
138  CZ 101.6        $ Lid liner outer
139 9 RPP -15.2400 15.2400 125.5776 161.4424 3.8100 54.1020   $ Anchor cavity outer
140 9 RPP -14.6050 14.6050 126.2126 160.8074 3.8100 54.1020   $ Anchor cavity inner
141 9 RPP -15.2400 15.2400 -161.4424 -125.5776 3.8100 54.1020   $ Anchor cavity outer
142 9 RPP -14.6050 14.6050 -160.8074 -126.2126 3.8100 54.1020   $ Anchor cavity inner
143  CZ 5.0800        $ Lifting bar
144  CZ 103.1875        $ Air outlet radius
145  RPP -64.7700 64.7700 -172.7200 172.7200 29.0830 39.1160   $ Air outlet steel X
146  RPP -172.7200 172.7200 -64.7700 64.7700 29.0830 39.1160   $ Air outlet steel Y
147  RPP -64.1350 64.1350 -172.7200 172.7200 29.7180 38.4810   $ Air outlet void X
148  RPP -172.7200 172.7200 -64.1350 64.1350 29.7180 38.4810   $ Air outlet void Y
149  RCC 0.0000 0.0000 51.5620 0.0000 0.0000 2.5400 111.7600  $ Sectional flange
150  RCC 0.0000 0.0000 54.1020 0.0000 0.0000 1.9050 111.7600  $ Lid top
151  RCC 0.0000 0.0000 38.7350 0.0000 0.0000 15.3670 100.3300  $ Lid shell
152  RCC 0.0000 0.0000 39.3700 0.0000 0.0000 14.7320 99.6950  $ Lid concrete
C Storage Cask & Pad Container
399  RCC  0.0000  0.0000  -132.7660  0.0000  0.0000  674.2432  172.7201
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  574.3432  172.8201
401  PZ  15.0959
402  PZ  62.9579
403  PZ  110.8198
404  PZ  158.6817
405  PZ  206.5437
406  PZ  254.4056
407  PZ  302.2675
408  PZ  350.1295
409  PZ  397.9914
410  PZ  445.8533
411  PZ  493.7153
C Radial Detector DRB (1ft)
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
500  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  604.8232  203.3001
501  PZ  17.6359
502  PZ  68.0379
503  PZ  118.4398
504  PZ  168.8417
505  PZ  219.2437
506  PZ  269.6456
507  PZ  320.0475
508  PZ  370.4495
509  PZ  420.8514
510  PZ  471.2533
511  PZ  521.6553
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  674.3432  272.8201
601  PZ  12.1902
602  PZ  57.1464
603  PZ  102.1026
604  PZ  147.0589
605  PZ  192.0151
606  PZ  236.9713
607  PZ  281.9275
608  PZ  326.8837
609  PZ  371.8399
610  PZ  416.7961
611  PZ  461.7523
612  PZ  506.7086
613  PZ  551.6648
614  PZ  596.6210
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  774.3432  372.8201
701  PZ  5.9512
702  PZ  44.6683
703  PZ  83.3855
704  PZ  122.1026
705  PZ  160.8198
706  PZ  199.5370
707  PZ  238.2541
708  PZ  276.9713
709  PZ  315.6884
710  PZ  354.4056
711  PZ  393.1228
712  PZ  431.8399
713  PZ  470.5571
714  PZ  509.2742
715  PZ  547.9914
716  PZ  586.7086
717  PZ  625.4257
718  PZ  664.1429
719  PZ  702.8600
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  974.3432  572.8201
801  PZ  15.9512
802  PZ  64.6683
803  PZ  113.3855
804  PZ  162.1026
805  PZ  210.8198
806  PZ  259.5370
807  PZ  308.2541
808  PZ  356.9713
809  PZ  405.6884
810  PZ  454.4056
811  PZ  503.1228
812  PZ  551.8399
813  PZ  600.5571
814  PZ  649.2742
815  PZ  697.9914
816  PZ  746.7086
817  PZ  795.4257
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
818  PZ  844.1429
819  PZ  892.8600
C
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6495E-02 40000 -1.6893E-01 24000 -1.7199E-04
      92238 -6.9340E-01 50000 -2.5798E-03  7014 -8.5993E-05
       8016 -9.8121E-02 26000 -2.1498E-04
C Homogenized Upper Plenum
m4    24000 -1.3648E-01 50000 -4.2477E-03 25055 -1.4336E-02
      26000 -4.9854E-01  7014 -1.4159E-04 28000 -6.8098E-02
      40000 -2.7816E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Neutron Poison
m9    13027 -0.6605 5010 -0.0478 5011 -0.2179
      6012 -0.0737
C Aluminum
m10   13027 -1.0
C Lead
m11   82000 -1.0
C NS-4-FR
m12   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m13   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Balsa
m15   6012 6 1001 10 8016 5
C NS-4-FR (Accident)
m16   5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
      5011 -7.7389E-03
C Copper
m17   29063 -6.8499E-01 29065 -3.1501E-01
C Damaged Fuel
m18   92235 -4.4075E-02 92238 -8.3742E-01  8016 -1.1850E-01
nonu                  $ Disable subcritical multiplication
C
C Cell Importances
C
imp:n 1 245r 0
C
C Source Definition - Fuel Neutron Response to Group 7
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=399:114:78:d5:3
si1   -10.70102 10.70102
sp1   0 1
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
si2   -10.70102 10.70102
sp2   0 1     si3 a 8.5979 17.7419 26.8859 36.0299 45.1739 54.3179 63.4619
      319.4939 328.6379 337.7819 346.9259 356.0699 365.2139 374.3579
sp3 d 0.0784 0.1479 0.2569 0.4185 0.6481 0.9633 1.3837
      1.3837 0.9633 0.6481 0.4185 0.2569 0.1479 0.0784
sb3 d 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
si4   6.070E+00 7.000E+00
sp4   0 1
C Source Information
si5 l       40 41 42
         43 44 45 46 47
      48 49 50 51 52 53 54
      55 56 57 58 59 60 61
      62 63 64 65 66 67 68
         69 70 71 72 73
            74 75 76
C Source Probability
sp5           1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
            1.0 1.0 1.0
mode n
nps 1000000
C
C ANSI/ANS-6.1.1-1977 - Neutron Flux-to-Dose Conversion Factors
C (mrem/hr)/(neutrons/cm2-sec)
C
de0   2.5E-08 1E-07 1E-06 0.00001 0.0001 0.001 0.01
      0.1 0.5 1 2.5 5 7 10
      14 20
df0   3.67E-03 3.67E-03 4.46E-03 4.54E-03 4.18E-03 3.76E-03 3.56E-03
      2.17E-02 9.26E-02 1.32E-01 1.25E-01 1.56E-01 1.47E-01 1.47E-01
      2.08E-01 2.27E-01
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:n 5 3 5 0 -1 0
mesh geom=cyl ref=89 0 198 origin=0.1 0.1 -134
     imesh 90.2 91.4 101.0 105.4 172.7 672.7
     iints 5 1 1 1 4 1
     jmesh 101 104 112 117 129 141 149 515 547 580 603 658 673 1173
     jints 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
C wwge:n  1e-5 1e-3 1 20
fc2 Radial Surface Tally
f2:n +400.1
fm2 6.9492E+01
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Radial 1ft Tally
f12:n +500.1
fm12 6.9492E+01
fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  T
tf12
fc22 Radial 1m Tally
f22:n +600.1
fm22 6.9492E+01
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  T
```

Figure 5.8.8-5 Concrete Cask Sample Input File – PWR TSC (cont'd)

```
tf22
fc32 Radial 2m Tally
f32:n +700.1
fm32 6.9492E+01
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf32
fc42 Radial 4m Tally
f42:n +800.1
fm42 6.9492E+01
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 75 165 90 -15 75 90 90 90 0
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
MAGNASTOR VCC - strShlDryTopNg_ng08b_10g
C Top Axial Biasing - Fuel N-Gamma Source
C Fuel Assembly Cells - ng08b - v1.0
1 1 -1.3934 -1      u=6 $ Lower Nozzle
2 2 -2.5369 -2 +1     u=6 $ Lower Plenum
3 3 -3.5640 -3 +2     u=6 $ Fuel
4 4 -0.5758 -4 +3     u=6 $ Upper Plenum
5 5 -0.5558 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube w/Poison v1.2
7 8 -7.8212 -7 +6     u=5 $ Tube
8 9 -2.6379 -8 : -9 : -10 : -11      u=5 $ Poison
9 0          #7 #8       u=5 $ Void
C Cells - BWR Basket v1.3
10 0          -12 -13 fill=5 trcl = ( -15.7009 78.5045 0.0000 )     u=4 $ Assy loc 1
11 like 10 but fill=5 trcl = ( 15.7009 78.5045 0.0000 )     u=4 $ Assy loc 3
12 like 10 but fill=5 trcl = ( -31.4018 62.8036 0.0000 )     u=4 $ Assy loc 5
13 like 10 but fill=5 trcl = ( 0.0000 62.8036 0.0000 )     u=4 $ Assy loc 7
14 like 10 but fill=5 trcl = ( 31.4018 62.8036 0.0000 )     u=4 $ Assy loc 9
15 like 10 but fill=5 trcl = ( -47.1027 47.1027 0.0000 )     u=4 $ Assy loc 12
16 like 10 but fill=5 trcl = ( -15.7009 47.1027 0.0000 )     u=4 $ Assy loc 14
17 like 10 but fill=5 trcl = ( 15.7009 47.1027 0.0000 )     u=4 $ Assy loc 16
18 like 10 but fill=5 trcl = ( 47.1027 47.1027 0.0000 )     u=4 $ Assy loc 18
19 like 10 but fill=5 trcl = ( -62.8036 31.4018 0.0000 )     u=4 $ Assy loc 20
20 like 10 but fill=5 trcl = ( -31.4018 31.4018 0.0000 )     u=4 $ Assy loc 22
21 like 10 but fill=5 trcl = ( 0.0000 31.4018 0.0000 )     u=4 $ Assy loc 24
22 like 10 but fill=5 trcl = ( 31.4018 31.4018 0.0000 )     u=4 $ Assy loc 26
23 like 10 but fill=5 trcl = ( 62.8036 31.4018 0.0000 )     u=4 $ Assy loc 28
24 like 10 but fill=5 trcl = ( -78.5045 15.7009 0.0000 )     u=4 $ Assy loc 29
25 like 10 but fill=5 trcl = ( -47.1027 15.7009 0.0000 )     u=4 $ Assy loc 31
26 like 10 but fill=5 trcl = ( -15.7009 15.7009 0.0000 )     u=4 $ Assy loc 33
27 like 10 but fill=5 trcl = ( 15.7009 15.7009 0.0000 )     u=4 $ Assy loc 35
28 like 10 but fill=5 trcl = ( 47.1027 15.7009 0.0000 )     u=4 $ Assy loc 37
29 like 10 but fill=5 trcl = ( 78.5045 15.7009 0.0000 )     u=4 $ Assy loc 39
30 like 10 but fill=5 trcl = ( -62.8036 0.0000 0.0000 )     u=4 $ Assy loc 41
31 like 10 but fill=5 trcl = ( -31.4018 0.0000 0.0000 )     u=4 $ Assy loc 43
32 like 10 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )     u=4 $ Assy loc 45
33 like 10 but fill=5 trcl = ( 31.4018 0.0000 0.0000 )     u=4 $ Assy loc 47
34 like 10 but fill=5 trcl = ( 62.8036 0.0000 0.0000 )     u=4 $ Assy loc 49
35 like 10 but fill=5 trcl = ( -78.5045 -15.7009 0.0000 )     u=4 $ Assy loc 51
36 like 10 but fill=5 trcl = ( -47.1027 -15.7009 0.0000 )     u=4 $ Assy loc 53
37 like 10 but fill=5 trcl = ( -15.7009 -15.7009 0.0000 )     u=4 $ Assy loc 55
38 like 10 but fill=5 trcl = ( 15.7009 -15.7009 0.0000 )     u=4 $ Assy loc 57
39 like 10 but fill=5 trcl = ( 47.1027 -15.7009 0.0000 )     u=4 $ Assy loc 59
40 like 10 but fill=5 trcl = ( 78.5045 -15.7009 0.0000 )     u=4 $ Assy loc 61
41 like 10 but fill=5 trcl = ( -62.8036 -31.4018 0.0000 )     u=4 $ Assy loc 62
42 like 10 but fill=5 trcl = ( -31.4018 -31.4018 0.0000 )     u=4 $ Assy loc 64
43 like 10 but fill=5 trcl = ( 0.0000 -31.4018 0.0000 )     u=4 $ Assy loc 66
44 like 10 but fill=5 trcl = ( 31.4018 -31.4018 0.0000 )     u=4 $ Assy loc 68
45 like 10 but fill=5 trcl = ( 62.8036 -31.4018 0.0000 )     u=4 $ Assy loc 70
46 like 10 but fill=5 trcl = ( -47.1027 -47.1027 0.0000 )     u=4 $ Assy loc 72
47 like 10 but fill=5 trcl = ( -15.7009 -47.1027 0.0000 )     u=4 $ Assy loc 74
48 like 10 but fill=5 trcl = ( 15.7009 -47.1027 0.0000 )     u=4 $ Assy loc 76
49 like 10 but fill=5 trcl = ( 47.1027 -47.1027 0.0000 )     u=4 $ Assy loc 78
50 like 10 but fill=5 trcl = ( -31.4018 -62.8036 0.0000 )     u=4 $ Assy loc 81
51 like 10 but fill=5 trcl = ( 0.0000 -62.8036 0.0000 )     u=4 $ Assy loc 83
52 like 10 but fill=5 trcl = ( 31.4018 -62.8036 0.0000 )     u=4 $ Assy loc 85
53 like 10 but fill=5 trcl = ( -15.7009 -78.5045 0.0000 )     u=4 $ Assy loc 87
54 like 10 but fill=5 trcl = ( 15.7009 -78.5045 0.0000 )     u=4 $ Assy loc 89
55 8 -7.8212 -14 #29  #40     u=4 $ Thick side support +x
56 8 -7.8212 -15 #24  #35     u=4 $ Thick side support -x
57 8 -7.8212 -16 #10  #11     u=4 $ Thick side support +y
58 8 -7.8212 -17 #53  #54     u=4 $ Thick side support -y
59 8 -7.8212 -18 +14 #29  #40     u=4 $ Thin side support +x
60 8 -7.8212 -19 +15 #24  #35     u=4 $ Thin side support -x
61 8 -7.8212 -20 +16 #10  #11     u=4 $ Thin side support +y
62 8 -7.8212 -21 +17 #53  #54     u=4 $ Thin side support -y
63 8 -7.8212 -24 +25 +22 +27  #15 #18 #46 #49     u=4 $ Corner part 1
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
64 8 -7.8212 -22 +23 +27  #15 #18 #46 #49     u=4 $ Corner part 2
65 8 -7.8212 -26 +27 +22 +24  +14.2 +15.1 +16.4 +17.3
             #10 #11 #12 #14 #19 #23 #24 #29
             #35 #40 #41 #45 #50 #52 #53 #54       u=4 $ Corner diagonal
66 0         +28 +29
             #11 #13 #14 #17 #18 #21 #22
             #23 #27 #28 #29 #32 #33 #34
             #55 #57 #59 #61 #63 #64 #65       u=4 $ Basket +x+y
67 0         +28 -29
             #32 #33 #34 #38 #39 #40 #43
             #44 #45 #48 #49 #51 #52 #54
             #55 #58 #59 #62 #63 #64 #65       u=4 $ Basket +x-y
68 0         -28 +29
             #10 #12 #13 #15 #16 #19 #20
             #21 #24 #25 #26 #30 #31 #32
             #56 #57 #60 #61 #63 #64 #65       u=4 $ Basket -x+y
69 0         -28 -29
             #30 #31 #32 #35 #36 #37 #41
             #42 #43 #46 #47 #50 #51 #53
             #56 #58 #60 #62 #63 #64 #65       u=4 $ Basket -x+y
C Cells - BWR Canister Cavity v1.3
70 0         -30 fill=6 trcl = ( -15.7009 78.5045 0.0000 )    u=3 $ Assy loc 1
71 like 70 but fill=6 trcl = ( 0.0000 78.5045 0.0000 )    u=3 $ Assy loc 2
72 like 70 but fill=6 trcl = ( 15.7009 78.5045 0.0000 )    u=3 $ Assy loc 3
73 like 70 but fill=6 trcl = ( -47.1027 62.8036 0.0000 )    u=3 $ Assy loc 4
74 like 70 but fill=6 trcl = ( -31.4018 62.8036 0.0000 )    u=3 $ Assy loc 5
75 like 70 but fill=6 trcl = ( -15.7009 62.8036 0.0000 )    u=3 $ Assy loc 6
76 like 70 but fill=6 trcl = ( 0.0000 62.8036 0.0000 )    u=3 $ Assy loc 7
77 like 70 but fill=6 trcl = ( 15.7009 62.8036 0.0000 )    u=3 $ Assy loc 8
78 like 70 but fill=6 trcl = ( 31.4018 62.8036 0.0000 )    u=3 $ Assy loc 9
79 like 70 but fill=6 trcl = ( 47.1027 62.8036 0.0000 )    u=3 $ Assy loc 10
80 like 70 but fill=6 trcl = ( -62.8036 47.1027 0.0000 )    u=3 $ Assy loc 11
81 like 70 but fill=6 trcl = ( -47.1027 47.1027 0.0000 )    u=3 $ Assy loc 12
82 like 70 but fill=6 trcl = ( -31.4018 47.1027 0.0000 )    u=3 $ Assy loc 13
83 like 70 but fill=6 trcl = ( -15.7009 47.1027 0.0000 )    u=3 $ Assy loc 14
84 like 70 but fill=6 trcl = ( 0.0000 47.1027 0.0000 )    u=3 $ Assy loc 15
85 like 70 but fill=6 trcl = ( 15.7009 47.1027 0.0000 )    u=3 $ Assy loc 16
86 like 70 but fill=6 trcl = ( 31.4018 47.1027 0.0000 )    u=3 $ Assy loc 17
87 like 70 but fill=6 trcl = ( 47.1027 47.1027 0.0000 )    u=3 $ Assy loc 18
88 0         -30  trcl = ( 62.8036 47.1027 0.0000 )    u=3 $ Assy loc 19
89 like 70 but fill=6 trcl = ( -62.8036 31.4018 0.0000 )    u=3 $ Assy loc 20
90 like 70 but fill=6 trcl = ( -47.1027 31.4018 0.0000 )    u=3 $ Assy loc 21
91 like 70 but fill=6 trcl = ( -31.4018 31.4018 0.0000 )    u=3 $ Assy loc 22
92 like 70 but fill=6 trcl = ( -15.7009 31.4018 0.0000 )    u=3 $ Assy loc 23
93 like 70 but fill=6 trcl = ( 0.0000 31.4018 0.0000 )    u=3 $ Assy loc 24
94 like 70 but fill=6 trcl = ( 15.7009 31.4018 0.0000 )    u=3 $ Assy loc 25
95 like 70 but fill=6 trcl = ( 31.4018 31.4018 0.0000 )    u=3 $ Assy loc 26
96 like 70 but fill=6 trcl = ( 47.1027 31.4018 0.0000 )    u=3 $ Assy loc 27
97 like 70 but fill=6 trcl = ( 62.8036 31.4018 0.0000 )    u=3 $ Assy loc 28
98 like 70 but fill=6 trcl = ( -78.5045 15.7009 0.0000 )    u=3 $ Assy loc 29
99 like 70 but fill=6 trcl = ( -62.8036 15.7009 0.0000 )    u=3 $ Assy loc 30
100 like 70 but fill=6 trcl = ( -47.1027 15.7009 0.0000 )    u=3 $ Assy loc 31
101 like 70 but fill=6 trcl = ( -31.4018 15.7009 0.0000 )    u=3 $ Assy loc 32
102 like 70 but fill=6 trcl = ( -15.7009 15.7009 0.0000 )    u=3 $ Assy loc 33
103 like 70 but fill=6 trcl = ( 0.0000 15.7009 0.0000 )    u=3 $ Assy loc 34
104 like 70 but fill=6 trcl = ( 15.7009 15.7009 0.0000 )    u=3 $ Assy loc 35
105 like 70 but fill=6 trcl = ( 31.4018 15.7009 0.0000 )    u=3 $ Assy loc 36
106 like 70 but fill=6 trcl = ( 47.1027 15.7009 0.0000 )    u=3 $ Assy loc 37
107 like 70 but fill=6 trcl = ( 62.8036 15.7009 0.0000 )    u=3 $ Assy loc 38
108 like 70 but fill=6 trcl = ( 78.5045 15.7009 0.0000 )    u=3 $ Assy loc 39
109 like 70 but fill=6 trcl = ( -78.5045 0.0000 0.0000 )    u=3 $ Assy loc 40
110 like 70 but fill=6 trcl = ( -62.8036 0.0000 0.0000 )    u=3 $ Assy loc 41
111 like 70 but fill=6 trcl = ( -47.1027 0.0000 0.0000 )    u=3 $ Assy loc 42
112 like 70 but fill=6 trcl = ( -31.4018 0.0000 0.0000 )    u=3 $ Assy loc 43
113 like 70 but fill=6 trcl = ( -15.7009 0.0000 0.0000 )    u=3 $ Assy loc 44
114 like 70 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 45
115 like 70 but fill=6 trcl = ( 15.7009 0.0000 0.0000 )    u=3 $ Assy loc 46
116 like 70 but fill=6 trcl = ( 31.4018 0.0000 0.0000 )    u=3 $ Assy loc 47
117 like 70 but fill=6 trcl = ( 47.1027 0.0000 0.0000 )    u=3 $ Assy loc 48
118 like 70 but fill=6 trcl = ( 62.8036 0.0000 0.0000 )    u=3 $ Assy loc 49
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
119 like 70 but fill=6 trcl = ( 78.5045 0.0000 0.0000 )    u=3 $ Assy loc 50
120 like 70 but fill=6 trcl = ( -78.5045 -15.7009 0.0000 )    u=3 $ Assy loc 51
121 like 70 but fill=6 trcl = ( -62.8036 -15.7009 0.0000 )    u=3 $ Assy loc 52
122 like 70 but fill=6 trcl = ( -47.1027 -15.7009 0.0000 )    u=3 $ Assy loc 53
123 like 70 but fill=6 trcl = ( -31.4018 -15.7009 0.0000 )    u=3 $ Assy loc 54
124 like 70 but fill=6 trcl = ( -15.7009 -15.7009 0.0000 )    u=3 $ Assy loc 55
125 like 70 but fill=6 trcl = ( 0.0000 -15.7009 0.0000 )    u=3 $ Assy loc 56
126 like 70 but fill=6 trcl = ( 15.7009 -15.7009 0.0000 )    u=3 $ Assy loc 57
127 like 70 but fill=6 trcl = ( 31.4018 -15.7009 0.0000 )    u=3 $ Assy loc 58
128 like 70 but fill=6 trcl = ( 47.1027 -15.7009 0.0000 )    u=3 $ Assy loc 59
129 like 70 but fill=6 trcl = ( 62.8036 -15.7009 0.0000 )    u=3 $ Assy loc 60
130 like 70 but fill=6 trcl = ( 78.5045 -15.7009 0.0000 )    u=3 $ Assy loc 61
131 like 70 but fill=6 trcl = ( -62.8036 -31.4018 0.0000 )    u=3 $ Assy loc 62
132 like 70 but fill=6 trcl = ( -47.1027 -31.4018 0.0000 )    u=3 $ Assy loc 63
133 like 70 but fill=6 trcl = ( -31.4018 -31.4018 0.0000 )    u=3 $ Assy loc 64
134 like 70 but fill=6 trcl = ( -15.7009 -31.4018 0.0000 )    u=3 $ Assy loc 65
135 like 70 but fill=6 trcl = ( 0.0000 -31.4018 0.0000 )    u=3 $ Assy loc 66
136 like 70 but fill=6 trcl = ( 15.7009 -31.4018 0.0000 )    u=3 $ Assy loc 67
137 like 70 but fill=6 trcl = ( 31.4018 -31.4018 0.0000 )    u=3 $ Assy loc 68
138 like 70 but fill=6 trcl = ( 47.1027 -31.4018 0.0000 )    u=3 $ Assy loc 69
139 like 70 but fill=6 trcl = ( 62.8036 -31.4018 0.0000 )    u=3 $ Assy loc 70
140 0         -30  trcl = ( -62.8036 -47.1027 0.0000 )    u=3 $ Assy loc 71
141 like 70 but fill=6 trcl = ( -47.1027 -47.1027 0.0000 )    u=3 $ Assy loc 72
142 like 70 but fill=6 trcl = ( -31.4018 -47.1027 0.0000 )    u=3 $ Assy loc 73
143 like 70 but fill=6 trcl = ( -15.7009 -47.1027 0.0000 )    u=3 $ Assy loc 74
144 like 70 but fill=6 trcl = ( 0.0000 -47.1027 0.0000 )    u=3 $ Assy loc 75
145 like 70 but fill=6 trcl = ( 15.7009 -47.1027 0.0000 )    u=3 $ Assy loc 76
146 like 70 but fill=6 trcl = ( 31.4018 -47.1027 0.0000 )    u=3 $ Assy loc 77
147 like 70 but fill=6 trcl = ( 47.1027 -47.1027 0.0000 )    u=3 $ Assy loc 78
148 like 70 but fill=6 trcl = ( 62.8036 -47.1027 0.0000 )    u=3 $ Assy loc 79
149 like 70 but fill=6 trcl = ( -47.1027 -62.8036 0.0000 )    u=3 $ Assy loc 80
150 like 70 but fill=6 trcl = ( -31.4018 -62.8036 0.0000 )    u=3 $ Assy loc 81
151 like 70 but fill=6 trcl = ( -15.7009 -62.8036 0.0000 )    u=3 $ Assy loc 82
152 like 70 but fill=6 trcl = ( 0.0000 -62.8036 0.0000 )    u=3 $ Assy loc 83
153 like 70 but fill=6 trcl = ( 15.7009 -62.8036 0.0000 )    u=3 $ Assy loc 84
154 like 70 but fill=6 trcl = ( 31.4018 -62.8036 0.0000 )    u=3 $ Assy loc 85
155 like 70 but fill=6 trcl = ( 47.1027 -62.8036 0.0000 )    u=3 $ Assy loc 86
156 like 70 but fill=6 trcl = ( -15.7009 -78.5045 0.0000 )    u=3 $ Assy loc 87
157 like 70 but fill=6 trcl = ( 0.0000 -78.5045 0.0000 )    u=3 $ Assy loc 88
158 like 70 but fill=6 trcl = ( 15.7009 -78.5045 0.0000 )    u=3 $ Assy loc 89
159 0         +31
              #70 #71 #72 #73 #74 #75 #76 #77 #78 #79
              #80 #81 #82 #83 #84 #85 #86 #87 #88 #89
              #90 #91 #92 #93 #94 #95 #96 #97 #98 #99
              #100 #101 #102 #103 #104 #105 #106 #107 #108 #109
              #110 #111 #112 #113 #114 #115 #116 #117 #118 #119      fill=4 u=3 $ Cavity
+y
160 0         -31
              #109 #110 #111 #112 #113 #114 #115 #116 #117 #118
              #119 #120 #121 #122 #123 #124 #125 #126 #127 #128
              #129 #130 #131 #132 #133 #134 #135 #136 #137 #138
              #139 #140 #141 #142 #143 #144 #145 #146 #147 #148
              #149 #150 #151 #152 #153 #154 #155 #156 #157 #158      fill=4 u=3 $ Cavity
-y
C Cells - Canister v1.2
161 0         -32 fill=3      u=2 $ Cavity
162 7 -7.9400 -38 +32.3      u=2 $ Canister Bottom
163 7 -7.9400 -33 +32.2 -36 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Bottom Drain Port
164 7 -7.9400 -34 +36 -37 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Middle Drain Port
165 7 -7.9400 -35 +37 -38.2 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Top Drain Port
166 like 163 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Bottom Vent Port
167 like 164 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Middle Vent Port
168 like 165 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Top Vent Port
169 7 -7.9400 -38 -32.3 +32.1     u=2 $ Canister Shell
170 7 -7.9400 -38 -32.1 +32.2 #163 #164 #165 #166 #167 #168     u=2 $ Lid
171 0         +38       u=2 $ Outside
C VCC Cells - v1.1.2
172 8 -7.8212 -39       u=1 $ Pedestal plate
173 8 -7.8212 -40 +41      u=1 $ Stand
174 8 -7.8212 -46 +47 +53 +54    u=1 $ Bottom plate outer
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
175 8 -7.8212 (-47 +48 -42) : (-47 +48 -43)       u=1 $ Bottom plate connector
176 8 -7.8212 -48       u=1 $ Bottom plate inner
177 8 -7.8212 (-41 -63 +64 -50) : (-41 -61 +62 +63 -50)       u=1 $ Support rail inside
stand
178 8 -7.8212 (+40 -63 +64 -50) : (+40 -61 +62 +63 -50)       u=1 $ Support rail outside
stand
179 8 -7.8212 (-58 +60 +42 +43 -51) : (-59 +60 +42 +43 -51 +58)       u=1 $ Air inlet top
180 8 -7.8212 (-55 +53 +57 -51 +42 +43 +46) : (-56 +54 +57 -51 +42 +43 +46)
                    u=1 $ Air inlet wall
181 8 -7.8212 (-42 +44 +40 -51 +46) : (-43 +45 +40 -51 +46)       u=1 $ Air inlet angular
wall
182 8 -7.8212 (-57 -55 +53 +42 +43 +54 +46) : (-57 -56 +54 +42 +43 +53 +46)
                    u=1 $ Air inlet remaining wall
183 13 -2.3234 -51 +49 +42 +43 +46 +58 +59 +55 +56 +52      fill=7 u=1 $ Concrete
184 13 -2.3234 -52       u=1 $ Concrete pad
185 8 -7.8212 -49 +50      u=1 $ Liner
186 8 -7.8212 -65 +49       u=1 $ Top flange
187 8 -7.8212 (-66 +78 -50) : (-67 +79 -50) : (-68 +80 -50) : (-69 +81 -50) :
              (-70 +82 -50) : (-71 +83 -50) : (-72 +84 -50) : (-73 +85 -50) :
              (-74 +86 -50) : (-75 +87 -50) : (-76 +88 -50) : (-77 +89 -50)
                    u=1 $ Standoffs
188 0         (-46 +47 -53) : (-46 +47 -54)       u=1 $ Bottom plate outer void
189 0         -47 +48 +42 +43    u=1 $ Bottom plate connector void
190 0         (-41 -64 -50) : (-41 -62 +63 -50)       u=1 $ Support rail inside stand
void
191 0         (+40 -64 -50) : (+40 -62 +63 -50)       u=1 $ Support rail outside stand
void
192 0         (-53 +40 +42 +43 -51 +46) : (-54 +40 +42 +43 -51 +46 +53)
                    u=1 $ Air inlet void
193 0         -60 +40 +42 +43       u=1 $ Air inlet top void
194 0         (-44 +46 +40) : (-45 +46 +40)       u=1 $ Connector void
195 0         -41 +61 +63       u=1 $ Stand void
196 0         -50 +39 +40 +61 +63 #187
              fill=2 ( 0.0000 0.0000 6.9850 )      u=1 $ Cavity
197 0         +51 +49 +65 fill=9 ( 0.0000 0.0000 485.4702 )   u=1 $ Outside
C VCC Rebar Cells - v1.1.2
198 8 -7.8212 -90       u=7 $ Inner hoop 1
199 8 -7.8212 -91       u=7 $ Inner hoop 2
200 8 -7.8212 -92       u=7 $ Inner hoop 3
201 8 -7.8212 -93       u=7 $ Inner hoop 4
202 8 -7.8212 -94       u=7 $ Inner hoop 5
203 8 -7.8212 -95       u=7 $ Inner hoop 6
204 8 -7.8212 -96       u=7 $ Inner hoop 7
205 8 -7.8212 -97       u=7 $ Inner hoop 8
206 8 -7.8212 -98       u=7 $ Inner hoop 9
207 8 -7.8212 -99       u=7 $ Inner hoop 10
208 8 -7.8212 -100       u=7 $ Inner hoop 11
209 8 -7.8212 -101       u=7 $ Inner hoop 12
210 8 -7.8212 -102       u=7 $ Inner hoop 13
211 8 -7.8212 -103       u=7 $ Outer hoop 1
212 8 -7.8212 -104       u=7 $ Outer hoop 2
213 8 -7.8212 -105       u=7 $ Outer hoop 3
214 8 -7.8212 -106       u=7 $ Outer hoop 4
215 8 -7.8212 -107       u=7 $ Outer hoop 5
216 8 -7.8212 -108       u=7 $ Outer hoop 6
217 8 -7.8212 -109       u=7 $ Outer hoop 7
218 8 -7.8212 -110       u=7 $ Outer hoop 8
219 8 -7.8212 -111       u=7 $ Outer hoop 9
220 8 -7.8212 -112       u=7 $ Outer hoop 10
221 8 -7.8212 -113       u=7 $ Outer hoop 11
222 8 -7.8212 -114       u=7 $ Outer hoop 12
223 8 -7.8212 -115       u=7 $ Outer hoop 13
224 8 -7.8212 -116       u=7 $ Outer hoop 14
225 8 -7.8212 -117       u=7 $ Outer hoop 15
226 8 -7.8212 -118       u=7 $ Outer hoop 16
227 8 -7.8212 -119       u=7 $ Outer hoop 17
228 8 -7.8212 -120       u=7 $ Outer hoop 18
229 8 -7.8212 -121       u=7 $ Outer hoop 19
230 8 -7.8212 -122       u=7 $ Outer hoop 20
231 8 -7.8212 -123       u=7 $ Outer hoop 21
232 8 -7.8212 -124       u=7 $ Outer hoop 22
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
233 8 -7.8212 -125        u=7 $ Outer hoop 23
234 8 -7.8212 -126        u=7 $ Outer hoop 24
235 8 -7.8212 -127        u=7 $ Outer hoop 25
236 8 -7.8212 -128        u=7 $ Outer hoop 26
237 8 -7.8212 -129        u=7 $ Outer hoop 27
238 8 -7.8212 -130        u=7 $ Outer hoop 28
239 8 -7.8212 -131        u=7 $ Outer hoop 29
240 8 -7.8212 -132        u=7 $ Outer hoop 30
241 8 -7.8212 -133        u=7 $ Outer hoop 31
242 8 -7.8212 -134        u=7 $ Outer hoop 32
243 8 -7.8212 -135        u=7 $ Outer hoop 33
244 8 -7.8212 -136        u=7 $ Outer hoop 34
245 8 -7.8212 -137        u=7 $ Outer hoop 35
246 8 -7.8212 -138        u=7 $ Outer hoop 36
247 8 -7.8212 -139        u=7 $ Outer hoop 37
248 8 -7.8212 -140        u=7 $ Outer hoop 38
249 8 -7.8212 -141        u=7 $ Outer hoop 39
250 8 -7.8212 -142        u=7 $ Outer hoop 40
251 8 -7.8212 -143        u=7 $ Outer hoop 41
252 8 -7.8212 -144        u=7 $ Outer hoop 42
253 8 -7.8212 -145        u=7 $ Outer hoop 43
254 8 -7.8212 -146        u=7 $ Outer hoop 44
255 8 -7.8212 -147        u=7 $ Outer hoop 45
256 8 -7.8212 -148        u=7 $ Outer hoop 46
257 8 -7.8212 -149        u=7 $ Outer hoop 47
258 8 -7.8212 -150        u=7 $ Outer hoop 48
259 13 -2.3234 #198 #199 #200 #201 #202 #203 #204 #205 #206 #207          $ Concrete
        #208 #209 #210 #211 #212 #213 #214 #215 #216 #217
        #218 #219 #220 #221 #222 #223 #224 #225 #226 #227
        #228 #229 #230 #231 #232 #233 #234 #235 #236 #237
        #238 #239 #240 #241 #242 #243 #244 #245 #246 #247
        #248 #249 #250 #251 #252 #253 #254 #255 #256 #257
        #258        fill=8 u=7
260 8 -7.8212 -151   trcl = ( 113.3475 0.0000 0.0000 )    u=8 $ Inner bar 1
261 like 260 but   trcl = ( 109.4853 29.3365 0.0000 )    u=8 $ Inner bar 2
262 like 260 but   trcl = ( 98.1618 56.6738 0.0000 )    u=8 $ Inner bar 3
263 like 260 but   trcl = ( 80.1488 80.1488 0.0000 )    u=8 $ Inner bar 4
264 like 260 but   trcl = ( 56.6738 98.1618 0.0000 )    u=8 $ Inner bar 5
265 like 260 but   trcl = ( 29.3365 109.4853 0.0000 )    u=8 $ Inner bar 6
266 like 260 but   trcl = ( 0.0000 113.3475 0.0000 )    u=8 $ Inner bar 7
267 like 260 but   trcl = ( -29.3365 109.4853 0.0000 )    u=8 $ Inner bar 8
268 like 260 but   trcl = ( -56.6738 98.1618 0.0000 )    u=8 $ Inner bar 9
269 like 260 but   trcl = ( -80.1488 80.1488 0.0000 )    u=8 $ Inner bar 10
270 like 260 but   trcl = ( -98.1618 56.6738 0.0000 )    u=8 $ Inner bar 11
271 like 260 but   trcl = ( -109.4853 29.3365 0.0000 )    u=8 $ Inner bar 12
272 like 260 but   trcl = ( -113.3475 0.0000 0.0000 )    u=8 $ Inner bar 13
273 like 260 but   trcl = ( -109.4853 -29.3365 0.0000 )    u=8 $ Inner bar 14
274 like 260 but   trcl = ( -98.1618 -56.6738 0.0000 )    u=8 $ Inner bar 15
275 like 260 but   trcl = ( -80.1488 -80.1488 0.0000 )    u=8 $ Inner bar 16
276 like 260 but   trcl = ( -56.6738 -98.1618 0.0000 )    u=8 $ Inner bar 17
277 like 260 but   trcl = ( -29.3365 -109.4853 0.0000 )    u=8 $ Inner bar 18
278 like 260 but   trcl = ( 0.0000 -113.3475 0.0000 )    u=8 $ Inner bar 19
279 like 260 but   trcl = ( 29.3365 -109.4853 0.0000 )    u=8 $ Inner bar 20
280 like 260 but   trcl = ( 56.6737 -98.1618 0.0000 )    u=8 $ Inner bar 21
281 like 260 but   trcl = ( 80.1488 -80.1488 0.0000 )    u=8 $ Inner bar 22
282 like 260 but   trcl = ( 98.1618 -56.6738 0.0000 )    u=8 $ Inner bar 23
283 like 260 but   trcl = ( 109.4853 -29.3365 0.0000 )    u=8 $ Inner bar 24
284 8 -7.8212 -151   trcl = ( 159.0675 0.0000 0.0000 )    u=8 $ Outer bar 1
285 like 284 but   trcl = ( 158.0673 17.8099 0.0000 )    u=8 $ Outer bar 2
286 like 284 but   trcl = ( 155.0793 35.3958 0.0000 )    u=8 $ Outer bar 3
287 like 284 but   trcl = ( 150.1412 52.5367 0.0000 )    u=8 $ Outer bar 4
288 like 284 but   trcl = ( 143.3149 69.0168 0.0000 )    u=8 $ Outer bar 5
289 like 284 but   trcl = ( 134.6863 84.6290 0.0000 )    u=8 $ Outer bar 6
290 like 284 but   trcl = ( 124.3640 99.1770 0.0000 )    u=8 $ Outer bar 7
291 like 284 but   trcl = ( 112.4777 112.4777 0.0000 )    u=8 $ Outer bar 8
292 like 284 but   trcl = ( 99.1770 124.3640 0.0000 )    u=8 $ Outer bar 9
293 like 284 but   trcl = ( 84.6290 134.6863 0.0000 )    u=8 $ Outer bar 10
294 like 284 but   trcl = ( 69.0168 143.3149 0.0000 )    u=8 $ Outer bar 11
295 like 284 but   trcl = ( 52.5367 150.1412 0.0000 )    u=8 $ Outer bar 12
296 like 284 but   trcl = ( 35.3958 155.0793 0.0000 )    u=8 $ Outer bar 13
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
297 like 284 but   trcl = ( 17.8099 158.0673 0.0000 )    u=8 $ Outer bar 14
298 like 284 but   trcl = ( 0.0000 159.0675 0.0000 )    u=8 $ Outer bar 15
299 like 284 but   trcl = ( -17.8099 158.0673 0.0000 )    u=8 $ Outer bar 16
300 like 284 but   trcl = ( -35.3958 155.0793 0.0000 )    u=8 $ Outer bar 17
301 like 284 but   trcl = ( -52.5367 150.1412 0.0000 )    u=8 $ Outer bar 18
302 like 284 but   trcl = ( -69.0168 143.3149 0.0000 )    u=8 $ Outer bar 19
303 like 284 but   trcl = ( -84.6290 134.6863 0.0000 )    u=8 $ Outer bar 20
304 like 284 but   trcl = ( -99.1770 124.3640 0.0000 )    u=8 $ Outer bar 21
305 like 284 but   trcl = ( -112.4777 112.4777 0.0000 )    u=8 $ Outer bar 22
306 like 284 but   trcl = ( -124.3640 99.1770 0.0000 )    u=8 $ Outer bar 23
307 like 284 but   trcl = ( -134.6863 84.6290 0.0000 )    u=8 $ Outer bar 24
308 like 284 but   trcl = ( -143.3149 69.0168 0.0000 )    u=8 $ Outer bar 25
309 like 284 but   trcl = ( -150.1412 52.5367 0.0000 )    u=8 $ Outer bar 26
310 like 284 but   trcl = ( -155.0793 35.3958 0.0000 )    u=8 $ Outer bar 27
311 like 284 but   trcl = ( -158.0673 17.8099 0.0000 )    u=8 $ Outer bar 28
312 like 284 but   trcl = ( -159.0675 0.0000 0.0000 )    u=8 $ Outer bar 29
313 like 284 but   trcl = ( -158.0673 -17.8099 0.0000 )    u=8 $ Outer bar 30
314 like 284 but   trcl = ( -155.0793 -35.3958 0.0000 )    u=8 $ Outer bar 31
315 like 284 but   trcl = ( -150.1412 -52.5367 0.0000 )    u=8 $ Outer bar 32
316 like 284 but   trcl = ( -143.3149 -69.0168 0.0000 )    u=8 $ Outer bar 33
317 like 284 but   trcl = ( -134.6863 -84.6290 0.0000 )    u=8 $ Outer bar 34
318 like 284 but   trcl = ( -124.3640 -99.1770 0.0000 )    u=8 $ Outer bar 35
319 like 284 but   trcl = ( -112.4777 -112.4777 0.0000 )    u=8 $ Outer bar 36
320 like 284 but   trcl = ( -99.1770 -124.3640 0.0000 )    u=8 $ Outer bar 37
321 like 284 but   trcl = ( -84.6290 -134.6863 0.0000 )    u=8 $ Outer bar 38
322 like 284 but   trcl = ( -69.0168 -143.3149 0.0000 )    u=8 $ Outer bar 39
323 like 284 but   trcl = ( -52.5367 -150.1412 0.0000 )    u=8 $ Outer bar 40
324 like 284 but   trcl = ( -35.3958 -155.0793 0.0000 )    u=8 $ Outer bar 41
325 like 284 but   trcl = ( -17.8099 -158.0673 0.0000 )    u=8 $ Outer bar 42
326 like 284 but   trcl = ( 0.0000 -159.0675 0.0000 )    u=8 $ Outer bar 43
327 like 284 but   trcl = ( 17.8099 -158.0673 0.0000 )    u=8 $ Outer bar 44
328 like 284 but   trcl = ( 35.3958 -155.0793 0.0000 )    u=8 $ Outer bar 45
329 like 284 but   trcl = ( 52.5367 -150.1412 0.0000 )    u=8 $ Outer bar 46
330 like 284 but   trcl = ( 69.0168 -143.3149 0.0000 )    u=8 $ Outer bar 47
331 like 284 but   trcl = ( 84.6290 -134.6863 0.0000 )    u=8 $ Outer bar 48
332 like 284 but   trcl = ( 99.1770 -124.3640 0.0000 )    u=8 $ Outer bar 49
333 like 284 but   trcl = ( 112.4777 -112.4777 0.0000 )    u=8 $ Outer bar 50
334 like 284 but   trcl = ( 124.3640 -99.1770 0.0000 )    u=8 $ Outer bar 51
335 like 284 but   trcl = ( 134.6863 -84.6290 0.0000 )    u=8 $ Outer bar 52
336 like 284 but   trcl = ( 143.3149 -69.0168 0.0000 )    u=8 $ Outer bar 53
337 like 284 but   trcl = ( 150.1412 -52.5367 0.0000 )    u=8 $ Outer bar 54
338 like 284 but   trcl = ( 155.0793 -35.3958 0.0000 )    u=8 $ Outer bar 55
339 like 284 but   trcl = ( 158.0673 -17.8099 0.0000 )    u=8 $ Outer bar 56
340 13 -2.3234 #260 #261 #262 #263 #264 #265 #266 #267 #268         $ Concrete
        #269 #270 #271 #272 #273 #274 #275 #276 #277 #278
        #279 #280 #281 #282 #283 #284 #285 #286
        #287 #288 #289 #290 #291 #292 #293 #294 #295 #296
        #297 #298 #299 #300 #301 #302 #303 #304 #305 #306
        #307 #308 #309 #310 #311 #312 #313 #314 #315 #316
        #317 #318 #319 #320 #321 #322 #323 #324 #325 #326
        #327 #328 #329 #330 #331 #332 #333 #334 #335 #336
        #337 #338 #339        u=8
C VCC Lid Cells
341 13 -2.3234 -153 +152      u=9 $ Lid base
342 13 -2.3234 -155 +156      u=9 $ Lid base disk
343 8 -7.8212 -156 +157 +165 +166    u=9 $ Lid liner
344 8 -7.8212 -159 +160      u=9 $ Anchor steel -x-y
345 8 -7.8212 -161 +162      u=9 $ Anchor steel +x+y
346 8 -7.8212 -154 +153 -163 trcl = ( 71.1200 123.1835 0.0000 )    u=9 $ Lift support
347 like 346 but   trcl = ( -123.1835 71.1200 0.0000 )    u=9 $ Lift support
348 like 346 but   trcl = ( -71.1200 -123.1835 0.0000 )    u=9 $ Lift support
349 like 346 but   trcl = ( 123.1835 -71.1200 0.0000 )    u=9 $ Lift support
350 8 -7.8212 -169 +157 +156     u=9 $ Sectional flange
351 8 -7.8212 (-165 +166 +167 -154 +164) : (-166 +165 +168 -154 +164)       u=9 $ Outlet
steel
352 8 -7.8212 -170       u=9 $ Lid top
353 8 -7.8212 -171 +172      u=9 $ Lid shell
354 13 -2.3234 -172       u=9 $ Lid concrete
355 13 -2.3234 -154 +153 +165 +166 +156 +159 +161 +157
        #346 #347 #348 #349 #350 #352        u=9 $ Concrete
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
356 13 -2.3234 -152 +155 +158     u=9 $ Lid base void 1
357 8 -7.8212 -152 +155 -158 +157    u=9 $ Lid base void 2
358 0          (-167 +168 -154 +164) : (-168 +167 -154 +164)       u=9 $ Outlet void
359 0          #341 #342 #343 #344 #345 #346 #347 #348 #349
               #350 #351 #352 #353 #354 #355 #356 #357 #358        u=9 $ Outside
C Detector Cells - Axial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ Outlet
600  0  -600  +400  +500  $ 1ft
700  0  -700  +400  +500  +600  $ 1m
800  0  -800  +400  +500  +600  +700  $ 2m
900  0  -900  +400  +500  +600  +700  +800  $ 4m
1000  0  +400  +500  +600  +700  +800  +900  $ Exterior

C Fuel Assembly Surfaces - ng08b - v1.0
1 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 17.1704  $ Lower Nozzle
2 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 18.7579  $ Lower Plenum
3 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 399.7579  $ Fuel
4 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 428.4980  $ Upper Plenum
5 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 447.5480  $ Upper Nozzle
C Surfaces - Fuel Tube w/Poison v1.2
6 RPP -7.7343 7.7343 -7.7343 7.7343 7.6200 429.4124  $ Tube void
7 RPP -8.3693 8.3693 -8.3693 8.3693 7.6200 429.4124  $ Tube
8 RPP -7.7343 -7.4803 -6.7310 6.7310 9.2075 427.8249  $ Poison left
9 RPP 7.4803 7.7343 -6.7310 6.7310 9.2075 427.8249  $ Poison right
10 RPP -6.7310 6.7310 7.4803 7.7343 9.2075 427.8249  $ Poison top
11 RPP -6.7310 6.7310 -7.7343 -7.4803 9.2075 427.8249  $ Poison bottom
C Surfaces - BWR Basket v1.3
12  RPP -8.3693 8.3693 -8.3693 8.3693 7.6200 455.9300  $ Tube opening
13 9 RPP -11.0998 11.0998 -11.0998 11.0998 7.6200 455.9300  $ Tube radius
14  RPP 85.9213 87.5088 -8.3693 8.3693 7.6200 455.9300  $ Thick side support +x
15  RPP -87.5088 -85.9213 -8.3693 8.3693 7.6200 455.9300  $ Thick side support -x
16  RPP -8.3693 8.3693 85.9213 87.5088 7.6200 455.9300  $ Thick side support +y
17  RPP -8.3693 8.3693 -87.5088 -85.9213 7.6200 455.9300  $ Thick side support -y
18  RPP 86.8738 87.5088 -22.2250 22.2250 7.6200 429.4124  $ Thin side support +x
19  RPP -87.5088 -86.8738 -22.2250 22.2250 7.6200 429.4124  $ Thin side support -x
20  RPP -22.2250 22.2250 86.8738 87.5088 7.6200 429.4124  $ Thin side support +y
21  RPP -22.2250 22.2250 -87.5088 -86.8738 7.6200 429.4124  $ Thin side support -y
22  RPP -71.9667 71.9667 -55.4720 55.4720 7.6200 448.3100  $ Corner outer
23  RPP -71.1729 71.1729 -54.6783 54.6783 7.6200 448.3100  $ Corner inner
24  RPP -55.4720 55.4720 -71.9667 71.9667 7.6200 448.3100  $ Corner outer
25  RPP -54.6783 54.6783 -71.1729 71.1729 7.6200 448.3100  $ Corner inner
26 9 RPP -76.2402 76.2402 -76.2402 76.2402 7.6200 448.3100  $ Corner dia. outer
27 9 RPP -75.4465 75.4465 -75.4465 75.4465 7.6200 448.3100  $ Corner dia. inner
28  PX 0.0000        $ Cut plane
29  PY 0.0000        $ Cut plane
C Surfaces - BWR Canister Cavity v1.3
30 RPP -7.0084 7.0084 -7.0084 7.0084 0.0000 447.5481   $ Assy opening
31 PY 0.0000         $ Cut plane
C Surfaces - Canister v1.2
32 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 457.2000 90.1700   $ Cavity
33 CZ 2.6924          $ Bot Cylinder Radius
34 CZ 6.7691          $ Mid Cyclinder Radius
35 CZ 7.4041          $ Top Cylinder Radius
36 PZ 468.5538          $ Port plane bot/mid
37 PZ 477.2152          $ Port plane mid/top
38 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 487.0450 91.4400   $ Canister
C VCC Surfaces - v1.1.2
39  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
40  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 63.5000  $ Stand outer
41  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 62.3888  $ Stand inner
42 9 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate A
43 10 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate B
44 9 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall A
45 10 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall B
46  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
47  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 100.3300  $ Connector radius
48  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
49  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 105.3846  $ VCC liner outer
50  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 100.9396  $ VCC liner inner
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 618.2362 172.7200  $ Concrete
RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
RPP -172.7200 172.7200 -63.5000 63.5000 -32.7660 -21.4630   $ Air inlet void X
RPP -63.5000 63.5000 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet void Y
RPP -172.7200 172.7200 -64.7700 64.7700 -32.7660 -21.4630   $ Air inlet wall X
RPP -64.7700 64.7700 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet wall Y
RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 11.3030 100.3300  $ Air inlet divider
RPP -172.7200 172.7200 -64.7700 64.7700 -21.4630 -16.3830   $ Air inlet top X
RPP -64.7700 64.7700 -172.7200 172.7200 -21.4630 -16.3830   $ Air inlet top Y
RCC 0.0000 0.0000 -21.4630 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
RPP -106.6800 106.6800 -5.7150 5.7150 -16.3830 -5.0800   $ Support rail exterior X
RPP -106.6800 106.6800 -4.4450 4.4450 -16.3830 -5.0800   $ Support rail interior X
RPP -5.7150 5.7150 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail exterior Y
RPP -4.4450 4.4450 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail interior Y
RCC 0.0000 0.0000 485.4702 0.0000 0.0000 2.5400 115.5446  $ Top flange
RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 1
11 RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 2
12 RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 3
9 RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 4
13 RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 5
14 RPP -100.9396 100.9396 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 6
RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 7
11 RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 8
12 RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 9
9 RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 10
13 RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 11
14 RPP -0.4432 0.4432 -100.9396 100.9396 175.5902 480.3902   $ Standoff outer 12
RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 1
11 RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 2
12 RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 3
9 RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 4
13 RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 5
14 RPP -93.3196 93.3196 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 6
RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 7
11 RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 8
12 RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 9
9 RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 10
13 RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 11
14 RPP -0.4432 0.4432 -93.3196 93.3196 175.5902 480.3902   $ Standoff inner 12
C VCC Rebar Surfaces - v1.1.2
TZ 0.0000 0.0000 23.3499 111.4425 0.9525 0.9525   $ Inner hoop 1
TZ 0.0000 0.0000 58.0027 111.4425 0.9525 0.9525   $ Inner hoop 2
TZ 0.0000 0.0000 92.6556 111.4425 0.9525 0.9525   $ Inner hoop 3
TZ 0.0000 0.0000 127.3084 111.4425 0.9525 0.9525   $ Inner hoop 4
TZ 0.0000 0.0000 161.9613 111.4425 0.9525 0.9525   $ Inner hoop 5
TZ 0.0000 0.0000 196.6141 111.4425 0.9525 0.9525   $ Inner hoop 6
TZ 0.0000 0.0000 231.2670 111.4425 0.9525 0.9525   $ Inner hoop 7
TZ 0.0000 0.0000 265.9199 111.4425 0.9525 0.9525   $ Inner hoop 8
TZ 0.0000 0.0000 300.5727 111.4425 0.9525 0.9525   $ Inner hoop 9
TZ 0.0000 0.0000 335.2256 111.4425 0.9525 0.9525   $ Inner hoop 10
TZ 0.0000 0.0000 369.8784 111.4425 0.9525 0.9525   $ Inner hoop 11
TZ 0.0000 0.0000 404.5313 111.4425 0.9525 0.9525   $ Inner hoop 12
TZ 0.0000 0.0000 439.1841 111.4425 0.9525 0.9525   $ Inner hoop 13
TZ 0.0000 0.0000 -1.4022 160.9725 0.9525 0.9525   $ Outer hoop 1
TZ 0.0000 0.0000 8.4986 160.9725 0.9525 0.9525   $ Outer hoop 2
TZ 0.0000 0.0000 18.3994 160.9725 0.9525 0.9525   $ Outer hoop 3
TZ 0.0000 0.0000 28.3003 160.9725 0.9525 0.9525   $ Outer hoop 4
TZ 0.0000 0.0000 38.2011 160.9725 0.9525 0.9525   $ Outer hoop 5
TZ 0.0000 0.0000 48.1019 160.9725 0.9525 0.9525   $ Outer hoop 6
TZ 0.0000 0.0000 58.0027 160.9725 0.9525 0.9525   $ Outer hoop 7
TZ 0.0000 0.0000 67.9035 160.9725 0.9525 0.9525   $ Outer hoop 8
TZ 0.0000 0.0000 77.8043 160.9725 0.9525 0.9525   $ Outer hoop 9
TZ 0.0000 0.0000 87.7052 160.9725 0.9525 0.9525   $ Outer hoop 10
TZ 0.0000 0.0000 97.6060 160.9725 0.9525 0.9525   $ Outer hoop 11
TZ 0.0000 0.0000 107.5068 160.9725 0.9525 0.9525   $ Outer hoop 12
TZ 0.0000 0.0000 117.4076 160.9725 0.9525 0.9525   $ Outer hoop 13
TZ 0.0000 0.0000 127.3084 160.9725 0.9525 0.9525   $ Outer hoop 14
TZ 0.0000 0.0000 137.2092 160.9725 0.9525 0.9525   $ Outer hoop 15
TZ 0.0000 0.0000 147.1101 160.9725 0.9525 0.9525   $ Outer hoop 16
TZ 0.0000 0.0000 157.0109 160.9725 0.9525 0.9525   $ Outer hoop 17
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
120  TZ 0.0000 0.0000 166.9117 160.9725 0.9525 0.9525   $ Outer hoop 18
121  TZ 0.0000 0.0000 176.8125 160.9725 0.9525 0.9525   $ Outer hoop 19
122  TZ 0.0000 0.0000 186.7133 160.9725 0.9525 0.9525   $ Outer hoop 20
123  TZ 0.0000 0.0000 196.6141 160.9725 0.9525 0.9525   $ Outer hoop 21
124  TZ 0.0000 0.0000 206.5150 160.9725 0.9525 0.9525   $ Outer hoop 22
125  TZ 0.0000 0.0000 216.4158 160.9725 0.9525 0.9525   $ Outer hoop 23
126  TZ 0.0000 0.0000 226.3166 160.9725 0.9525 0.9525   $ Outer hoop 24
127  TZ 0.0000 0.0000 236.2174 160.9725 0.9525 0.9525   $ Outer hoop 25
128  TZ 0.0000 0.0000 246.1182 160.9725 0.9525 0.9525   $ Outer hoop 26
129  TZ 0.0000 0.0000 256.0190 160.9725 0.9525 0.9525   $ Outer hoop 27
130  TZ 0.0000 0.0000 265.9199 160.9725 0.9525 0.9525   $ Outer hoop 28
131  TZ 0.0000 0.0000 275.8207 160.9725 0.9525 0.9525   $ Outer hoop 29
132  TZ 0.0000 0.0000 285.7215 160.9725 0.9525 0.9525   $ Outer hoop 30
133  TZ 0.0000 0.0000 295.6223 160.9725 0.9525 0.9525   $ Outer hoop 31
134  TZ 0.0000 0.0000 305.5231 160.9725 0.9525 0.9525   $ Outer hoop 32
135  TZ 0.0000 0.0000 315.4239 160.9725 0.9525 0.9525   $ Outer hoop 33
136  TZ 0.0000 0.0000 325.3248 160.9725 0.9525 0.9525   $ Outer hoop 34
137  TZ 0.0000 0.0000 335.2256 160.9725 0.9525 0.9525   $ Outer hoop 35
138  TZ 0.0000 0.0000 345.1264 160.9725 0.9525 0.9525   $ Outer hoop 36
139  TZ 0.0000 0.0000 355.0272 160.9725 0.9525 0.9525   $ Outer hoop 37
140  TZ 0.0000 0.0000 364.9280 160.9725 0.9525 0.9525   $ Outer hoop 38
141  TZ 0.0000 0.0000 374.8288 160.9725 0.9525 0.9525   $ Outer hoop 39
142  TZ 0.0000 0.0000 384.7297 160.9725 0.9525 0.9525   $ Outer hoop 40
143  TZ 0.0000 0.0000 394.6305 160.9725 0.9525 0.9525   $ Outer hoop 41
144  TZ 0.0000 0.0000 404.5313 160.9725 0.9525 0.9525   $ Outer hoop 42
145  TZ 0.0000 0.0000 414.4321 160.9725 0.9525 0.9525   $ Outer hoop 43
146  TZ 0.0000 0.0000 424.3329 160.9725 0.9525 0.9525   $ Outer hoop 44
147  TZ 0.0000 0.0000 434.2337 160.9725 0.9525 0.9525   $ Outer hoop 45
148  TZ 0.0000 0.0000 444.1346 160.9725 0.9525 0.9525   $ Outer hoop 46
149  TZ 0.0000 0.0000 454.0354 160.9725 0.9525 0.9525   $ Outer hoop 47
150  TZ 0.0000 0.0000 463.9362 160.9725 0.9525 0.9525   $ Outer hoop 48
151  RCC 0.0000 0.0000 -11.3030 0.0000 0.0000 485.1400 0.9525  $ Bar
C VCC Lid Surfaces
152  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 116.459  $ Lid base
153  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 172.7199  $ Lid base outer
154  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 54.1020 172.7199  $ Lid container
155  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 0.9525 116.4590  $ Lid base disk
156  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 48.7045 101.5746  $ Lid liner
157  CZ 100.9396        $ Lid liner inner
158  CZ 101.5746        $ Lid liner outer
159 9 RPP -15.2400 15.2400 125.5776 161.4424 3.8100 54.1020   $ Anchor cavity outer
160 9 RPP -14.6050 14.6050 126.2126 160.8074 3.8100 54.1020   $ Anchor cavity inner
161 9 RPP -15.2400 15.2400 -161.4424 -125.5776 3.8100 54.1020   $ Anchor cavity outer
162 9 RPP -14.6050 14.6050 -160.8074 -126.2126 3.8100 54.1020   $ Anchor cavity inner
163  CZ 5.0800        $ Lifting bar
164  CZ 100.9396        $ Air outlet radius
165  RPP -64.7700 64.7700 -172.7200 172.7200 29.0830 39.1160   $ Air outlet steel X
166  RPP -172.7200 172.7200 -64.7700 64.7700 29.0830 39.1160   $ Air outlet steel Y
167  RPP -63.5000 63.5000 -172.7200 172.7200 29.7180 38.4810   $ Air outlet void X
168  RPP -172.7200 172.7200 -63.5000 63.5000 29.7180 38.4810   $ Air outlet void Y
169  RCC 0.0000 0.0000 51.5620 0.0000 0.0000 2.5400 111.7600  $ Sectional flange
170  RCC 0.0000 0.0000 54.1020 0.0000 0.0000 1.9050 111.7600  $ Lid top
171  RCC 0.0000 0.0000 38.7350 0.0000 0.0000 15.3670 100.3300  $ Lid shell
172  RCC 0.0000 0.0000 39.3700 0.0000 0.0000 14.7320 99.6950  $ Lid concrete
C Axial Detector DTA (Surface)
400  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  672.4112  172.8201
401  CZ  17.2820
402  CZ  34.5640
403  CZ  51.8460
404  CZ  69.1280
405  CZ  86.4101
406  CZ  103.6921
407  CZ  120.9741
408  CZ  138.2561
409  CZ  155.5381
C Axial Detector DTAA (Outlet)
500  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  672.5112  172.8201
501  CZ  101.6000
502     PX  0.0000
503  1  PX  0.0000
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
504  2  PX  0.0000
505  3  PX  0.0000
506  4  PX  0.0000
507     PY  0.0000
508  5  PX  0.0000
509  6  PX  0.0000
510  7  PX  0.0000
511  8  PX  0.0000
C Axial Detector DTB (1ft)
600  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  702.8912  203.3001
601  CZ  20.3300
602  CZ  40.6600
603  CZ  60.9900
604  CZ  81.3200
605  CZ  101.6501
606  CZ  121.9801
607  CZ  142.3101
608  CZ  162.6401
609  CZ  182.9701
C Axial Detector DTC (1m)
700  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  772.4112  272.8201
701  CZ  27.2820
702  CZ  54.5640
703  CZ  81.8460
704  CZ  109.1280
705  CZ  136.4101
706  CZ  163.6921
707  CZ  190.9741
708  CZ  218.2561
709  CZ  245.5381
C Axial Detector DTD (2m)
800  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  872.4112  372.8201
801  CZ  37.2820
802  CZ  74.5640
803  CZ  111.8460
804  CZ  149.1280
805  CZ  186.4101
806  CZ  223.6921
807  CZ  260.9741
808  CZ  298.2561
809  CZ  335.5381
C Axial Detector DTE (4m)
900  RCC  0.0000  0.0000  -132.8660  0.0000  0.0000  1072.4112  572.8201
901  CZ  57.2820
902  CZ  114.5640
903  CZ  171.8460
904  CZ  229.1280
905  CZ  286.4101
906  CZ  343.6921
907  CZ  400.9741
908  CZ  458.2561
909  CZ  515.5381

C
C Materials List - Common Materials - v1.4
C
C Homogenized Lower Nozzle
m1    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03 7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel
m3    92235 -3.7407E-02 40000 -1.4859E-01 24000 -1.5128E-04
      92238 -7.1074E-01 50000 -2.2692E-03 7014 -7.5639E-05
      8016 -1.0058E-01 26000 -1.8910E-04
C Homogenized Upper Plenum
m4    24000 -1.6451E-01 50000 -2.0233E-03 25055 -1.7302E-02
      26000 -6.0142E-01 7014 -6.7444E-05 28000 -8.2186E-02
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
      40000 -1.3249E-01
C Homogenized Upper Nozzle
m5    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99 6012 -0.01
C Neutron Poison
m9    13027 -0.6822 5010 -0.0448 5011 -0.2040
      6012 -0.0690
C Aluminum
m10   13027 -1.0
C Lead
m11   82000 -1.0
C NS-4-FR
m12   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m13   26000 -0.014 20000 -0.044 14000 -0.337
      1001 -0.010 8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Balsa
m15   6012 6 1001 10 8016 5
nonu $ No subcritical multiplication
C
C Cell Importances
C
imp:n,p 1 364r 0
C
C BWR Source Definition - Fuel Neutron Response to Group 10
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=400:196:161:d5:3
si1   -7.00786 7.00786
sp1   0 1
si2   -7.00786 7.00786
sp2   0 1
si3 a 18.7579 28.2829 37.8079 47.3329 56.8579 66.3829 75.9079
      228.3079 228.3081 323.5579 333.0829 342.6079 352.1329 361.6579
      371.1829 380.7079 390.2329 399.7579
sp3 d 1.711E-06 2.388E-03 2.991E-02 1.437E-01 4.501E-01 1.105E+00 2.314E+00
      2.314E+00 2.018E+00 2.018E+00 1.170E+00 6.284E-01 3.031E-01 1.255E-01
      4.110E-02 8.970E-03 8.104E-04 1.711E-06
sb3 d 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+01 1.00E+01 1.00E+02 1.00E+03
si4   2.870E+00 3.680E+00
sp4   0 1
C Source Information
si5 l                   70  71  72
               73  74  75  76  77  78  79
           80  81  82  83  84  85  86  87
           89  90  91  92  93  94  95  96  97
       98  99 100 101 102 103 104 105 106 107 108
      109 110 111 112 113 114 115 116 117 118 119
      120 121 122 123 124 125 126 127 128 129 130
          131 132 133 134 135 136 137 138 139
              141 142 143 144 145 146 147 148
              149 150 151 152 153 154 155
                      156 157 158
C Source Probability
sp5                   1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
              1.0 1.0 1.0 1.0 1.0 1.0 1.0
                      1.0 1.0 1.0
C Source Biasing
sb5                           1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
      1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
            1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                  1E+00 1E+00 1E+00 1E+00 1E+00 1E+00 1E+00
                              1E+00 1E+00 1E+00
mode n p
nps 30000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Top Axial N-Gamma
C
wwg 2 0 0 0 0
wwp:n 5 3 5 0 -1 0
wwge:n  1e-5 1e-3 1 20
wwp:p 5 3 5 0 -1 0
wwge:p  1e-3 1 20
mesh geom=cyl ref=0 0 406 origin=0.1 0.1 -134
     imesh 90.2 91.4 100.9 105.4 172.7 672.7
     iints 1 1 1 1 1 1
     jmesh 101 104 112 117 129 141 160 541 588 598 621 657 673 1173
     jints 1 1 1 1 1 3 1 10 1 1 4 1 2 1
     kmesh 1
     kints 1
fc2 Axial Surface Tally
f2:p +400.2
fm2 2.2977E+02
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  T
tf2
fc12 Axial Outlet Tally Q1 (+x+y)
f12:p +500.2
fm12 2.2977E+02
fs12 -501  -502  -507
     -503  -504  -505  -506  T
sd12 3.2429E+04  3.0700E+04  1.5350E+04  3.0700E+03  4r  6.1400E+04
tf12
fc22 Axial Outlet Tally Q2 (-x+y)
f22:p +500.2
fm22 2.2977E+02
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
fs22 -501  +502  -507
     +508  +509  +510  +511  T
sd22 3.2429E+04  3.0700E+04  1.5350E+04  3.0700E+03  4r  6.1400E+04
tf22
fc32 Axial Outlet Tally Q3 (-x-y)
f32:p +500.2
fm32 2.2977E+02
fs32 -501  +502  +507
     +503  +504  +505  +506  T
sd32 3.2429E+04  3.0700E+04  1.5350E+04  3.0700E+03  4r  6.1400E+04
tf32
fc42 Axial Outlet Tally Q4 (+x-y)
f42:p +500.2
fm42 2.2977E+02
fs42 -501  -502  +507
     -508  -509  -510  -511  T
sd42 3.2429E+04  3.0700E+04  1.5350E+04  3.0700E+03  4r  6.1400E+04
tf42
fc52 Axial 1ft Tally
f52:p +600.2
fm52 2.2977E+02
fs52  -601  -602  -603  -604  -605  -606
     -607  -608  -609  T
tf52
fc62 Axial 1m Tally
f62:p +700.2
fm62 2.2977E+02
fs62  -701  -702  -703  -704  -705  -706
     -707  -708  -709  T
tf62
fc72 Axial 2m Tally
f72:p +800.2
fm72 2.2977E+02
fs72  -801  -802  -803  -804  -805  -806
     -807  -808  -809  T
tf72
fc82 Axial 4m Tally
f82:p +900.2
fm82 2.2977E+02
fs82  -901  -902  -903  -904  -905  -906
     -907  -908  -909  T
tf82
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328135 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
```

Figure 5.8.8-6 Concrete Cask Sample Input File – BWR TSC

```
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
```

Figure 5.8.8-7 NAC-CASC Sample Input File - 2x10 PWR Cask Array

```
MAGNASTOR PWR 2x10 Cask Array * Gamma * Axis Detectors
 0.0012250 0.1796102
***** Radial Gamma ***** Reference Angular Distribution *****
         0         0         0         0         0         1
         1
     0.000
         1
         1    19.000
         1   156.000
         1
         1    19.000
         1   156.000
         1
         1    19.000
         1    28.000
         1
         1    19.000
         1    28.000
         1
         1   156.000
         1    28.000
         1
         1   156.000
         1    28.000
         0
   -14.000    14.000   -78.000    78.000     0.000    19.000
       320
     0.000    85.000     3.000
     0.000    90.000     3.000
     0.000    95.000     3.000
     0.000   100.000     3.000
     0.000   125.000     3.000
     0.000   150.000     3.000
     0.000   175.000     3.000
     0.000   200.000     3.000
     0.000   225.000     3.000
     0.000   250.000     3.000
     0.000   275.000     3.000
     0.000   300.000     3.000
     0.000   325.000     3.000
     0.000   350.000     3.000
     0.000   375.000     3.000
     0.000   400.000     3.000
     0.000   425.000     3.000
     0.000   450.000     3.000
     0.000   475.000     3.000
     0.000   500.000     3.000
     0.000   525.000     3.000
     0.000   550.000     3.000
     0.000   575.000     3.000
     0.000   600.000     3.000
     0.000   625.000     3.000
     0.000   650.000     3.000
     0.000   675.000     3.000
     0.000   700.000     3.000
     0.000   725.000     3.000
     0.000   750.000     3.000
     0.000   775.000     3.000
     0.000   800.000     3.000
     0.000   825.000     3.000
     0.000   850.000     3.000
     0.000   875.000     3.000
     0.000   900.000     3.000
     0.000   925.000     3.000
     0.000   950.000     3.000
     0.000   975.000     3.000
     0.000  1000.000     3.000
     0.000  1025.000     3.000
```

Figure 5.8.8-7 NAC-CASC Sample Input File - 2×10 PWR Cask Array

```
     0.000  1050.000     3.000
     0.000  1075.000     3.000
     0.000  1100.000     3.000
     0.000  1125.000     3.000
     0.000  1150.000     3.000
     0.000  1175.000     3.000
     0.000  1200.000     3.000
     0.000  1225.000     3.000
     0.000  1250.000     3.000
     0.000  1275.000     3.000
     0.000  1300.000     3.000
     0.000  1325.000     3.000
     0.000  1350.000     3.000
     0.000  1375.000     3.000
     0.000  1400.000     3.000
     0.000  1425.000     3.000
     0.000  1450.000     3.000
     0.000  1475.000     3.000
     0.000  1500.000     3.000
     0.000  1525.000     3.000
     0.000  1550.000     3.000
     0.000  1575.000     3.000
     0.000  1600.000     3.000
     0.000  1625.000     3.000
     0.000  1650.000     3.000
     0.000  1675.000     3.000
     0.000  1700.000     3.000
     0.000  1725.000     3.000
     0.000  1750.000     3.000
     0.000  1775.000     3.000
     0.000  1800.000     3.000
     0.000  1825.000     3.000
     0.000  1850.000     3.000
     0.000  1875.000     3.000
     0.000  1900.000     3.000
     0.000  1925.000     3.000
     0.000  1950.000     3.000
     0.000  1975.000     3.000
     0.000  2000.000     3.000
(additional detectors omitted for clarity)
         3        20         1         1        23         0        10
  1.00E-02  2.00E-02  5.00E-02  1.00E-01  2.00E-01  3.00E-01  4.00E-01  6.00E-01
  8.00E-01  1.00E+00  1.22E+00  1.44E+00  1.66E+00  2.00E+00  2.50E+00  3.00E+00
  4.00E+00  5.00E+00  6.50E+00  8.00E+00  1.00E+01  1.20E+01  1.40E+01
ONESET
ngp_grad.dat
 7.970E+05 6.157E+07 3.061E+09 6.673E+09 3.088E+09 2.401E+09 3.570E+09 2.228E+09
 1.569E+09 1.247E+09 8.864E+08 3.242E+08 3.454E+08 4.897E+08 1.413E+07 1.773E+07
 1.288E+07 1.181E+07 1.196E+07 1.421E+06 5.619E+04 0.000E+00
 2.602E+10
CASK
RADIAL    CURVED        1      1000
CASK A-1
     1.070
    -8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-2
     1.070
    -8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-3
     1.070
    -8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-4
     1.070
    -8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-5
     1.070
    -8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-6
     1.070
    -8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
```

Figure 5.8.8-7 NAC-CASC Sample Input File - 2×10 PWR Cask Array

```
CASK A-7
     1.070
    -8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-8
     1.070
    -8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-9
     1.070
    -8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-10
     1.070
    -8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-1
     1.070
     8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-2
     1.070
     8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-3
     1.070
     8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-4
     1.070
     8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-5
     1.070
     8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-6
     1.070
     8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-7
     1.070
     8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-8
     1.070
     8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-9
     1.070
     8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-10
     1.070
     8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
***** Axial Gamma ***** Reference Angular Distribution *****
         1         0         1         1         0         0
         3        20         1         1        23         0        10
  1.00E-02  2.00E-02  5.00E-02  1.00E-01  2.00E-01  3.00E-01  4.00E-01  6.00E-01
  8.00E-01  1.00E+00  1.22E+00  1.44E+00  1.66E+00  2.00E+00  2.50E+00  3.00E+00
  4.00E+00  5.00E+00  6.50E+00  8.00E+00  1.00E+01  1.20E+01  1.40E+01
ONESET
ngp_gaxl.dat
 4.914E+05 5.504E+07 1.996E+09 3.654E+09 2.497E+09 1.969E+09 2.048E+09 7.754E+08
 2.879E+08 1.389E+08 5.968E+07 3.760E+06 3.371E+06 3.386E+06 4.934E+05 1.125E+06
 8.856E+05 7.945E+05 1.289E+06 1.778E+05 3.280E+03 0.000E+00
 1.350E+10
CASK
AXIAL     DISK          1      1000
CASK A-1
     1.000
    -8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-2
     1.000
    -8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-3
     1.000
    -8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-4
     1.000
    -8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
```

Figure 5.8.8-7 NAC-CASC Sample Input File - 2×10 PWR Cask Array

```
CASK A-5
     1.000


    -8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-6
     1.000
    -8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-7
     1.000
    -8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-8
     1.000
    -8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-9
     1.000
    -8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-10
     1.000
    -8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-1
     1.000
     8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-2
     1.000
     8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-3
     1.000
     8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-4
     1.000
     8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-5
     1.000
     8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-6
     1.000
     8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-7
     1.000
     8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-8
     1.000
     8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-9
     1.000
     8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-10
     1.000
     8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
```

Figure 5.8.8-8 NAC-CASC Sample Input File - 2×10 BWR Cask Array

```
MAGNASTOR BWR 2x10 Cask Array * Neutron * Axis Detectors
 0.0012250 0.4202091
***** Radial Neutron ***** Reference Angular Distribution *****
         0         0         0         0         0         1
         1
     0.000
         1
         1    19.000
         1   156.000
         1
         1    19.000
         1   156.000
         1
         1    19.000
         1    28.000
         1
         1    19.000
         1    28.000
         1
         1   156.000
         1    28.000
         1
         1   156.000
         1    28.000
         0
   -14.000    14.000   -78.000    78.000     0.000    19.000
       320
     0.000    85.000     3.000
     0.000    90.000     3.000
     0.000    95.000     3.000
     0.000   100.000     3.000
     0.000   125.000     3.000
     0.000   150.000     3.000
     0.000   175.000     3.000
     0.000   200.000     3.000
     0.000   225.000     3.000
     0.000   250.000     3.000
     0.000   275.000     3.000
     0.000   300.000     3.000
     0.000   325.000     3.000
     0.000   350.000     3.000
     0.000   375.000     3.000
     0.000   400.000     3.000
     0.000   425.000     3.000
     0.000   450.000     3.000
     0.000   475.000     3.000
     0.000   500.000     3.000
     0.000   525.000     3.000
     0.000   550.000     3.000
     0.000   575.000     3.000
     0.000   600.000     3.000
     0.000   625.000     3.000
     0.000   650.000     3.000
     0.000   675.000     3.000
     0.000   700.000     3.000
     0.000   725.000     3.000
     0.000   750.000     3.000
     0.000   775.000     3.000
     0.000   800.000     3.000
     0.000   825.000     3.000
     0.000   850.000     3.000
     0.000   875.000     3.000
     0.000   900.000     3.000
     0.000   925.000     3.000
     0.000   950.000     3.000
     0.000   975.000     3.000
     0.000  1000.000     3.000
     0.000  1025.000     3.000
```

Figure 5.8.8-8 NAC-CASC Sample Input File - 2×10 BWR Cask Array

```
     0.000  1050.000     3.000
     0.000  1075.000     3.000
     0.000  1100.000     3.000
     0.000  1125.000     3.000
     0.000  1150.000     3.000
     0.000  1175.000     3.000
     0.000  1200.000     3.000
     0.000  1225.000     3.000
     0.000  1250.000     3.000
     0.000  1275.000     3.000
     0.000  1300.000     3.000
     0.000  1325.000     3.000
     0.000  1350.000     3.000
     0.000  1375.000     3.000
     0.000  1400.000     3.000
     0.000  1425.000     3.000
     0.000  1450.000     3.000
     0.000  1475.000     3.000
     0.000  1500.000     3.000
     0.000  1525.000     3.000
     0.000  1550.000     3.000
     0.000  1575.000     3.000
     0.000  1600.000     3.000
     0.000  1625.000     3.000
     0.000  1650.000     3.000
     0.000  1675.000     3.000
     0.000  1700.000     3.000
     0.000  1725.000     3.000
     0.000  1750.000     3.000
     0.000  1775.000     3.000
     0.000  1800.000     3.000
     0.000  1825.000     3.000
     0.000  1850.000     3.000
     0.000  1875.000     3.000
     0.000  1900.000     3.000
     0.000  1925.000     3.000
     0.000  1950.000     3.000
     0.000  1975.000     3.000
     0.000  2000.000     3.000
(additional detectors omitted for clarity)
         1        20         1         1        29         0        10
  1.10E-20  7.09E-08  5.50E-07  1.50E-06  4.00E-06  1.60E-05  4.81E-05  1.66E-04
  3.54E-04  9.61E-04  2.95E-03  9.12E-03  2.48E-02  6.74E-02  1.10E-01  3.90E-01
  6.40E-01  1.74E+00  2.87E+00  3.68E+00  4.72E+00  6.07E+00  7.00E+00  8.25E+00
  1.00E+01  1.13E+01  1.25E+01  1.36E+01  1.46E+01
ONESET
ngb_nrad.dat
 2.016E+07 7.878E+06 4.705E+05 4.247E+05 6.954E+05 5.049E+05 7.235E+05 4.519E+05
 5.096E+05 6.437E+05 6.781E+05 1.025E+06 7.901E+05 4.113E+05 1.396E+06 4.586E+05
 6.695E+05 6.993E+05 8.499E+04 7.021E+04 6.538E+04 2.489E+04 5.611E+03 3.818E+03
 1.363E+03 0.000E+00 0.000E+00 0.000E+00
 3.885E+07
CASK
RADIAL    CURVED        1      1000
CASK A-1
     1.000
    -8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-2
     1.000
    -8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-3
     1.000
    -8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-4
     1.000
    -8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-5
     1.000
    -8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-6
```

Figure 5.8.8-8 NAC-CASC Sample Input File - 2×10 BWR Cask Array

```
     1.000
    -8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-7
     1.000
    -8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-8
     1.000
    -8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-9
     1.000
    -8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-10
     1.000
    -8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-1
     1.000
     8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-2
     1.000
     8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-3
     1.000
     8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-4
     1.000
     8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-5
     1.000
     8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-6
     1.000
     8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-7
     1.000
     8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-8
     1.000
     8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-9
     1.000
     8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-10
     1.000
     8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
***** Axial Neutron ***** Reference Angular Distribution *****
         1         0         1         1         0         0
         1        20         1         1        29         0        10
  1.10E-20  7.09E-08  5.50E-07  1.50E-06  4.00E-06  1.60E-05  4.81E-05  1.66E-04
  3.54E-04  9.61E-04  2.95E-03  9.12E-03  2.48E-02  6.74E-02  1.10E-01  3.90E-01
  6.40E-01  1.74E+00  2.87E+00  3.68E+00  4.72E+00  6.07E+00  7.00E+00  8.25E+00
  1.00E+01  1.13E+01  1.25E+01  1.36E+01  1.46E+01
ONESET
ngb_naxl.dat
 5.508E+06 3.381E+06 7.423E+05 7.377E+05 1.006E+06 7.927E+05 8.356E+05 4.941E+05
 5.925E+05 6.022E+05 5.853E+05 5.040E+05 4.664E+05 2.601E+05 5.412E+05 2.270E+05
 1.674E+05 3.775E+04 7.554E+03 1.096E+04 1.259E+03 3.766E+02 5.919E+02 0.000E+00
 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 1.750E+07
CASK
AXIAL     DISK          1      1000
CASK A-1
     1.000
    -8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-2
     1.000
    -8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-3
     1.000
    -8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-4
```

Figure 5.8.8-8 NAC-CASC Sample Input File - 2×10 BWR Cask Array

```
     1.000
    -8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-5
     1.000
    -8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-6
     1.000
    -8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-7
     1.000
    -8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-8
     1.000
    -8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-9
     1.000
    -8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK A-10
     1.000
    -8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-1
     1.000
     8.000   -72.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-2
     1.000
     8.000   -56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-3
     1.000
     8.000   -40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-4
     1.000
     8.000   -24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-5
     1.000
     8.000    -8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-6
     1.000
     8.000     8.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-7
     1.000
     8.000    24.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-8
     1.000
     8.000    40.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-9
     1.000
     8.000    56.000     0.000     5.667     5.667     0.000    18.773    18.773
CASK B-10
     1.000
     8.000    72.000     0.000     5.667     5.667     0.000    18.773    18.773
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC

```
MAGNASTOR Stainless Steel Transfer Cask - trfShwDryTopFn_ng17b_37b23e5.6y
C Top Axial Biasing - Fuel Neutron Source
C Fuel Assembly Cells - ng17b - v1.0
1 1 -2.8768 -1      u=6 $ Lower Nozzle
2 2 -0.5685 -2 +1    u=6 $ Lower Plenum
3 3 -3.7837 -3 +2    u=6 $ Fuel
4 4 -0.7317 -4 +3    u=6 $ Upper Plenum
5 5 -1.6143 -5 +4    u=6 $ Upper Nozzle
6 0         +5      u=6 $ Outside
C Cells - Fuel Tube  v1.0
7 8 -7.8212 -8 +7    u=5 $ Tube
8 13 -2.6507 -9 -7    u=5 $ Poison
9 13 -2.6507 -10 -7    u=5 $ Poison
10 13 -2.6507 -11 -7    u=5 $ Poison
11 13 -2.6507 -12 -7    u=5 $ Poison
12 0         -7 #8 #9 #10 #11     u=5 $ Space Inside Tube
13 0         +7 +8    u=5 $ Space Below and Outside Tube
C Cells - PWR Basket v1.0
14 0         -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )    u=4 $ Assy loc 1
15 like 14 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )    u=4 $ Assy loc 3
16 like 14 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )    u=4 $ Assy loc 4
17 like 14 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )    u=4 $ Assy loc 6
18 like 14 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )    u=4 $ Assy loc 8
19 like 14 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )    u=4 $ Assy loc 9
20 like 14 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )    u=4 $ Assy loc 11
21 like 14 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )    u=4 $ Assy loc 13
22 like 14 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )    u=4 $ Assy loc 15
23 like 14 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )    u=4 $ Assy loc 17
24 like 14 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 19
25 like 14 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )    u=4 $ Assy loc 21
26 like 14 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 23
27 like 14 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 25
28 like 14 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 27
29 like 14 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 29
30 like 14 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 30
31 like 14 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )    u=4 $ Assy loc 32
32 like 14 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 34
33 like 14 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 35
34 like 14 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 37
35 8 -7.8212 -15 #22 #29      u=4 $ Side support +x
36 8 -7.8212 -16 #19 #26      u=4 $ Side support -x
37 8 -7.8212 -17 #14 #15      u=4 $ Side support +y
38 8 -7.8212 -18 #33 #34      u=4 $ Side support -y
39 8 -7.8212 -19 +20 +21      u=4 $ Corner
40 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #14 #15 #19 #22 #26 #29 #33 #34       u=4 $ Corner diagonal
41 0          #14 #15 #16 #17 #18 #19 #20 #21 #22 #23 #24
              #25 #26 #27 #28 #29 #30 #31 #32 #33 #34
              #35 #36 #37 #38 #39 #40      u=4 $ Outside Basket Structure
C Cells - PWR Canister Cavity v1.0
42 0         -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )    u=3 $ Assy loc 1
43 like 42 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )    u=3 $ Assy loc 2
44 like 42 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )    u=3 $ Assy loc 3
45 like 42 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )    u=3 $ Assy loc 4
46 like 42 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )    u=3 $ Assy loc 5
47 like 42 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )    u=3 $ Assy loc 6
48 like 42 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )    u=3 $ Assy loc 7
49 like 42 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )    u=3 $ Assy loc 8
50 like 42 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )    u=3 $ Assy loc 9
51 like 42 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )    u=3 $ Assy loc 10
52 like 42 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )    u=3 $ Assy loc 11
53 like 42 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )    u=3 $ Assy loc 12
54 like 42 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )    u=3 $ Assy loc 13
55 like 42 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )    u=3 $ Assy loc 14
56 like 42 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )    u=3 $ Assy loc 15
57 like 42 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )    u=3 $ Assy loc 16
58 like 42 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )    u=3 $ Assy loc 17
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
59 like 42 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
60 like 42 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
61 like 42 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
62 like 42 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
63 like 42 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
64 like 42 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
65 like 42 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
66 like 42 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
67 like 42 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
68 like 42 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
69 like 42 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
70 like 42 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
71 like 42 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
72 like 42 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
73 like 42 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
74 like 42 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
75 like 42 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
76 like 42 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
77 like 42 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
78 like 42 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
79 0         #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52 #53 #54
             #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65 #66 #67
             #68 #69 #70 #71 #72 #73 #74 #75 #76 #77 #78      fill=4 u=3 $ Cavity
C Cells - Canister w/Weld Shield v1.0
80 0         -24 #92  #93  fill=3    u=2 $ Cavity
81 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
82 0         -25 +24.2 -28 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Bottom Drain Port
83 14 -3.9700 -26 +28 -30 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Middle Drain Port
84 0         -27 +30 -31.2 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Top Drain Port
85 like 82 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Bottom Vent Port
86 like 83 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Middle Vent Port
87 like 84 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Top Vent Port
88 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
89 8 -7.8212 -31 -24.1 +24.2 -29 #82 #83  #85 #86   u=2 $ Lower lid
90 7 -7.9400 -31 -24.1 +29 #83 #84  #86 #87    u=2 $ Upper lid
91 7 -7.9400 (-32 +35 +36) : (-33 +35 +36) : (-34 +35 +36)       u=2 $ Weld Shield
92 8 -7.8212 -39 +38 +37 -24.2 trcl = ( 62.7565 43.1314 0.0000 )   u=2 $ Drain port
shield
93 8 -7.8212 -39 +38 +37 -24.2 trcl = ( -62.7565 -43.1314 0.0000 )   u=2 $ Vent port
shield
94 0         +31 #91       u=2 $ Outside void
C Transfer Cask Cells - v1.2_ng17b
95 0         -57  #108  fill=2 ( 0.0000 0.0000 7.0350 )   u=1 $ Canister and Weld Shield
96 0         -40 -41 +57 -48   u=1 $ Gap MTC to Canister below seal
97 6 -0.9982 -40 -41 +57 -49 +48  u=1 $ Gap between seals
98 0         -40 -41 +57 +49 #108   u=1 $ Gap MTC to Canister above seal
99 7 -7.9400 -40 +41 -46    u=1 $ Bottom forging
100 7 -7.9400 -42 +41 +46 -47   u=1 $ Inner shell
101 0         -43 +42 +46 -47   u=1 $ Gap
102 10 -11.344 -44 +43 +46 -47   u=1 $ Lead shell
103 11 -1.6316 -45 +44 +46 -47   u=1 $ NS4FR shell
104 7 -7.9400 -40 +45 +46 -47   u=1 $ Outer shell
105 7 -7.9400 -40 +41 +47    u=1 $ Top forging
106 7 -7.9400 (-50 +51 -56) : (-50 -52 -56)      u=1 $ Door rail
107 7 -7.9400 -55 -53 +54 -56 +57  u=1 $ Door steel
108 7 -7.9400 -59 +58 -40    u=1 $ Weld bar
109 0         +40 #106  #107  +57   u=1 $ VoidC
C
C Detector Cells - Axial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ PortAzi
600  0  -600  +400  +500  $ AnnulusAzi
700  0  -700  +400  +500  +600  $ 1ft
800  0  -800  +400  +500  +600  +700  $ 1m
900  0  -900  +400  +500  +600  +700  +800  $ 2m
1000  0  -1000  +400  +500  +600  +700  +800  +900  $ 4m
1100  0  +400  +500  +600  +700  +800  +900  +1000  $ Exterior
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
C Fuel Assembly Surfaces - ng17b - v1.0
1 RPP -10.8407 10.8407 -10.8407 10.8407 0.0000 5.0800  $ Lower Nozzle
2 RPP -10.8407 10.8407 -10.8407 10.8407 0.0000 19.1230  $ Lower Plenum 3 RPP -10.8407
10.8407 -10.8407 10.8407 0.0000 382.3430  $ Fuel
4 RPP -10.8407 10.8407 -10.8407 10.8407 0.0000 397.0350  $ Upper Plenum
5 RPP -10.8407 10.8407 -10.8407 10.8407 0.0000 420.9256  $ Upper Nozzle
6 PZ 261.2697       $ Flood elevation
C Surfaces - Fuel Tube v1.0
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4200  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
C Surfaces - PWR Basket v1.0
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.0
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4200  $ Tube opening
14 8 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4200  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 8 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 8 RPP -77.8329 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.0
23 RPP -10.8412 10.8412 -10.8412 10.8412 0.0000 420.9257   $ Assy opening
C Surfaces - Canister w/Weld Shield v1.0
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4200 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1200         $ Lower/upper lid
30 PZ 459.4860         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9950 0.0000 0.0000 469.2750 91.4500   $ Canister
32 RCC 0.0000 0.0000 462.2800 0.0000 0.0000 5.0800 78.1050   $ Weld shield bot
33 RCC 0.0000 0.0000 467.3600 0.0000 0.0000 5.0800 71.7550   $ Weld shield mid
34 RCC 0.0000 0.0000 472.4400 0.0000 0.0000 5.0900 66.6750   $ Weld shield top
35 RCC 62.7565 43.1314 462.2800 0.0000 0.0000 15.2500 8.8900   $ Weld shield cutout +x+y
36 RCC -62.7565 -43.1314 462.2800 0.0000 0.0000 15.2500 8.8900   $ Weld shield cutout -x-
y
37 PZ 433.0700         $ Port shield elevation
38 CZ 2.8575         $ Port shield ID
39 CZ 5.0800         $ Port shield OD
C Transfer Cask Surfaces - v1.2_ng17b
40 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 471.1700 111.7600  $ Cask (Without Rail /
Doors)
41 CZ 92.7100        $ Cavity
42 CZ 94.6150        $ Inner shell
43 CZ 94.7420        $ Gap
44 CZ 102.8700        $ Lead shell
45 CZ 108.5850        $ NS4FR shell
46 PZ 30.4800        $ Bottom forging
47 PZ 435.6100        $ Top forging
48 PZ 3.9116        $ Lower Elevation Water Jaccket
49 PZ 463.3214        $ Upper Elevation Water Jaccket
50 RPP -104.0765 104.0765 -111.7600 111.7600 -12.7000 0.0000   $ Door container
51 PY 97.0026        $ Inside rail +y
52 PY -97.0026        $ Inside rail -y
53 PY 96.5200        $ Door +y
54 PY -96.5200        $ Door -y
55 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000   $ Door prism
       108.4699 0.0000 0.0000 89.7374 -73.7172 0.0000
       -89.7374 -73.7172 0.0000
56 RCC 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000 111.7600  $ Door container
57 RCC 0.0000 0.0000 0.0500 0.0000 0.0000 484.5550 91.4400  $ Canister and Weld Shield
58 CZ 90.8049        $ Weld bar inner
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
59 RCC 0.0000 0.0000 469.3150 0.0000 0.0000 1.9050 92.7100  $ Weld bar outerC Axial
Detector DTA (Surface)
400  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  497.4050  111.8600
401  CZ  9.3217
402  CZ  18.6433
403  CZ  27.9650
404  CZ  37.2867
405  CZ  46.6083
406  CZ  55.9300
407  CZ  65.2517
408  CZ  74.5733
409  CZ  83.8950
410  CZ  93.2167
411  CZ  102.5383
C Axial Detector DTAA (PortAzi)
500  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  497.5550  83.5533
501  CZ  68.7451
502     PX  0.0000
503  1  PX  0.0000
504  2  PX  0.0000
505  3  PX  0.0000
506  4  PX  0.0000
507  5  PX  0.0000
508  6  PX  0.0000
509  7  PX  0.0000
510  8  PX  0.0000
511  9  PX  0.0000
512  10  PX  0.0000
513  11  PX  0.0000
514  12  PX  0.0000
515  13  PX  0.0000
516  14  PX  0.0000
517  15  PX  0.0000
518     PY  0.0000
519  16  PX  0.0000
520  17  PX  0.0000
521  18  PX  0.0000
522  19  PX  0.0000
523  20  PX  0.0000
524  21  PX  0.0000
525  22  PX  0.0000
526  23  PX  0.0000
527  24  PX  0.0000
528  25  PX  0.0000
529  26  PX  0.0000
530  27  PX  0.0000
531  28  PX  0.0000
532  29  PX  0.0000
533  30  PX  0.0000
C Axial Detector DTAB (AnnulusAzi)
600  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  497.6550  92.7100
601  CZ  83.5533
602     PX  0.0000
603  8  PX  0.0000
604     PY  0.0000
605  23  PX  0.0000
C Axial Detector DTB (1ft)
700  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  527.9350  142.3400
701  CZ  11.8617
702  CZ  23.7233
703  CZ  35.5850
704  CZ  47.4467
705  CZ  59.3083
706  CZ  71.1700
707  CZ  83.0317
708  CZ  94.8933
709  CZ  106.7550
710  CZ  118.6167
711  CZ  130.4783
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
C Axial Detector DTC (1m)
800  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  597.4550  211.8600
801  CZ  17.6550
802  CZ  35.3100
803  CZ  52.9650
804  CZ  70.6200
805  CZ  88.2750
806  CZ  105.9300  807  CZ  123.5850
808  CZ  141.2400
809  CZ  158.8950
810  CZ  176.5500
811  CZ  194.2050
C Axial Detector DTD (2m)
900  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  697.4550  311.8600
901  CZ  25.9883
902  CZ  51.9767
903  CZ  77.9650
904  CZ  103.9533
905  CZ  129.9417
906  CZ  155.9300
907  CZ  181.9183
908  CZ  207.9067
909  CZ  233.8950
910  CZ  259.8833
911  CZ  285.8717
C Axial Detector DTE (4m)
1000  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  897.4550  511.8600
1001  CZ  42.6550
1002  CZ  85.3100
1003  CZ  127.9650
1004  CZ  170.6200
1005  CZ  213.2750
1006  CZ  255.9300
1007  CZ  298.5850
1008  CZ  341.2400
1009  CZ  383.8950
1010  CZ  426.5500
1011  CZ  469.2050

C
C Materials List - Common Materials - v1.0
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -7.9558E-02 50000 -8.7652E-03 28000 -3.9487E-02
      26000 -2.8961E-01  7014 -2.9217E-04
      40000 -5.7398E-01 25055 -8.3130E-03
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6231E-02 40000 -1.7480E-01 24000 -1.7796E-04
      92238 -6.8839E-01 50000 -2.6694E-03  7014 -8.8980E-05
       8016 -9.7413E-02 26000 -2.2245E-04
C Homogenized Upper Plenum
m4    24000 -1.0797E-01 50000 -6.5102E-03 25055 -1.1320E-02
      26000 -3.9390E-01  7014 -2.1701E-04 28000 -5.3768E-02
      40000 -4.2631E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Aluminum
m9    13027 -1.0
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
C Lead
m10   82000 -1.0
C NS-4-FR
m11   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
 C Concrete
m12   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Neutron Absorber
m13   13027 -0.7470 5010 -0.0356 5011 -0.1624
      6012 -0.0549
nonu                  $ Disable subcritical multiplication
C
C Cell Importances
C
imp:n 1 115r 0
C
C PWR Source Definition - Fuel Neutron - ng17b_37b23e5.6y
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=400:95:80:d5:3
si1   -10.84072 10.84072
sp1   0 1
si2   -10.84072 10.84072
sp2   0 1
si3 a 19.1230 28.2035 37.2840 46.3645 55.4450 64.5255 73.6060
      327.8600 336.9405 346.0210 355.1015 364.1820 373.2625 382.3430
sp3 d 0.0784 0.1479 0.2569 0.4185 0.6481 0.9633 1.3837
      1.3837 0.9633 0.6481 0.4185 0.2569 0.1479 0.0784
si4   1.000E-11 7.090E-08 5.500E-07 1.500E-06 4.000E-06 1.600E-05
      4.810E-05 1.660E-04 3.540E-04 9.610E-04 2.950E-03 9.120E-03
      2.480E-02 6.740E-02 1.100E-01 3.900E-01 6.400E-01 1.740E+00
      2.870E+00 3.680E+00 4.720E+00 6.070E+00 7.000E+00 8.250E+00
      1.000E+01 1.125E+01 1.250E+01 1.360E+01 1.460E+01
sp4   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
      0.0000E+00 0.0000E+00 3.0250E+02 1.3580E+07 3.9150E+07 1.5020E+08
      9.5900E+07 4.0330E+07 2.9960E+07 1.7670E+07 5.2800E+06 3.0590E+06
      1.1390E+06 3.6320E+05 1.0930E+05 2.6240E+04 0.0000E+00
C Source Information
si5 l
            42 43 44
         45 46 47 48 49
      50 51 52 53 54 55 56
      57 58 59 60 61 62 63
      64 65 66 67 68 69 70
         71 72 73 74 75
            76 77 78
C Source Probability
sp5           1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
              1.0 1.0 1.0
mode n
nps 3000000
C
C ANSI/ANS-6.1.1-1977 - Neutron Flux-to-Dose Rate Conversion Factors
C (mrem/hr)/(neutrons/cm2-sec)
C
de0   2.5E-08 1E-07 0.000001 0.00001 0.0001 0.001 0.01
      0.1 0.5 1 2.5 5 7 10
      14 20
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
df0   3.67E-03 3.67E-03 4.46E-03 4.54E-03 4.18E-03 3.76E-03 3.56E-03
      2.17E-02 9.26E-02 1.32E-01 1.25E-01 1.56E-01 1.47E-01 1.47E-01
      2.08E-01 2.27E-01
C
C Weight Window Generation - Top Axial
C
wwg 2 0 0 0 0
wwp:n 5 3 5 0 -1 0
mesh geom=cyl ref=0 0 388 origin=0.1 0.1 -14
     imesh 90.2 91.4 92.7 94.6 102.9 108.6 111.8 611.8
     iints 1 1 1 1 1 1 1 1
     jmesh 1 14 21 26 40 403 418 442 460 498 998
     jints 1 1 1 1 1 10 1 1 1 4 1
     kmesh 1
     kints 1
wwge:n  1e-5 1e-3 1 20
fc2 Axial Surface Tally
f2:n +400.2
fm2 2.7574E+10
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Axial PortAzi Tally Q1 (+x+y)
f12:n +500.2
fm12 2.7574E+10
fs12 -501  -502  -518
     +517  +516  +515  +514  +513  +512
     +511  +510  +509  +508  +507  +506
     +505  +504  +503  T
sd12 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf12
fc22 Axial PortAzi Tally Q2 (-x+y)
f22:n +500.2
fm22 2.7574E+10
fs22 -501  +502  -518
     -533  -532  -531  -530  -529  -528
     -527  -526  -525  -524  -523  -522
     -521  -520  -519  T
sd22 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf22
fc32 Axial PortAzi Tally Q3 (-x-y)
f32:n +500.2
fm32 2.7574E+10
fs32 -501  +502  +518
     -517  -516  -515  -514  -513  -512
     -511  -510  -509  -508  -507  -506
     -505  -504  -503  T
sd32 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf32
fc42 Axial PortAzi Tally Q4 (+x-y)
f42:n +500.2
fm42 2.7574E+10
fs42 -501  -502  +518
     +533  +532  +531  +530  +529  +528
     +527  +526  +525  +524  +523  +522
     +521  +520  +519  T
sd42 1.4847E+04  3.5426E+03  1.7713E+03  1.1071E+02  15r  7.0851E+03
tf42
fc52 Axial AnnulusAzi Tally Q1 (+x+y)
f52:n +600.2
fm52 2.7574E+10
fs52 -601  -602  -604
     +603  T
sd52 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf52
fc62 Axial AnnulusAzi Tally Q2 (-x+y)
f62:n +600.2
fm62 2.7574E+10
fs62 -601  +602  -604
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
     -605  T
sd62 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf62
fc72 Axial AnnulusAzi Tally Q3 (-x-y)
f72:n +600.2
fm72 2.7574E+10
fs72 -601  +602  +604
     -603  T
 sd72 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf72
fc82 Axial AnnulusAzi Tally Q4 (+x-y)
f82:n +600.2
fm82 2.7574E+10
fs82 -601  -602  +604
     +605  T
sd82 2.1932E+04  2.5352E+03  1.2676E+03  6.3381E+02  1r  5.0705E+03
tf82
fc92 Axial 1ft Tally
f92:n +700.2
fm92 2.7574E+10
fs92  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  T
tf92
fc102 Axial 1m Tally
f102:n +800.2
fm102 2.7574E+10
fs102  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  T
tf102
fc112 Axial 2m Tally
f112:n +900.2
fm112 2.7574E+10
fs112  -901  -902  -903  -904  -905  -906
     -907  -908  -909  -910  -911  T
tf112
fc122 Axial 4m Tally
f122:n +1000.2
fm122 2.7574E+10
fs122  -1001  -1002  -1003  -1004  -1005  -1006
     -1007  -1008  -1009  -1010  -1011  T
tf122
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 5.625 degree rotation around z-axis
*TR1 0.0 0.0 0.0 5.625 95.625 90 -84.375 5.625 90 90 90 0
C 11.25 degree rotation around z-axis
*TR2 0.0 0.0 0.0 11.250 101.250 90 -78.750 11.250 90 90 90 0
C 16.875 degree rotation around z-axis
*TR3 0.0 0.0 0.0 16.875 106.875 90 -73.125 16.875 90 90 90 0
C 22.5 degree rotation around z-axis
*TR4 0.0 0.0 0.0 22.500 112.500 90 -67.500 22.500 90 90 90 0
C 28.125 degree rotation around z-axis
*TR5 0.0 0.0 0.0 28.125 118.125 90 -61.875 28.125 90 90 90 0
C 33.75 degree rotation around z-axis
*TR6 0.0 0.0 0.0 33.750 123.750 90 -56.250 33.750 90 90 90 0
C 39.375 degree rotation around z-axis
*TR7 0.0 0.0 0.0 39.375 129.375 90 -50.625 39.375 90 90 90 0
C 45 degree rotation around z-axis
```

Figure 5.8.8-9 Stainless Steel Transfer Cask Sample Input File – PWR TSC (cont'd)

```
*TR8 0.0 0.0 0.0 45.000 135.000 90 -45.000 45.000 90 90 90 0
C 50.625 degree rotation around z-axis
*TR9 0.0 0.0 0.0 50.625 140.625 90 -39.375 50.625 90 90 90 0
C 56.25 degree rotation around z-axis
*TR10 0.0 0.0 0.0 56.250 146.250 90 -33.750 56.250 90 90 90 0
C 61.875 degree rotation around z-axis
*TR11 0.0 0.0 0.0 61.875 151.875 90 -28.125 61.875 90 90 90 0
C 67.5 degree rotation around z-axis
*TR12 0.0 0.0 0.0 67.500 157.500 90 -22.500 67.500 90 90 90 0
C 73.125 degree rotation around z-axis
*TR13 0.0 0.0 0.0 73.125 163.125 90 -16.875 73.125 90 90 90 0
C 78.75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 78.750 168.750 90 -11.250 78.750 90 90 90 0
C 84.375 degree rotation around z-axis
*TR15 0.0 0.0 0.0 84.375 174.375 90 -5.625 84.375 90 90 90 0
C 95.625 degree rotation around z-axis
*TR16 0.0 0.0 0.0 95.625 185.625 90 5.625 95.625 90 90 90 0
C 101.25 degree rotation around z-axis
*TR17 0.0 0.0 0.0 101.250 191.250 90 11.250 101.250 90 90 90 0
C 106.875 degree rotation around z-axis
*TR18 0.0 0.0 0.0 106.875 196.875 90 16.875 106.875 90 90 90 0
C 112.5 degree rotation around z-axis
*TR19 0.0 0.0 0.0 112.500 202.500 90 22.500 112.500 90 90 90 0
C 118.125 degree rotation around z-axis
*TR20 0.0 0.0 0.0 118.125 208.125 90 28.125 118.125 90 90 90 0
C 123.75 degree rotation around z-axis
*TR21 0.0 0.0 0.0 123.750 213.750 90 33.750 123.750 90 90 90 0
C 129.375 degree rotation around z-axis
*TR22 0.0 0.0 0.0 129.375 219.375 90 39.375 129.375 90 90 90 0
C 135 degree rotation around z-axis
*TR23 0.0 0.0 0.0 135.000 225.000 90 45.000 135.000 90 90 90 0
C 140.625 degree rotation around z-axis
*TR24 0.0 0.0 0.0 140.625 230.625 90 50.625 140.625 90 90 90 0
C 146.25 degree rotation around z-axis
*TR25 0.0 0.0 0.0 146.250 236.250 90 56.250 146.250 90 90 90 0
C 151.875 degree rotation around z-axis
*TR26 0.0 0.0 0.0 151.875 241.875 90 61.875 151.875 90 90 90 0
C 157.5 degree rotation around z-axis
*TR27 0.0 0.0 0.0 157.500 247.500 90 67.500 157.500 90 90 90 0
C 163.125 degree rotation around z-axis
*TR28 0.0 0.0 0.0 163.125 253.125 90 73.125 163.125 90 90 90 0
C 168.75 degree rotation around z-axis
*TR29 0.0 0.0 0.0 168.750 258.750 90 78.750 168.750 90 90 90 0
C 174.375 degree rotation around z-axis
*TR30 0.0 0.0 0.0 174.375 264.375 90 84.375 174.375 90 90 90 0
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC

```
MAGNASTOR Augmented Shield VCC - strShlDryRadFg_ng14b_32b21e4.1y
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng14b - v1.0
1 1 -2.5071 -1      u=6 $ Lower Nozzle
2 2 -2.7253 -2 +1     u=6 $ Lower Plenum
3 3 -3.9171 -3 +2     u=6 $ Fuel
4 4 -1.0067 -4 +3     u=6 $ Upper Plenum
5 5 -2.8608 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube  v1.0
7 8 -7.8212 -8 +7     u=5 $ Tube
8 0          #7  -6    u=5 $ Outside below PFE
9 0          #7  +6    u=5 $ Outside above PFE
C Cells - PWR Basket v1.0
10 0          -9 -10 fill=5 trcl = ( -23.5331 70.5993 0.0000 )    u=4 $ Assy loc 1
11 like 10 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )    u=4 $ Assy loc 3
12 like 10 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )    u=4 $ Assy loc 4
13 like 10 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )    u=4 $ Assy loc 6
14 like 10 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )    u=4 $ Assy loc 8
15 like 10 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )    u=4 $ Assy loc 9
16 like 10 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )    u=4 $ Assy loc 11
17 like 10 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )    u=4 $ Assy loc 13
18 like 10 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )    u=4 $ Assy loc 15
19 like 10 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )    u=4 $ Assy loc 17
20 like 10 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 19
21 like 10 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )    u=4 $ Assy loc 21
22 like 10 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 23
23 like 10 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 25
24 like 10 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 27
25 like 10 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 29
26 like 10 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 30
27 like 10 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )    u=4 $ Assy loc 32
28 like 10 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 34
29 like 10 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 35
30 like 10 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 37
31 8 -7.8212 -11 #18 #25      u=4 $ Side support +x
32 8 -7.8212 -12 #15 #22      u=4 $ Side support -x
33 8 -7.8212 -13 #10 #11      u=4 $ Side support +y
34 8 -7.8212 -14 #29 #30      u=4 $ Side support -y
35 8 -7.8212 -15 +16 +17      u=4 $ Corner
36 8 -7.8212 -17 +18 +16  +11.2 +12.1 +13.4 +14.3
            #10 #11 #15 #18 #22 #25 #29 #30       u=4 $ Corner diagonal
37 0         -6 #10 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20
                #21 #22 #23 #24 #25 #26 #27 #28 #29 #30
                #31 #32 #33 #34 #35 #36      u=4 $ Basket below PFE
38 0         +6 #10 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20
               #21 #22 #23 #24 #25 #26 #27 #28 #29 #30
               #31 #32 #33 #34 #35 #36      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.0
39 0         -19 fill=6 trcl = ( -23.5331 70.5993 0.0000 )    u=3 $ Assy loc 1
40 like 39 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )    u=3 $ Assy loc 2
41 like 39 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )    u=3 $ Assy loc 3
42 like 39 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )    u=3 $ Assy loc 4
43 like 39 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )    u=3 $ Assy loc 5
44 like 39 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )    u=3 $ Assy loc 6
45 like 39 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )    u=3 $ Assy loc 7
46 like 39 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )    u=3 $ Assy loc 8
47 like 39 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )    u=3 $ Assy loc 9
48 like 39 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )    u=3 $ Assy loc 10
49 like 39 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )    u=3 $ Assy loc 11
50 like 39 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )    u=3 $ Assy loc 12
51 like 39 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )    u=3 $ Assy loc 13
52 like 39 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )    u=3 $ Assy loc 14
53 like 39 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )    u=3 $ Assy loc 15
54 like 39 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )    u=3 $ Assy loc 16
55 like 39 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )    u=3 $ Assy loc 17
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
56 like 39 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
57 like 39 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
58 like 39 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
59 like 39 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
60 like 39 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
61 like 39 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
62 like 39 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
63 like 39 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
64 like 39 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
65 like 39 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
66 like 39 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
67 like 39 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
68 like 39 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
69 like 39 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
70 like 39 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
71 like 39 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
72 like 39 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
73 like 39 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
74 like 39 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
75 like 39 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
76 0         #39 #40 #41 #42 #43 #44 #45 #46 #47 #48 #49 #50 #51
             #52 #53 #54 #55 #56 #57 #58 #59 #60 #61 #62 #63 #64
             #65 #66 #67 #68 #69 #70 #71 #72 #73 #74 #75      fill=4 u=3 $ Cavity
C Cells - Canister v1.0
77 0         -20 fill=3      u=2 $ Cavity
78 7 -7.9400 -27 +20.3      u=2 $ Canister Bottom
79 7 -7.9400 -21 +20.2 -24 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Bottom Drain Port
80 7 -7.9400 -22 +24 -26 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Middle Drain Port
81 7 -7.9400 -23 +26 -27.2 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Top Drain Port
82 like 79 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Bottom Vent Port
83 like 80 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Middle Vent Port
84 like 81 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Top Vent Port
85 7 -7.9400 -27 -20.3 +20.1     u=2 $ Canister Shell
86 8 -7.8212 -27 -20.1 +20.2 -25 #79 #80  #82 #83   u=2 $ Lower lid
87 7 -7.9400 -27 -20.1 +25 #80 #81  #83 #84    u=2 $ Upper lid
88 0         +27       u=2 $ Outside
C VCC Cells - v1.1_ng14b
89 8 -7.8212 -28       u=1 $ Pedestal plate
90 8 -7.8212 -29 +30      u=1 $ Stand
91 8 -7.8212 -35 +36 +42 +43    u=1 $ Bottom plate outer
92 8 -7.8212 (-36 +37 -31) : (-36 +37 -32)       u=1 $ Bottom plate connector
93 8 -7.8212 -37       u=1 $ Bottom plate inner
94 8 -7.8212 (-30 -57 +58 -39) : (-30 -55 +56 +57 -39)       u=1 $ Support rail inside
stand
95 8 -7.8212 (+29 -57 +58 -38) : (+29 -55 +56 +57 -38)       u=1 $ Support rail outside
stand
96 8 -7.8212 (-47 +49 +31 +32 -40) :
             (-48 +49 +31 +32 -40 +47)       u=1 $ Air inlet top
97 8 -7.8212 (-44 +42 +46 -40 +31 +32 +35) :
             (-45 +43 +46 -40 +31 +32 +35)       u=1 $ Air inlet wall
98 8 -7.8212 (-31 +33 +29 -40 +35) : (-32 +34 +29 -40 +35)       u=1 $ Air inlet angular
wall
99 8 -7.8212 (-46 -44 +42 +31 +32 +43 +35) :
             (-46 -45 +43 +31 +32 +42 +35)       u=1 $ Air inlet remaining wall
100 8 -7.8212 -50 +52 +39 -40    u=1 $ Air outlet steel X
101 8 -7.8212 -51 +53 +39 -40    u=1 $ Air outlet steel Y
102 12 -2.3234 -40 +38 +31 +32 +35 +47 +48 +44 +45 +41 +59 +50 +51
             fill=7 u=1 $ Concrete
103 12 -2.3234 -41       u=1 $ Concrete pad
104 8 -7.8212 -38 +39 +50 +51 +55 +57  u=1 $ Liner
105 8 -7.8212 -59 +60      u=1 $ Top flange
106 0         -59 -60 +62     u=1 $ Flange void
107 8 -7.8212 -61       u=1 $ Lid top
108 8 -7.8212 -62 +64      u=1 $ Lid middle steel A
109 8 -7.8212 -62 -64 -66 +65    u=1 $ Lid middle steel B
110 12 -2.2432 (-62 -64 +66):(-62 -65 -66)       u=1 $ Lid middle concrete
111 8 -7.8212 -63 +65      u=1 $ Lid bottom steel A
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
112 8 -7.8212 -63 -65 -67      u=1 $ Lid bottom steel B
113 12 -2.2432 -63 -65 +67      u=1 $ Lid bottom concrete
114 8 -7.8212 (-68 +80 -39) :
              (-69 +81 -39) :
              (-70 +82 -39) :
              (-71 +83 -39) :
              (-72 +84 -39) :
              (-73 +85 -39) :
              (-74 +86 -39) :
              (-75 +87 -39) :
              (-76 +88 -39) :
              (-77 +89 -39) :
              (-78 +90 -39) :
              (-79 +91 -39)        u=1 $ Standoffs
115 8 -7.8212 -92        u=1 $ -x inlet pipe 1
116 8 -7.8212 -93        u=1 $ -x inlet pipe 2
117 8 -7.8212 -94        u=1 $ -x inlet pipe 3
118 8 -7.8212 -95        u=1 $ -x inlet pipe 4
119 8 -7.8212 -96        u=1 $ -x inlet pipe 5
120 8 -7.8212 -97        u=1 $ -x inlet pipe 6
121 8 -7.8212 -98        u=1 $ -x inlet pipe 7
122 8 -7.8212 -99        u=1 $ -x inlet pipe 8
123 8 -7.8212 -100        u=1 $ -x inlet pipe 9
124 8 -7.8212 -101        u=1 $ -x inlet pipe 10
125 8 -7.8212 -102        u=1 $ -x inlet pipe 11
126 8 -7.8212 -103        u=1 $ -x inlet pipe 12
127 8 -7.8212 -104        u=1 $ -x inlet pipe 13
128 8 -7.8212 -105        u=1 $ -x inlet pipe 14
129 8 -7.8212 -106        u=1 $ -x inlet pipe 15
130 8 -7.8212 -107        u=1 $ -x inlet pipe 16
131 8 -7.8212 -108        u=1 $ -x inlet pipe 17
132 8 -7.8212 -109        u=1 $ +x inlet pipe 1
133 8 -7.8212 -110        u=1 $ +x inlet pipe 2
134 8 -7.8212 -111        u=1 $ +x inlet pipe 3
135 8 -7.8212 -112        u=1 $ +x inlet pipe 4
136 8 -7.8212 -113        u=1 $ +x inlet pipe 5
137 8 -7.8212 -114        u=1 $ +x inlet pipe 6
138 8 -7.8212 -115        u=1 $ +x inlet pipe 7
139 8 -7.8212 -116        u=1 $ +x inlet pipe 8
140 8 -7.8212 -117        u=1 $ +x inlet pipe 9
141 8 -7.8212 -118        u=1 $ +x inlet pipe 10
142 8 -7.8212 -119        u=1 $ +x inlet pipe 11
143 8 -7.8212 -120        u=1 $ +x inlet pipe 12
144 8 -7.8212 -121        u=1 $ +x inlet pipe 13
145 8 -7.8212 -122        u=1 $ +x inlet pipe 14
146 8 -7.8212 -123        u=1 $ +x inlet pipe 15
147 8 -7.8212 -124        u=1 $ +x inlet pipe 16
148 8 -7.8212 -125        u=1 $ +x inlet pipe 17
149 8 -7.8212 -126        u=1 $ -y inlet pipe 1
150 8 -7.8212 -127        u=1 $ -y inlet pipe 2
151 8 -7.8212 -128        u=1 $ -y inlet pipe 3
152 8 -7.8212 -129        u=1 $ -y inlet pipe 4
153 8 -7.8212 -130        u=1 $ -y inlet pipe 5
154 8 -7.8212 -131        u=1 $ -y inlet pipe 6
155 8 -7.8212 -132        u=1 $ -y inlet pipe 7
156 8 -7.8212 -133        u=1 $ -y inlet pipe 8
157 8 -7.8212 -134        u=1 $ -y inlet pipe 9
158 8 -7.8212 -135        u=1 $ -y inlet pipe 10
159 8 -7.8212 -136        u=1 $ -y inlet pipe 11
160 8 -7.8212 -137        u=1 $ -y inlet pipe 12
161 8 -7.8212 -138        u=1 $ -y inlet pipe 13
162 8 -7.8212 -139        u=1 $ -y inlet pipe 14
163 8 -7.8212 -140        u=1 $ -y inlet pipe 15
164 8 -7.8212 -141        u=1 $ -y inlet pipe 16
165 8 -7.8212 -142        u=1 $ -y inlet pipe 17
166 8 -7.8212 -143        u=1 $ +y inlet pipe 1
167 8 -7.8212 -144        u=1 $ +y inlet pipe 2
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
168 8 -7.8212 -145       u=1 $ +y inlet pipe 3
169 8 -7.8212 -146       u=1 $ +y inlet pipe 4
170 8 -7.8212 -147       u=1 $ +y inlet pipe 5
171 8 -7.8212 -148       u=1 $ +y inlet pipe 6
172 8 -7.8212 -149       u=1 $ +y inlet pipe 7
173 8 -7.8212 -150       u=1 $ +y inlet pipe 8
174 8 -7.8212 -151       u=1 $ +y inlet pipe 9
175 8 -7.8212 -152       u=1 $ +y inlet pipe 10
176 8 -7.8212 -153       u=1 $ +y inlet pipe 11
177 8 -7.8212 -154       u=1 $ +y inlet pipe 12
178 8 -7.8212 -155       u=1 $ +y inlet pipe 13
179 8 -7.8212 -156       u=1 $ +y inlet pipe 14
180 8 -7.8212 -157       u=1 $ +y inlet pipe 15
181 8 -7.8212 -158       u=1 $ +y inlet pipe 16
182 8 -7.8212 -159       u=1 $ +y inlet pipe 17
183 0         -35 +36 -42 +93 +96 +110 +113
              +92 +93 +94 +95 +96 +97 +98
              +99 +100 +101 +102 +103 +104 +105
              +106 +107 +108 +109 +110 +111 +112
              +113 +114 +115 +116 +117 +118 +119
              +120 +121 +122 +123 +124 +125       u=1 $ Bottom plate outer void x
184 0         -35 +36 -43 +115 +118 +120 +123
              +126 +127 +128 +129 +130 +131 +132
              +133 +134 +135 +136 +137 +138 +139
              +140 +141 +142 +143 +144 +145 +146
              +147 +148 +149 +150 +151 +152 +153
              +154 +155 +156 +157 +158 +159       u=1 $ Bottom plate outer void y
185 0         -36 +37 +31 +32    u=1 $ Bottom plate connector void
186 0         (-30 -58 -39) : (-30 -56 +57 -39)       u=1 $ Support rail inside stand
void
187 0         (+29 -58 -38) : (+29 -56 +57 -38)       u=1 $ Support rail outside stand
void
188 0         -42 +29 +31 +32 -40 +35
              +92 +93 +94 +95 +96 +97 +98
              +99 +100 +101 +102 +103 +104 +105
              +106 +107 +108 +109 +110 +111 +112
              +113 +114 +115 +116 +117 +118 +119
              +120 +121 +122 +123 +124 +125       u=1 $ Air inlet void x
189 0         -43 +29 +31 +32 -40 +35 +42
              +126 +127 +128 +129 +130 +131 +132
              +133 +134 +135 +136 +137 +138 +139
              +140 +141 +142 +143 +144 +145 +146
              +147 +148 +149 +150 +151 +152 +153
              +154 +155 +156 +157 +158 +159       u=1 $ Air inlet void y
190 0         -49 +29 +31 +32       u=1 $ Air inlet top void
191 0         (-33 +35 +29) : (-34 +35 +29)       u=1 $ Connector void
192 0         -30 +55 +57       u=1 $ Stand void
193 0         -52 +39 -40     u=1 $ Air outlet void X
194 0         -53 +39 -40     u=1 $ Air outlet void Y
195 0         -39 +28 +29 +55 +57 +62 +63 #114
              fill=2 ( 0.0000 0.0000 6.9850 )       u=1 $ Cavity
196 0         +40 +38 +59 +61    u=1 $ Outside
C VCC Rebar Cells - v1.1_ng14b
197 8 -7.8212 -160       u=7 $ Outer hoop 1
198 8 -7.8212 -161       u=7 $ Outer hoop 2
199 8 -7.8212 -162       u=7 $ Outer hoop 3
200 8 -7.8212 -163       u=7 $ Outer hoop 4
201 8 -7.8212 -164       u=7 $ Outer hoop 5
202 8 -7.8212 -165       u=7 $ Outer hoop 6
203 8 -7.8212 -166       u=7 $ Outer hoop 7
204 8 -7.8212 -167       u=7 $ Outer hoop 8
205 8 -7.8212 -168       u=7 $ Outer hoop 9
206 8 -7.8212 -169       u=7 $ Outer hoop 10
207 8 -7.8212 -170       u=7 $ Outer hoop 11
208 8 -7.8212 -171       u=7 $ Outer hoop 12
209 8 -7.8212 -172       u=7 $ Outer hoop 13
210 8 -7.8212 -173       u=7 $ Outer hoop 14
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
211 8 -7.8212 -174       u=7 $ Outer hoop 15
212 8 -7.8212 -175       u=7 $ Outer hoop 16
213 8 -7.8212 -176       u=7 $ Outer hoop 17
214 8 -7.8212 -177       u=7 $ Outer hoop 18
215 8 -7.8212 -178       u=7 $ Outer hoop 19
216 8 -7.8212 -179       u=7 $ Outer hoop 20
217 8 -7.8212 -180       u=7 $ Outer hoop 21
218 8 -7.8212 -181       u=7 $ Outer hoop 22
219 8 -7.8212 -182       u=7 $ Outer hoop 23
220 8 -7.8212 -183       u=7 $ Outer hoop 24
221 8 -7.8212 -184       u=7 $ Outer hoop 25
222 8 -7.8212 -185       u=7 $ Outer hoop 26
223 8 -7.8212 -186       u=7 $ Outer hoop 27
224 8 -7.8212 -187       u=7 $ Outer hoop 28
225 8 -7.8212 -188       u=7 $ Outer hoop 29
226 8 -7.8212 -189       u=7 $ Outer hoop 30
227 8 -7.8212 -190       u=7 $ Outer hoop 31
228 8 -7.8212 -191       u=7 $ Outer hoop 32
229 8 -7.8212 -192       u=7 $ Outer hoop 33
230 8 -7.8212 -193       u=7 $ Outer hoop 34
231 8 -7.8212 -194       u=7 $ Outer hoop 35
232 8 -7.8212 -195       u=7 $ Outer hoop 36
233 8 -7.8212 -196       u=7 $ Outer hoop 37
234 8 -7.8212 -197       u=7 $ Outer hoop 38
235 8 -7.8212 -198       u=7 $ Outer hoop 39
236 8 -7.8212 -199       u=7 $ Outer hoop 40
237 8 -7.8212 -200       u=7 $ Outer hoop 41
238 8 -7.8212 -201       u=7 $ Outer hoop 42
239 8 -7.8212 -202       u=7 $ Outer hoop 43
240 8 -7.8212 -203       u=7 $ Outer hoop 44
241 8 -7.8212 -204       u=7 $ Outer hoop 45
242 8 -7.8212 -205       u=7 $ Outer hoop 46
243 8 -7.8212 -206       u=7 $ Outer hoop 47
244 8 -7.8212 -207       u=7 $ Outer hoop 48
245 12 -2.3234 #197 #198 #199 #200 #201 #202 #203         $ Concrete
        #204 #205 #206 #207 #208 #209 #210 #211 #212 #213
        #214 #215 #216 #217 #218 #219 #220 #221 #222 #223
        #224 #225 #226 #227 #228 #229 #230 #231 #232 #233
        #234 #235 #236 #237 #238 #239 #240 #241 #242 #243
        #244       fill=8 u=7
246 8 -7.8212 -208   trcl = ( 160.3375 0.0000 0.0000 )    u=8 $ Outer bar 1
247 like 246 but   trcl = ( 159.3293 17.9521 0.0000 )    u=8 $ Outer bar 2
248 like 246 but   trcl = ( 156.3175 35.6785 0.0000 )    u=8 $ Outer bar 3
249 like 246 but   trcl = ( 151.3399 52.9561 0.0000 )    u=8 $ Outer bar 4
250 like 246 but   trcl = ( 144.4591 69.5678 0.0000 )    u=8 $ Outer bar 5
251 like 246 but   trcl = ( 135.7616 85.3047 0.0000 )    u=8 $ Outer bar 6
252 like 246 but   trcl = ( 125.3569 99.9688 0.0000 )    u=8 $ Outer bar 7
253 like 246 but   trcl = ( 113.3757 113.3757 0.0000 )    u=8 $ Outer bar 8
254 like 246 but   trcl = ( 99.9688 125.3569 0.0000 )    u=8 $ Outer bar 9
255 like 246 but   trcl = ( 85.3047 135.7616 0.0000 )    u=8 $ Outer bar 10
256 like 246 but   trcl = ( 69.5678 144.4591 0.0000 )    u=8 $ Outer bar 11
257 like 246 but   trcl = ( 52.9561 151.3399 0.0000 )    u=8 $ Outer bar 12
258 like 246 but   trcl = ( 35.6785 156.3175 0.0000 )    u=8 $ Outer bar 13
259 like 246 but   trcl = ( 17.9521 159.3293 0.0000 )    u=8 $ Outer bar 14
260 like 246 but   trcl = ( 0.0000 160.3375 0.0000 )    u=8 $ Outer bar 15
261 like 246 but   trcl = ( -17.9521 159.3293 0.0000 )    u=8 $ Outer bar 16
262 like 246 but   trcl = ( -35.6785 156.3175 0.0000 )    u=8 $ Outer bar 17
263 like 246 but   trcl = ( -52.9561 151.3399 0.0000 )    u=8 $ Outer bar 18
264 like 246 but   trcl = ( -69.5678 144.4591 0.0000 )    u=8 $ Outer bar 19
265 like 246 but   trcl = ( -85.3047 135.7616 0.0000 )    u=8 $ Outer bar 20
266 like 246 but   trcl = ( -99.9688 125.3569 0.0000 )    u=8 $ Outer bar 21
267 like 246 but   trcl = ( -113.3757 113.3757 0.0000 )    u=8 $ Outer bar 22
268 like 246 but   trcl = ( -125.3569 99.9688 0.0000 )    u=8 $ Outer bar 23
269 like 246 but   trcl = ( -135.7616 85.3047 0.0000 )    u=8 $ Outer bar 24
270 like 246 but   trcl = ( -144.4591 69.5678 0.0000 )    u=8 $ Outer bar 25
271 like 246 but   trcl = ( -151.3399 52.9561 0.0000 )    u=8 $ Outer bar 26
272 like 246 but   trcl = ( -156.3175 35.6785 0.0000 )    u=8 $ Outer bar 27
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
273 like 246 but   trcl = ( -159.3293 17.9521 0.0000 )    u=8 $ Outer bar 28
274 like 246 but   trcl = ( -160.3375 0.0000 0.0000 )    u=8 $ Outer bar 29
275 like 246 but   trcl = ( -159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 30
276 like 246 but   trcl = ( -156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 31
277 like 246 but   trcl = ( -151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 32
278 like 246 but   trcl = ( -144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 33
279 like 246 but   trcl = ( -135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 34
280 like 246 but   trcl = ( -125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 35
281 like 246 but   trcl = ( -113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 36
282 like 246 but   trcl = ( -99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 37
283 like 246 but   trcl = ( -85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 38
284 like 246 but   trcl = ( -69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 39
285 like 246 but   trcl = ( -52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 40
286 like 246 but   trcl = ( -35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 41
287 like 246 but   trcl = ( -17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 42
288 like 246 but   trcl = ( 0.0000 -160.3375 0.0000 )    u=8 $ Outer bar 43
289 like 246 but   trcl = ( 17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 44
290 like 246 but   trcl = ( 35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 45
291 like 246 but   trcl = ( 52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 46
292 like 246 but   trcl = ( 69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 47
293 like 246 but   trcl = ( 85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 48
294 like 246 but   trcl = ( 99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 49
295 like 246 but   trcl = ( 113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 50
296 like 246 but   trcl = ( 125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 51
297 like 246 but   trcl = ( 135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 52
298 like 246 but   trcl = ( 144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 53
299 like 246 but   trcl = ( 151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 54
300 like 246 but   trcl = ( 156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 55
301 like 246 but   trcl = ( 159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 56
302 12 -2.3234 #246 #247 #248
        #249 #250 #251 #252 #253 #254 #255 #256 #257 #258
        #259 #260 #261 #262 #263 #264 #265 #266 #267 #268
        #269 #270 #271 #272 #273 #274 #275 #276 #277 #278
        #279 #280 #281 #282 #283 #284 #285 #286 #287 #288
        #289 #290 #291 #292 #293 #294 #295 #296 #297 #298
        #299 #300 #301        u=8
C Detector Cells - Radial Biasing
399  0  -399  fill=1  $ Cask
400  0  -400  +399  $ Surface
500  0  -500  +399  +400  $ 1ft
600  0  -600  +399  +400  +500  $ 1m
700  0  -700  +399  +400  +500  +600  $ 2m
800  0  -800  +399  +400  +500  +600  +700  $ 4m
900  0  +399  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.0
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094       $ Flood elevation
C Surfaces - Fuel Tube v1.0
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4200  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
C Surfaces - PWR Basket v1.0
9  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4200  $ Tube opening
10 9 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4200  $ Tube radius
11  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
12  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
13  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
14  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
15  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
16  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
17 9 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
18 9 RPP -77.83291 77.8329 -77.83291 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.0
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
19 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister v1.0
20 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4200 90.1700   $ Cavity
21 CZ 2.6924          $ Bot Cylinder Radius
22 CZ 6.7691          $ Mid Cyclinder Radius
23 CZ 7.4041          $ Top Cylinder Radius
24 PZ 450.8500          $ Port plane bot/mid
25 PZ 452.1200          $ Lower/upper lid
26 PZ 459.4860          $ Port plane mid/top
27 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.2650 91.4400   $ Canister
C VCC Surfaces - v1.1_ng14b
28  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
29  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 63.4999  $ Stand outer
30  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 62.3888  $ Stand inner
31 9 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate A
32 10 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate B
33 9 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall A
34 10 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall B
35  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
36  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 100.3300  $ Connector radius
37  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
38  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 535.4828 108.585  $ VCC liner outer
39  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 535.4828 100.965  $ VCC liner inner
40  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 654.5328 172.7200  $ Concrete
41  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
42  RPP -172.7200 172.7200 -63.5000 63.5000 -33.0200 -21.5900   $ Air inlet void X
43  RPP -63.5000 63.5000 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet void Y
44  RPP -172.7200 172.7200 -64.7700 64.7700 -33.0200 -21.5900   $ Air inlet wall X
45  RPP -64.7700 64.7700 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet wall Y
46  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 11.4300 100.3300  $ Air inlet divider
47  RPP -172.7200 172.7200 -64.7700 64.7700 -21.5900 -16.5100   $ Air inlet top X
48  RPP -64.7700 64.7700 -172.7200 172.7200 -21.5900 -16.5100   $ Air inlet top Y
49  RCC 0.0000 0.0000 -21.5900 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
50  RPP -172.7200 172.7200 -64.7700 64.7700 494.3348 504.4948   $ Air outlet steel X
51  RPP -64.7700 64.7700 -172.7200 172.7200 494.3348 504.4948   $ Air outlet steel Y
52  RPP -172.7200 172.7200 -63.5000 63.5000 494.9698 503.8598   $ Air outlet void X
53  RPP -63.5000 63.5000 -172.7200 172.7200 494.9698 503.8598   $ Air outlet void Y
54  CZ 100.3300        $ Air outlet radius
55  RPP -108.5850 108.5850 -5.7150 5.7150 -16.5100 -5.0800   $ Support rail exterior X
56  RPP -108.5850 108.5850 -4.4450 4.4450 -16.5100 -5.0800   $ Support rail interior X
57  RPP -5.7150 5.7150 -108.5850 108.5850 -16.5100 -5.0800   $ Support rail exterior Y
58  RPP -4.4450 4.4450 -108.5850 108.5850 -16.5100 -5.0800   $ Support rail interior Y
59  RCC 0.0000 0.0000 518.9728 0.0000 0.0000 2.5400 118.7450  $ Top flange
60  CZ 102.8700        $ Top flange ID
61  RCC 0.0000 0.0000 521.5128 0.0000 0.0000 1.9050 116.2050  $ Lid top
62  RCC 0.0000 0.0000 506.1458 0.0000 0.0000 15.3670 100.3300  $ Lid middle
63  RCC 0.0000 0.0000 490.9058 0.0000 0.0000 15.2400 76.2000  $ Lid bottom
64  CZ 99.6950        $ Middle concrete radius
65  CZ 75.5650        $ Bottom concrete radius
66  PZ 506.7808        $ Lid middle upper
67  PZ 491.5408        $ Lid bottom upper
68  RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 1
69 11 RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 2
70 12 RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 3
71 9 RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 4
72 13 RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 5
73 14 RPP -100.9650 100.9650 -0.4432 0.4432 172.2628 477.0628   $ Standoff outer 6
74  RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 7
75 11 RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 8
76 12 RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 9
77 9 RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 10
78 13 RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 11
79 14 RPP -0.4432 0.4432 -100.9650 100.9650 172.2628 477.0628   $ Standoff outer 12
80  RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 1
81 11 RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 2
82 12 RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 3
83 9 RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 4
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
84 13 RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 5
85 14 RPP -93.3450 93.3450 -0.4432 0.4432 172.2628 477.0628   $ Standoff inner 6
86  RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 7
87 11 RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 8
88 12 RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 9
89 9 RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 10
90 13 RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 11
91 14 RPP -0.4432 0.4432 -93.3450 93.3450 172.2628 477.0628   $ Standoff inner 12
92  RCC -146.0500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 1
93  RCC -146.0500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 2
94  RCC -146.0500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 3
95  RCC -146.0500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 4
96  RCC -146.0500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 5
97  RCC -146.0500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 6
98  RCC -133.3500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 7
99  RCC -133.3500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 8
100  RCC -133.3500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 9
101  RCC -133.3500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 10
102  RCC -133.3500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 11
103  RCC -133.3500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 12
104  RCC -120.6500 43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 13
105  RCC -120.6500 21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 14
106  RCC -120.6500 -0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 15
107  RCC -120.6500 -22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 16
108  RCC -120.6500 -44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 17
109  RCC 146.0500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 1
110  RCC 146.0500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 2
111  RCC 146.0500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 3
112  RCC 146.0500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 4
113  RCC 146.0500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 5
114  RCC 146.0500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 6
115  RCC 133.3500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 7
116  RCC 133.3500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 8
117  RCC 133.3500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 9
118  RCC 133.3500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 10
119  RCC 133.3500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 11
120  RCC 133.3500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 12
121  RCC 120.6500 -43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 13
122  RCC 120.6500 -21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 14
123  RCC 120.6500 0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 15
124  RCC 120.6500 22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 16
125  RCC 120.6500 44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 17
126  RCC -58.4200 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 1
127  RCC -36.5760 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 2
128  RCC -14.7320 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 3
129  RCC 7.1120 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 4
130  RCC 28.9560 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 5
131  RCC 50.8000 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 6
132  RCC -50.8000 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 7
133  RCC -28.9560 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 8
134  RCC -7.1120 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 9
135  RCC 14.7320 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 10
136  RCC 36.5760 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 11
137  RCC 58.4200 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 12
138  RCC -43.1800 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 13
139  RCC -21.3360 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 14
140  RCC 0.5080 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 15
141  RCC 22.3520 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 16
142  RCC 44.1960 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 17
143  RCC 58.4200 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 1
144  RCC 36.5760 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 2
145  RCC 14.7320 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 3
146  RCC -7.1120 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 4
147  RCC -28.9560 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 5
148  RCC -50.8000 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 6
149  RCC 50.8000 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 7
150  RCC 28.9560 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 8
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
151  RCC 7.1120 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 9
152  RCC -14.7320 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 10
153  RCC -36.5760 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 11
154  RCC -58.4200 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 12
155  RCC 43.1800 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 13
156  RCC 21.3360 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 14
157  RCC -0.5080 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 15
158  RCC -22.3520 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 16
159  RCC -44.1960 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 17
C VCC Rebar Surfaces - v1.1_ng14b
160  TZ 0.0000 0.0000 -1.3218 162.2425 0.9525 0.9525   $ Outer hoop 1
161  TZ 0.0000 0.0000 8.7863 162.2425 0.9525 0.9525   $ Outer hoop 2
162  TZ 0.0000 0.0000 18.8945 162.2425 0.9525 0.9525   $ Outer hoop 3
163  TZ 0.0000 0.0000 29.0027 162.2425 0.9525 0.9525   $ Outer hoop 4
164  TZ 0.0000 0.0000 39.1108 162.2425 0.9525 0.9525   $ Outer hoop 5
165  TZ 0.0000 0.0000 49.2190 162.2425 0.9525 0.9525   $ Outer hoop 6
166  TZ 0.0000 0.0000 59.3271 162.2425 0.9525 0.9525   $ Outer hoop 7
167  TZ 0.0000 0.0000 69.4353 162.2425 0.9525 0.9525   $ Outer hoop 8
168  TZ 0.0000 0.0000 79.5435 162.2425 0.9525 0.9525   $ Outer hoop 9
169  TZ 0.0000 0.0000 89.6516 162.2425 0.9525 0.9525   $ Outer hoop 10
170  TZ 0.0000 0.0000 99.7598 162.2425 0.9525 0.9525   $ Outer hoop 11
171  TZ 0.0000 0.0000 109.8680 162.2425 0.9525 0.9525   $ Outer hoop 12
172  TZ 0.0000 0.0000 119.9761 162.2425 0.9525 0.9525   $ Outer hoop 13
173  TZ 0.0000 0.0000 130.0843 162.2425 0.9525 0.9525   $ Outer hoop 14
174  TZ 0.0000 0.0000 140.1924 162.2425 0.9525 0.9525   $ Outer hoop 15
175  TZ 0.0000 0.0000 150.3006 162.2425 0.9525 0.9525   $ Outer hoop 16
176  TZ 0.0000 0.0000 160.4088 162.2425 0.9525 0.9525   $ Outer hoop 17
177  TZ 0.0000 0.0000 170.5169 162.2425 0.9525 0.9525   $ Outer hoop 18
178  TZ 0.0000 0.0000 180.6251 162.2425 0.9525 0.9525   $ Outer hoop 19
179  TZ 0.0000 0.0000 190.7333 162.2425 0.9525 0.9525   $ Outer hoop 20
180  TZ 0.0000 0.0000 200.8414 162.2425 0.9525 0.9525   $ Outer hoop 21
181  TZ 0.0000 0.0000 210.9496 162.2425 0.9525 0.9525   $ Outer hoop 22
182  TZ 0.0000 0.0000 221.0578 162.2425 0.9525 0.9525   $ Outer hoop 23
183  TZ 0.0000 0.0000 231.1659 162.2425 0.9525 0.9525   $ Outer hoop 24
184  TZ 0.0000 0.0000 241.2741 162.2425 0.9525 0.9525   $ Outer hoop 25
185  TZ 0.0000 0.0000 251.3822 162.2425 0.9525 0.9525   $ Outer hoop 26
186  TZ 0.0000 0.0000 261.4904 162.2425 0.9525 0.9525   $ Outer hoop 27
187  TZ 0.0000 0.0000 271.5986 162.2425 0.9525 0.9525   $ Outer hoop 28
188  TZ 0.0000 0.0000 281.7067 162.2425 0.9525 0.9525   $ Outer hoop 29
189  TZ 0.0000 0.0000 291.8149 162.2425 0.9525 0.9525   $ Outer hoop 30
190  TZ 0.0000 0.0000 301.9231 162.2425 0.9525 0.9525   $ Outer hoop 31
191  TZ 0.0000 0.0000 312.0312 162.2425 0.9525 0.9525   $ Outer hoop 32
192  TZ 0.0000 0.0000 322.1394 162.2425 0.9525 0.9525   $ Outer hoop 33
193  TZ 0.0000 0.0000 332.2476 162.2425 0.9525 0.9525   $ Outer hoop 34
194  TZ 0.0000 0.0000 342.3557 162.2425 0.9525 0.9525   $ Outer hoop 35
195  TZ 0.0000 0.0000 352.4639 162.2425 0.9525 0.9525   $ Outer hoop 36
196  TZ 0.0000 0.0000 362.5720 162.2425 0.9525 0.9525   $ Outer hoop 37
197  TZ 0.0000 0.0000 372.6802 162.2425 0.9525 0.9525   $ Outer hoop 38
198  TZ 0.0000 0.0000 382.7884 162.2425 0.9525 0.9525   $ Outer hoop 39
199  TZ 0.0000 0.0000 392.8965 162.2425 0.9525 0.9525   $ Outer hoop 40
200  TZ 0.0000 0.0000 403.0047 162.2425 0.9525 0.9525   $ Outer hoop 41
201  TZ 0.0000 0.0000 413.1129 162.2425 0.9525 0.9525   $ Outer hoop 42
202  TZ 0.0000 0.0000 423.2210 162.2425 0.9525 0.9525   $ Outer hoop 43
203  TZ 0.0000 0.0000 433.3292 162.2425 0.9525 0.9525   $ Outer hoop 44
204  TZ 0.0000 0.0000 443.4373 162.2425 0.9525 0.9525   $ Outer hoop 45
205  TZ 0.0000 0.0000 453.5455 162.2425 0.9525 0.9525   $ Outer hoop 46
206  TZ 0.0000 0.0000 463.6537 162.2425 0.9525 0.9525   $ Outer hoop 47
207  TZ 0.0000 0.0000 473.7618 162.2425 0.9525 0.9525   $ Outer hoop 48
208  RCC 0.0000 0.0000 -11.4300 0.0000 0.0000 495.3000 0.9525  $ Bar
C Storage Cask & Pad Container
399  RCC  0.0000  0.0000  -133.0200  0.0000  0.0000  656.4378  172.7201
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  556.5378  172.8201
401  PZ  13.3582
402  PZ  59.7363
403  PZ  106.1145
404  PZ  152.4926
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
405  PZ  198.8708
406  PZ  245.2489
407  PZ  291.6271
408  PZ  338.0052
409  PZ  384.3834
410  PZ  430.7615
411  PZ  477.1397
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  587.0178  203.3001
501  PZ  15.8982
502  PZ  64.8163
503  PZ  113.7345
504  PZ  162.6526
505  PZ  211.5708
506  PZ  260.4889
507  PZ  309.4071
508  PZ  358.3252
509  PZ  407.2434
510  PZ  456.1615
511  PZ  505.0797
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  656.5378  272.8201
601  PZ  10.7492
602  PZ  54.5184
603  PZ  98.2876
604  PZ  142.0567
605  PZ  185.8259
606  PZ  229.5951
607  PZ  273.3643
608  PZ  317.1335
609  PZ  360.9027
610  PZ  404.6719
611  PZ  448.4411
612  PZ  492.2102
613  PZ  535.9794
614  PZ  579.7486
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  756.5378  372.8201
701  PZ  4.8069
702  PZ  42.6338
703  PZ  80.4607
704  PZ  118.2876
705  PZ  156.1145
706  PZ  193.9413
707  PZ  231.7682
708  PZ  269.5951
709  PZ  307.4220
710  PZ  345.2489
711  PZ  383.0758
712  PZ  420.9027
713  PZ  458.7296
714  PZ  496.5565
715  PZ  534.3834
716  PZ  572.2102
717  PZ  610.0371
718  PZ  647.8640
719  PZ  685.6909
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  956.5378  572.8201
801  PZ  14.8069
802  PZ  62.6338
803  PZ  110.4607
804  PZ  158.2876
805  PZ  206.1145
806  PZ  253.9413
807  PZ  301.7682
808  PZ  349.5951
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
809  PZ  397.4220
810  PZ  445.2489
811  PZ  493.0758
812  PZ  540.9027
813  PZ  588.7296
814  PZ  636.5565
815  PZ  684.3834
816  PZ  732.2102
817  PZ  780.0371
818  PZ  827.8640
819  PZ  875.6909

C
C Materials List - Common Materials - v1.0
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
      92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
       8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4    24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
      26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
      40000 -2.1362E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Aluminum
m9    13027 -1.0
C Lead
m10   82000 -1.0
C NS-4-FR
m11   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m12   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m13   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:p 1 307r 0
C
C Source Definition - Fuel Gamma - ng14b_32b21e4.1y
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=399:195:77:d5:3
si1   -9.85901 9.85901
sp1   0 1
si2   -9.85901 9.85901
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
sp2   0 1
si3 a 9.8374 19.0576 28.2778 37.4980 46.7182 55.9384 65.1586
      323.3242 332.5444 341.7646 350.9848 360.2050 369.4252 378.6454
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
sb3 d 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
si4   1.000E-02 2.000E-02 5.000E-02 1.000E-01 2.000E-01 3.000E-01
      4.000E-01 6.000E-01 8.000E-01 1.000E+00 1.220E+00 1.440E+00
      1.660E+00 2.000E+00 2.500E+00 3.000E+00 4.000E+00 5.000E+00
      6.500E+00 8.000E+00 1.000E+01 1.200E+01 1.400E+01
sp4   0.0000E+00 6.2752E+14 8.7664E+14 4.0250E+14 3.3810E+14 9.5410E+13
      7.0043E+13 7.5264E+14 1.9045E+15 2.9488E+14 4.5444E+13 4.6708E+13
      5.6468E+12 1.7127E+12 4.1272E+12 1.3579E+11 1.6921E+10 8.6551E+06
      3.4736E+06 6.8141E+05 1.4468E+05 7.4804E+03 0.0000E+00
C Source Information
si5 l       39 40 41
         42 43 44 45 46
      47 48 49 50 51 52 53
      54 55 56 57 58 59 60
      61 62 63 64 65 66 67
         68 69 70 71 72
            73 74 75
C Source Probability
sp5           1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0 1.0 1.0
            1.0 1.0 1.0
mode p
nps 400000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Rate Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=89 0 201 origin=0.1 0.1 -134
     imesh 90.2 91.4 101.0 108.6 172.7 672.7
     iints 5 1 1 2 5 1
     jmesh 101 104 112 118 129 141 151 520 550 580 603 625 656 657 1157
     jints 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +400.1
fm2 2.0224E+17
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
tf2
fc12 Radial 1ft Tally
f12:p +500.1
fm12 2.0224E+17
fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  T
tf12
fc22 Radial 1m Tally
f22:p +600.1
fm22 2.0224E+17
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  T
tf22
fc32 Radial 2m Tally
f32:p +700.1
fm32 2.0224E+17
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf32
fc42 Radial 4m Tally
f42:p +800.1
fm42 2.0224E+17
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
```

Figure 5.8.8-10 Augmented Shield Concrete Cask Sample Input File – PWR TSC (cont'd)

```
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 75 165 90 -15 75 90 90 90 0
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel

```
MAGNASTOR Transfer Cask - trfShwDryBotFgd_ng14b_44b25e06y
C Bottom Axial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng14b - v1.1
1 1 -2.5071 -1      u=7 $ Lower Nozzle
2 2 -2.7253 -2 +1     u=7 $ Lower Plenum
3 3 -3.9171 -3 +2     u=7 $ Fuel
4 4 -1.0067 -4 +3     u=7 $ Upper Plenum
5 5 -2.8608 -5 +4     u=7 $ Upper Nozzle
6 0          +5      u=7 $ Outside
C Cells - Fuel Tube  v1.3
13 8 -7.8212 -8 +7    u=5 $ Tube
14 9 -2.6336 -9 : -10 : -11 : -12     u=5 $ Poison
15 0          #13  #14  -6   u=5 $ Outside below PFE
16 0          #13  #14  +6   u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
17 0          -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )    u=4 $ Assy loc 1
18 like 17 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )    u=4 $ Assy loc 3
19 like 17 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )    u=4 $ Assy loc 4
20 like 17 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )    u=4 $ Assy loc 6
21 like 17 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )    u=4 $ Assy loc 8
22 like 17 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )    u=4 $ Assy loc 9
23 like 17 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )    u=4 $ Assy loc 11
24 like 17 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )    u=4 $ Assy loc 13
25 like 17 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )    u=4 $ Assy loc 15
26 like 17 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )    u=4 $ Assy loc 17
27 like 17 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 19
28 like 17 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )    u=4 $ Assy loc 21
29 like 17 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 23
30 like 17 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 25
31 like 17 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 27
32 like 17 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 29
33 like 17 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 30
34 like 17 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )    u=4 $ Assy loc 32
35 like 17 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 34
36 like 17 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 35
37 like 17 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 37
38 8 -7.8212 -15 #25 #32      u=4 $ Side support +x
39 8 -7.8212 -16 #22 #29      u=4 $ Side support -x
40 8 -7.8212 -17 #17 #18      u=4 $ Side support +y
41 8 -7.8212 -18 #36 #37      u=4 $ Side support -y
42 8 -7.8212 -19 +20 +21      u=4 $ Corner
43 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #17 #18 #22 #25 #29 #32 #36 #37       u=4 $ Corner diagonal
44 0         -6 #17 #18 #19 #20 #21 #22 #23 #24 #25 #26 #27
                #28 #29 #30 #31 #32 #33 #34 #35 #36 #37
                #38 #39 #40 #41 #42 #43      u=4 $ Basket below PFE
45 0         +6 #17 #18 #19 #20 #21 #22 #23 #24 #25 #26 #27
               #28 #29 #30 #31 #32 #33 #34 #35 #36 #37
               #38 #39 #40 #41 #42 #43      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
46 0          -23 fill=7 trcl = ( -23.5331 70.5993 0.0000 )    u=3 $ Assy loc 1
47 like 46 but fill=7 trcl = ( 0.0000 70.5993 0.0000 )    u=3 $ Assy loc 2
48 like 46 but fill=7 trcl = ( 23.5331 70.5993 0.0000 )    u=3 $ Assy loc 3
49 like 46 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )    u=3 $ Assy loc 4
50 like 46 but fill=7 trcl = ( -23.5331 47.0662 0.0000 )    u=3 $ Assy loc 5
51 like 46 but fill=7 trcl = ( 0.0000 47.0662 0.0000 )    u=3 $ Assy loc 6
52 like 46 but fill=7 trcl = ( 23.5331 47.0662 0.0000 )    u=3 $ Assy loc 7
53 like 46 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )    u=3 $ Assy loc 8
54 like 46 but fill=7 trcl = ( -70.5993 23.5331 0.0000 )    u=3 $ Assy loc 9
55 like 46 but fill=7 trcl = ( -47.0662 23.5331 0.0000 )    u=3 $ Assy loc 10
56 like 46 but fill=7 trcl = ( -23.5331 23.5331 0.0000 )    u=3 $ Assy loc 11
57 like 46 but fill=7 trcl = ( 0.0000 23.5331 0.0000 )    u=3 $ Assy loc 12
58 like 46 but fill=7 trcl = ( 23.5331 23.5331 0.0000 )    u=3 $ Assy loc 13
59 like 46 but fill=7 trcl = ( 47.0662 23.5331 0.0000 )    u=3 $ Assy loc 14
60 like 46 but fill=7 trcl = ( 70.5993 23.5331 0.0000 )    u=3 $ Assy loc 15
61 like 46 but fill=7 trcl = ( -70.5993 0.0000 0.0000 )    u=3 $ Assy loc 16
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
62 like 46 but fill=7 trcl = ( -47.0662 0.0000 0.0000 )    u=3 $ Assy loc 17
63 like 46 but fill=7 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
64 like 46 but fill=7 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
65 like 46 but fill=7 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
66 like 46 but fill=7 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
67 like 46 but fill=7 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
68 like 46 but fill=7 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
69 like 46 but fill=7 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
70 like 46 but fill=7 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
71 like 46 but fill=7 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
72 like 46 but fill=7 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
73 like 46 but fill=7 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
74 like 46 but fill=7 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
75 like 46 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
76 like 46 but fill=7 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
77 like 46 but fill=7 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
78 like 46 but fill=7 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
79 like 46 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
80 like 46 but fill=7 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
81 like 46 but fill=7 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
82 like 46 but fill=7 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
83 0         #46 #47 #48 #49 #50 #51 #52 #53 #54 #55 #56 #57 #58
             #59 #60 #61 #62 #63 #64 #65 #66 #67 #68 #69 #70 #71
             #72 #73 #74 #75 #76 #77 #78 #79 #80 #81 #82      fill=4 u=3 $ Cavity
C Cells - Canister w/Weld Shield v1.3
84 0         -24 #96  #97  fill=3    u=2 $ Cavity
85 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
86 0         -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Bottom Drain Port
87 14 -3.9700 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Middle Drain Port
88 0         -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Top Drain Port
89 like 86 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Bottom Vent Port
90 like 87 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Middle Vent Port
91 like 88 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Top Vent Port
92 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
93 8 -7.8212 -31 -24.1 +24.2 -29 #86 #87  #89 #90   u=2 $ Lower lid
94 7 -7.9400 -31 -24.1 +29 #87 #88  #90 #91    u=2 $ Upper lid
95 7 -7.9400 (-32 +35 +36) : (-33 +35 +36) : (-34 +35 +36)       u=2 $ Weld Shield
96 7 -7.9400 -39 +38 +37 -24.2 trcl = ( 61.7220 44.7040 0.0000 )   u=2 $ Drain port
shield
97 7 -7.9400 -39 +38 +37 -24.2 trcl = ( -61.7220 -44.7040 0.0000 ) u=2 $ Vent port shield
98 6 -0.9982 +31 #95  -40     u=2 $ Outside water
99 0         +31 #95  +40     u=2 $ Outside void
C Transfer Cask Cells - v1.3.1_ng14b
100 6 -0.9982 -41 -42 #110  fill=2 ( 0.0000 0.0000 6.9850 )   u=1 $ Cavity
101 8 -7.8212 -41 +42 -47    u=1 $ Bottom forging
102 8 -7.8212 -43 +42 +47 -48   u=1 $ Inner shell
103 0         -44 +43 +47 -48   u=1 $ Gap
104 11 -11.344 -45 +44 +47 -48   u=1 $ Lead shell
105 12 -1.6316 -46 +45 +47 -48   u=1 $ NS4FR shell
106 8 -7.8212 -41 +46 +47 -48   u=1 $ Outer shell
107 8 -7.8212 -41 +42 +48    u=1 $ Top forging
108 8 -7.8212 (-49 +50 -55) : (-49 -51 -55)      u=1 $ Door rail
109 8 -7.8212 -54 -52 +53 -55   u=1 $ Door steel
110 8 -7.8212 -57 +56     u=1 $ Weld bar
111 0         +41 #108  #109     u=1 $ Void
C Fuel Assembly Cells - ng14b - v1.1
7 1 -2.5071 -1     u=6 $ Lower Nozzle
8 2 -2.7253 -2 +1    u=6 $ Lower Plenum
9 18 -9.8635 -3 +2    u=6 $ Fuel
10 4 -1.0067 -4 +3    u=6 $ Upper Plenum
11 5 -2.8608 -5 +4    u=6 $ Upper Nozzle
12 0         +5     u=6 $ Outside
C Detector Cells - Axial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ 1ft
600  0  -600  +400  +500  $ 1m
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
700  0  -700  +400  +500  +600  $ 2m
800  0  -800  +400  +500  +600  +700  $ 4m
900  0  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.1
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094        $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 8 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 8 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 8 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.5
23 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister w/Weld Shield v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1962         $ Lower/upper lid
30 PZ 459.5114         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
32 RCC 0.0000 0.0000 462.3562 0.0000 0.0000 5.0800 78.1050   $ Weld shield bot
33 RCC 0.0000 0.0000 467.4362 0.0000 0.0000 5.0800 71.7550   $ Weld shield mid
34 RCC 0.0000 0.0000 472.5162 0.0000 0.0000 5.0800 66.6750   $ Weld shield top
35 RCC 61.7220 44.7040 462.3562 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout +x+y
36 RCC -61.7220 -44.7040 462.3562 0.0000 0.0000 15.2400 8.8900   $ Weld shield cutout -x-
y
37 PZ 433.1462         $ Port shield elevation
38 CZ 2.6924         $ Port shield ID
39 CZ 5.0800         $ Port shield OD
40 RCC 0.0000 0.0000 -3.0748 0.0000 0.0000 459.4098 99.0000   $ Water jacket
C Transfer Cask Surfaces - v1.3.1_ng14b
41 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 488.9500 111.7600  $ Cask
42 CZ 92.7100        $ Cavity
43 CZ 94.6150        $ Inner shell
44 CZ 94.7420        $ Gap
45 CZ 102.8700        $ Lead shell
46 CZ 108.5850        $ NS4FR shell
47 PZ 30.4800        $ Bottom forging
48 PZ 453.3900        $ Top forging
49 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door container
50 PY 97.0026        $ Inside rail +y
51 PY -97.0026        $ Inside rail -y
52 PY 96.5200        $ Door +y
53 PY -96.5200        $ Door -y
54 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000   $ Door prism
       108.4699 0.0000 0.0000 89.7374 -73.7172 0.0000
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
      -89.7374 -73.7172 0.0000
55 RCC 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000 111.7600  $ Door container
56 RCC 0.0000 0.0000 469.3412 0.0000 0.0000 1.9050 90.8049  $ Weld bar inner
57 RCC 0.0000 0.0000 469.3412 0.0000 0.0000 1.9050 92.7100  $ Weld bar outer
C Axial Detector DBA (Surface)
400  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  501.8500  111.8600
401  CZ  11.1860
402  CZ  22.3720
403  CZ  33.5580
404  CZ  44.7440
405  CZ  55.9300
406  CZ  67.1160
407  CZ  78.3020
408  CZ  89.4880
409  CZ  100.6740
C Axial Detector DBB (1ft)
500  RCC  0.0000  0.0000  -43.2800  0.0000  0.0000  532.3300  142.3400
501  CZ  14.2340
502  CZ  28.4680
503  CZ  42.7020
504  CZ  56.9360
505  CZ  71.1700
506  CZ  85.4040
507  CZ  99.6380
508  CZ  113.8720
509  CZ  128.1060
C Axial Detector DBC (1m)
600  RCC  0.0000  0.0000  -112.8000  0.0000  0.0000  601.8500  211.8600
601  CZ  21.1860
602  CZ  42.3720
603  CZ  63.5580
604  CZ  84.7440
605  CZ  105.9300
606  CZ  127.1160
607  CZ  148.3020
608  CZ  169.4880
609  CZ  190.6740
C Axial Detector DBD (2m)
700  RCC  0.0000  0.0000  -212.8000  0.0000  0.0000  701.8500  311.8600
701  CZ  31.1860
702  CZ  62.3720
703  CZ  93.5580
704  CZ  124.7440
705  CZ  155.9300
706  CZ  187.1160
707  CZ  218.3020
708  CZ  249.4880
709  CZ  280.6740
C Axial Detector DBE (4m)
800  RCC  0.0000  0.0000  -412.8000  0.0000  0.0000  901.8500  511.8600
801  CZ  51.1860
802  CZ  102.3720
803  CZ  153.5580
804  CZ  204.7440
805  CZ  255.9300
806  CZ  307.1160
807  CZ  358.3020
808  CZ  409.4880
809  CZ  460.6740

C
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
C Homogenized Lower Plenum
m2     24000 -1.0000E-03 50000 -1.5000E-02
       26000 -1.2500E-03  7014 -5.0000E-04
       40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3     92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
       92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
        8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4     24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
       26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
       40000 -2.1362E-01
C Homogenized Upper Nozzle
m5     24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
       28000 -9.5000E-02
C Water
m6     1001 2 8016 1
C Stainless Steel
m7     24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Carbon Steel
m8     26000 -0.99  6012 -0.01
C Neutron Poison
m9     13027 -0.6605 5010 -0.0478 5011 -0.2179
       6012 -0.0737
C Aluminum
m10    13027 -1.0
C Lead
m11    82000 -1.0
C NS-4-FR
m12    5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
       5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
       8016 -4.2500E-01
C Concrete
m13    26000 -0.014 20000 -0.044 14000 -0.337
        1001 -0.010  8016 -0.532 11023 -0.029
       13027 -0.034
C Vent Port Middle Cylinder
m14    24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Balsa
m15    6012 6 1001 10 8016 5
C NS-4-FR (Accident)
m16    5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
       5011 -7.7389E-03
C Copper
m17    29063 -6.8499E-01 29065 -3.1501E-01
C Damaged Fuel
m18    92235 -4.1222E-02
       92238 -7.8321E-01
        8016 -1.1083E-01
       40000 -6.3583E-02
       50000 -9.7099E-04
       26000 -8.0916E-05
       24000 -6.4732E-05
        7014 -3.2366E-05
C Damaged Lower Nozzle
m19    92235 -3.2602E-02
       92238 -6.1944E-01
        8016 -8.7656E-02
       24000 -4.9457E-02
       25055 -5.2060E-03
       26000 -1.8091E-01
       28000 -2.4728E-02
C Damaged Lower Plenum
m20    92235 -3.0443E-02
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
      92238 -5.7843E-01
       8016 -8.1852E-02
      24000 -3.0928E-04
      26000 -3.8660E-04
      40000 -3.0379E-01
      50000 -4.6392E-03
       7014 -1.5464E-04
C Damaged Upper Plenum
m21   92235 -3.9655E-02
      92238 -7.5344E-01
       8016 -1.0662E-01
      24000 -1.4932E-02
      26000 -5.4568E-02
      40000 -2.1423E-02
      50000 -3.2715E-04
       7014 -1.0905E-05
      25055 -1.5695E-03
      28000 -7.4552E-03
C Damaged upper Nozzle
m22   92235 -3.0832E-02
      92238 -5.8581E-01
       8016 -8.2897E-02
      24000 -5.7087E-02
      25055 -6.0091E-03
      26000 -2.0882E-01
      28000 -2.8543E-02
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:p 1 115r 0
C
C PWR Source Definition - Fuel Gamma - ng14b_44b25e06y
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=d5
si1   -9.85901 9.85901
sp1   0 1
si2   -9.85901 9.85901
sp2   0 1
si3 a 9.8374 19.0576 28.2778 37.4980 46.7182 55.9384 65.1586
      323.3242 332.5444 341.7646 350.9848 360.2050 369.4252 378.6454
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
si4   1.000E-02 2.000E-02 5.000E-02 1.000E-01 2.000E-01 3.000E-01
      4.000E-01 6.000E-01 8.000E-01 1.000E+00 1.220E+00 1.440E+00
      1.660E+00 2.000E+00 2.500E+00 3.000E+00 4.000E+00 5.000E+00
      6.500E+00 8.000E+00 1.000E+01 1.200E+01 1.400E+01
sp4   0.0000E+00 4.8667E+14 6.8756E+14 2.8806E+14 2.2654E+14 6.4874E+13
      4.3572E+13 5.4036E+14 2.0749E+15 2.4434E+14 3.3564E+13 4.8315E+13
      3.3945E+12 5.9002E+11 9.4049E+11 4.4422E+10 5.6146E+09 2.0157E+07
      8.0901E+06 1.5871E+06 3.3698E+05 1.7423E+04 0.0000E+00
C Source Information
si5 l 400:100:84:46:3
      400:100:84:47:3
      400:100:84:48:3
      400:100:84:49:9
      400:100:84:50:3
      400:100:84:51:3
      400:100:84:52:3
      400:100:84:53:9
      400:100:84:54:3
      400:100:84:55:3
      400:100:84:56:3
      400:100:84:57:3
      400:100:84:58:3
      400:100:84:59:3
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
        400:100:84:60:3
        400:100:84:61:3
        400:100:84:62:3
        400:100:84:63:3
        400:100:84:64:3
        400:100:84:65:3
        400:100:84:66:3
        400:100:84:67:3
        400:100:84:68:3
        400:100:84:69:3
        400:100:84:70:3
        400:100:84:71:3
        400:100:84:72:3
        400:100:84:73:3
        400:100:84:74:3
        400:100:84:75:9
        400:100:84:76:3
        400:100:84:77:3
        400:100:84:78:3
        400:100:84:79:9
        400:100:84:80:3
        400:100:84:81:3
        400:100:84:82:3
C Source Probability
sp5           1.0 1.0 1.0
            2.1837 1.0 1.0 1.0 2.1837
        1.0 1.0 1.0 1.0 1.0 1.0 1.0
        1.0 1.0 1.0 1.0 1.0 1.0 1.0
        1.0 1.0 1.0 1.0 1.0 1.0 1.0
            2.1837 1.0 1.0 1.0 2.1837
                1.0 1.0 1.0
mode p
nps 25000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Bottom Axial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=0 0 18 origin=0.1 0.1 -513
     imesh 90.2 91.4 92.7 94.6 102.9 108.6 111.8 611.8
     iints 1 1 1 1 1 1 1 1
     jmesh 500 513 520 528 530 898 920 929 959 997 1497
     jints 1 3 2 1 1 10 1 1 1 7 1
     kmesh 1
     kints 1
wwge:p  1e-3 1 20
fc2 Axial Surface Tally
f2:p +400.3
fm2 2.0994E+17
fs2  -401  -402  -403  -404  -405  -406
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
     -407  -408  -409  T
tf2
fc12 Axial 1ft Tally
f12:p +500.3
fm12 2.0994E+17

fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  T
tf12
fc22 Axial 1m Tally
f22:p +600.3
fm22 2.0994E+17
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  T
tf22
fc32 Axial 2m Tally
f32:p +700.3
fm32 2.0994E+17
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  T
tf32
fc42 Axial 4m Tally
f42:p +800.3
fm42 2.0994E+17
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 5.625 degree rotation around z-axis
*TR1 0.0 0.0 0.0 5.625 95.625 90 -84.375 5.625 90 90 90 0
C 11.25 degree rotation around z-axis
*TR2 0.0 0.0 0.0 11.250 101.250 90 -78.750 11.250 90 90 90 0
C 16.875 degree rotation around z-axis
*TR3 0.0 0.0 0.0 16.875 106.875 90 -73.125 16.875 90 90 90 0
C 22.5 degree rotation around z-axis
*TR4 0.0 0.0 0.0 22.500 112.500 90 -67.500 22.500 90 90 90 0
C 28.125 degree rotation around z-axis
*TR5 0.0 0.0 0.0 28.125 118.125 90 -61.875 28.125 90 90 90 0
C 33.75 degree rotation around z-axis
*TR6 0.0 0.0 0.0 33.750 123.750 90 -56.250 33.750 90 90 90 0
C 39.375 degree rotation around z-axis
*TR7 0.0 0.0 0.0 39.375 129.375 90 -50.625 39.375 90 90 90 0
C 45 degree rotation around z-axis
*TR8 0.0 0.0 0.0 45.000 135.000 90 -45.000 45.000 90 90 90 0
C 50.625 degree rotation around z-axis
*TR9 0.0 0.0 0.0 50.625 140.625 90 -39.375 50.625 90 90 90 0
C 56.25 degree rotation around z-axis
*TR10 0.0 0.0 0.0 56.250 146.250 90 -33.750 56.250 90 90 90 0
C 61.875 degree rotation around z-axis
*TR11 0.0 0.0 0.0 61.875 151.875 90 -28.125 61.875 90 90 90 0
C 67.5 degree rotation around z-axis
*TR12 0.0 0.0 0.0 67.500 157.500 90 -22.500 67.500 90 90 90 0
C 73.125 degree rotation around z-axis
*TR13 0.0 0.0 0.0 73.125 163.125 90 -16.875 73.125 90 90 90 0
```

Figure 5.8.8-11 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Active Fuel Damaged Fuel (cont'd)

```
C 78.75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 78.750 168.750 90 -11.250 78.750 90 90 90 0
C 84.375 degree rotation around z-axis
*TR15 0.0 0.0 0.0 84.375 174.375 90 -5.625 84.375 90 90 90 0
C 95.625 degree rotation around z-axis
*TR16 0.0 0.0 0.0 95.625 185.625 90 5.625 95.625 90 90 90 0
C 101.25 degree rotation around z-axis
*TR17 0.0 0.0 0.0 101.250 191.250 90 11.250 101.250 90 90 90 0
C 106.875 degree rotation around z-axis
*TR18 0.0 0.0 0.0 106.875 196.875 90 16.875 106.875 90 90 90 0
C 112.5 degree rotation around z-axis
*TR19 0.0 0.0 0.0 112.500 202.500 90 22.500 112.500 90 90 90 0
C 118.125 degree rotation around z-axis
*TR20 0.0 0.0 0.0 118.125 208.125 90 28.125 118.125 90 90 90 0
C 123.75 degree rotation around z-axis
*TR21 0.0 0.0 0.0 123.750 213.750 90 33.750 123.750 90 90 90 0
C 129.375 degree rotation around z-axis
*TR22 0.0 0.0 0.0 129.375 219.375 90 39.375 129.375 90 90 90 0
C 135 degree rotation around z-axis
*TR23 0.0 0.0 0.0 135.000 225.000 90 45.000 135.000 90 90 90 0
C 140.625 degree rotation around z-axis
*TR24 0.0 0.0 0.0 140.625 230.625 90 50.625 140.625 90 90 90 0
C 146.25 degree rotation around z-axis
*TR25 0.0 0.0 0.0 146.250 236.250 90 56.250 146.250 90 90 90 0
C 151.875 degree rotation around z-axis
*TR26 0.0 0.0 0.0 151.875 241.875 90 61.875 151.875 90 90 90 0
C 157.5 degree rotation around z-axis
*TR27 0.0 0.0 0.0 157.500 247.500 90 67.500 157.500 90 90 90 0
C 163.125 degree rotation around z-axis
*TR28 0.0 0.0 0.0 163.125 253.125 90 73.125 163.125 90 90 90 0
C 168.75 degree rotation around z-axis
*TR29 0.0 0.0 0.0 168.750 258.750 90 78.750 168.750 90 90 90 0
C 174.375 degree rotation around z-axis
*TR30 0.0 0.0 0.0 174.375 264.375 90 84.375 174.375 90 90 90 0
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
MAGNASTOR VCC - strShlDryRadLfn_ng14b_32b21e4.1y
C Radial Biasing - Lower Nozzle Source
C Fuel Assembly Cells - ng14b - v1.1
1 1 -2.5071 -1      u=7 $ Lower Nozzle
2 2 -2.7253 -2 +1    u=7 $ Lower Plenum
3 3 -3.9171 -3 +2    u=7 $ Fuel
4 4 -1.0067 -4 +3    u=7 $ Upper Plenum
5 5 -2.8608 -5 +4    u=7 $ Upper Nozzle
6 0         +5      u=7 $ Outside
C Cells - Fuel Tube  v1.3
13 8 -7.8212 -8 +7    u=5 $ Tube
14 9 -2.6336 -9 : -10 : -11 : -12     u=5 $ Poison
15 0         #13  #14  -6   u=5 $ Outside below PFE
16 0         #13  #14  +6   u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
17 0         -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )    u=4 $ Assy loc 1
18 like 17 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )    u=4 $ Assy loc 3
19 like 17 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )    u=4 $ Assy loc 4
20 like 17 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )    u=4 $ Assy loc 6
21 like 17 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )    u=4 $ Assy loc 8
22 like 17 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )    u=4 $ Assy loc 9
23 like 17 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )    u=4 $ Assy loc 11
24 like 17 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )    u=4 $ Assy loc 13
25 like 17 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )    u=4 $ Assy loc 15
26 like 17 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )    u=4 $ Assy loc 17
27 like 17 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 19
28 like 17 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )    u=4 $ Assy loc 21
29 like 17 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 23
30 like 17 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 25
31 like 17 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 27
32 like 17 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 29
33 like 17 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 30
34 like 17 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )    u=4 $ Assy loc 32
35 like 17 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 34
36 like 17 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 35
37 like 17 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 37
38 8 -7.8212 -15 #25 #32      u=4 $ Side support +x
39 8 -7.8212 -16 #22 #29      u=4 $ Side support -x
40 8 -7.8212 -17 #17 #18      u=4 $ Side support +y
41 8 -7.8212 -18 #36 #37      u=4 $ Side support -y
42 8 -7.8212 -19 +20 +21      u=4 $ Corner
43 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #17 #18 #22 #25 #29 #32 #36 #37       u=4 $ Corner diagonal
44 0         -6 #17 #18 #19 #20 #21 #22 #23 #24 #25 #26 #27
                #28 #29 #30 #31 #32 #33 #34 #35 #36 #37
                #38 #39 #40 #41 #42 #43      u=4 $ Basket below PFE
45 0         +6 #17 #18 #19 #20 #21 #22 #23 #24 #25 #26 #27
               #28 #29 #30 #31 #32 #33 #34 #35 #36 #37
               #38 #39 #40 #41 #42 #43      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
46 0         -23 fill=7 trcl = ( -23.5331 70.5993 0.0000 )    u=3 $ Assy loc 1
47 like 46 but fill=7 trcl = ( 0.0000 70.5993 0.0000 )    u=3 $ Assy loc 2
48 like 46 but fill=7 trcl = ( 23.5331 70.5993 0.0000 )    u=3 $ Assy loc 3
49 like 46 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )    u=3 $ Assy loc 4
50 like 46 but fill=7 trcl = ( -23.5331 47.0662 0.0000 )    u=3 $ Assy loc 5
51 like 46 but fill=7 trcl = ( 0.0000 47.0662 0.0000 )    u=3 $ Assy loc 6
52 like 46 but fill=7 trcl = ( 23.5331 47.0662 0.0000 )    u=3 $ Assy loc 7
53 like 46 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )    u=3 $ Assy loc 8
54 like 46 but fill=7 trcl = ( -70.5993 23.5331 0.0000 )    u=3 $ Assy loc 9
55 like 46 but fill=7 trcl = ( -47.0662 23.5331 0.0000 )    u=3 $ Assy loc 10
56 like 46 but fill=7 trcl = ( -23.5331 23.5331 0.0000 )    u=3 $ Assy loc 11
57 like 46 but fill=7 trcl = ( 0.0000 23.5331 0.0000 )    u=3 $ Assy loc 12
58 like 46 but fill=7 trcl = ( 23.5331 23.5331 0.0000 )    u=3 $ Assy loc 13
59 like 46 but fill=7 trcl = ( 47.0662 23.5331 0.0000 )    u=3 $ Assy loc 14
60 like 46 but fill=7 trcl = ( 70.5993 23.5331 0.0000 )    u=3 $ Assy loc 15
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
61 like 46 but fill=7 trcl = ( -70.5993 0.0000 0.0000 )    u=3 $ Assy loc 16
62 like 46 but fill=7 trcl = ( -47.0662 0.0000 0.0000 )    u=3 $ Assy loc 17
63 like 46 but fill=7 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
64 like 46 but fill=7 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
65 like 46 but fill=7 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
66 like 46 but fill=7 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
67 like 46 but fill=7 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
68 like 46 but fill=7 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
69 like 46 but fill=7 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
70 like 46 but fill=7 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
71 like 46 but fill=7 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
72 like 46 but fill=7 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
73 like 46 but fill=7 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
74 like 46 but fill=7 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
75 like 46 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
76 like 46 but fill=7 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
77 like 46 but fill=7 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
78 like 46 but fill=7 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
79 like 46 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
80 like 46 but fill=7 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
81 like 46 but fill=7 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
82 like 46 but fill=7 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
83 0          #46 #47 #48 #49 #50 #51 #52 #53 #54 #55 #56 #57 #58
              #59 #60 #61 #62 #63 #64 #65 #66 #67 #68 #69 #70 #71
              #72 #73 #74 #75 #76 #77 #78 #79 #80 #81 #82      fill=4 u=3 $ Cavity
C Cells - Canister v1.3
84 0          -24 fill=3      u=2 $ Cavity
85 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
86 7 -7.9400 -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Bottom Drain Port
87 7 -7.9400 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Middle Drain Port
88 7 -7.9400 -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Top Drain Port
89 like 86 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Bottom Vent Port
90 like 87 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Middle Vent Port
91 like 88 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Top Vent Port
92 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
93 8 -7.8212 -31 -24.1 +24.2 -29 #86 #87  #89 #90   u=2 $ Lower lid
94 7 -7.9400 -31 -24.1 +29 #87 #88  #90 #91    u=2 $ Upper lid
95 0          +31       u=2 $ Outside
C VCC Cells - v1.3.1_ng14b
96 8 -7.8212 -32       u=1 $ Pedestal plate
97 8 -7.8212 -33 +34      u=1 $ Stand
98 8 -7.8212 -39 +40 +46 +47    u=1 $ Bottom plate outer
99 8 -7.8212 (-40 +41 -35) : (-40 +41 -36)       u=1 $ Bottom plate connector
100 8 -7.8212 -41       u=1 $ Bottom plate inner
101 8 -7.8212 (-34 -56 +57 -43) : (-34 -54 +55 +56 -43)   u=1 $ Support rail inside stand
102 8 -7.8212 (+33 -56 +57 -43) : (+33 -54 +55 +56 -43)   u=1 $ Support rail outside
stand
103 8 -7.8212 (-51 +53 +35 +36 -44) :
              (-52 +53 +35 +36 -44 +51)       u=1 $ Air inlet top
104 8 -7.8212 (-48 +46 +50 -44 +35 +36 +39) :
              (-49 +47 +50 -44 +35 +36 +39)       u=1 $ Air inlet wall
105 8 -7.8212 (-35 +37 +33 -44 +39) : (-36 +38 +33 -44 +39)  u=1 $ Air inlet angular wall
106 8 -7.8212 (-50 -48 +46 +35 +36 +47 +39) :
              (-50 -49 +47 +35 +36 +46 +39)       u=1 $ Air inlet remaining wall
107 13 -2.3234 -44 +42 +35 +36 +39 +51 +52 +48 +49 +45      fill=8 u=1 $ Concrete
108 13 -2.3234 -45       u=1 $ Concrete pad
109 8 -7.8212 -42 +43      u=1 $ Liner
110 13 -2.3234 -58 +42      u=1 $ Top flange
111 8 -7.8212 (-59 +71 -43) :
              (-60 +72 -43) :
              (-61 +73 -43) :
              (-62 +74 -43) :
              (-63 +75 -43) :
              (-64 +76 -43) :
              (-65 +77 -43) :
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
                (-66 +78 -43) :
                (-67 +79 -43) :
                (-68 +80 -43) :
                (-69 +81 -43) :
                (-70 +82 -43)       u=1 $ Standoffs
112 0           (-39 +40 -46 +84 +87 +89 +92) :
                (-39 +40 -47 +94 +97 +99 +102)       u=1 $ Bottom plate outer void
113 0           -40 +41 +35 +36    u=1 $ Bottom plate connector void
114 0           (-34 -57 -43) : (-34 -55 +56 -43)      u=1 $ Support rail inside stand void
115 0           (+33 -57 -43) : (+33 -55 +56 -43)      u=1 $ Support rail outside stand
void
116 0           (-46 +33 +35 +36 -44 +39) :
                (-47 +33 +35 +36 -44 +39 +46)       u=1 $ Air inlet void
117 0           -53 +33 +35 +36       u=1 $ Air inlet top void
118 0           (-37 +39 +33) : (-38 +39 +33)       u=1 $ Connector void
119 0           -34 +54 +56       u=1 $ Stand void
120 0           -43 +32 +33 +54 +56 #111
                fill=2 ( 0.0000 0.0000 6.9850 )       u=1 $ Cavity
121 0           +44 +42 +58 fill=10 ( 0.0000 0.0000 485.4702 )   u=1 $ Outside
C VCC Rebar Cells - v1.3.1_ng14b
122 8 -7.8212 -83       u=8 $ Outer hoop 1
123 8 -7.8212 -84       u=8 $ Outer hoop 2
124 8 -7.8212 -85       u=8 $ Outer hoop 3
125 8 -7.8212 -86       u=8 $ Outer hoop 4
126 8 -7.8212 -87       u=8 $ Outer hoop 5
127 8 -7.8212 -88       u=8 $ Outer hoop 6
128 8 -7.8212 -89       u=8 $ Outer hoop 7
129 8 -7.8212 -90       u=8 $ Outer hoop 8
130 8 -7.8212 -91       u=8 $ Outer hoop 9
131 8 -7.8212 -92       u=8 $ Outer hoop 10
132 8 -7.8212 -93       u=8 $ Outer hoop 11
133 8 -7.8212 -94       u=8 $ Outer hoop 12
134 8 -7.8212 -95       u=8 $ Outer hoop 13
135 8 -7.8212 -96       u=8 $ Outer hoop 14
136 8 -7.8212 -97       u=8 $ Outer hoop 15
137 8 -7.8212 -98       u=8 $ Outer hoop 16
138 8 -7.8212 -99       u=8 $ Outer hoop 17
139 8 -7.8212 -100       u=8 $ Outer hoop 18
140 8 -7.8212 -101       u=8 $ Outer hoop 19
141 8 -7.8212 -102       u=8 $ Outer hoop 20
142 8 -7.8212 -103       u=8 $ Outer hoop 21
143 8 -7.8212 -104       u=8 $ Outer hoop 22
144 8 -7.8212 -105       u=8 $ Outer hoop 23
145 8 -7.8212 -106       u=8 $ Outer hoop 24
146 8 -7.8212 -107       u=8 $ Outer hoop 25
147 8 -7.8212 -108       u=8 $ Outer hoop 26
148 8 -7.8212 -109       u=8 $ Outer hoop 27
149 8 -7.8212 -110       u=8 $ Outer hoop 28
150 8 -7.8212 -111       u=8 $ Outer hoop 29
151 8 -7.8212 -112       u=8 $ Outer hoop 30
152 8 -7.8212 -113       u=8 $ Outer hoop 31
153 8 -7.8212 -114       u=8 $ Outer hoop 32
154 8 -7.8212 -115       u=8 $ Outer hoop 33
155 8 -7.8212 -116       u=8 $ Outer hoop 34
156 8 -7.8212 -117       u=8 $ Outer hoop 35
157 8 -7.8212 -118       u=8 $ Outer hoop 36
158 8 -7.8212 -119       u=8 $ Outer hoop 37
159 8 -7.8212 -120       u=8 $ Outer hoop 38
160 8 -7.8212 -121       u=8 $ Outer hoop 39
161 8 -7.8212 -122       u=8 $ Outer hoop 40
162 8 -7.8212 -123       u=8 $ Outer hoop 41
163 8 -7.8212 -124       u=8 $ Outer hoop 42
164 8 -7.8212 -125       u=8 $ Outer hoop 43
165 8 -7.8212 -126       u=8 $ Outer hoop 44
166 8 -7.8212 -127       u=8 $ Outer hoop 45
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
167 8 -7.8212 -128        u=8 $ Outer hoop 46
168 8 -7.8212 -129        u=8 $ Outer hoop 47
169 8 -7.8212 -130        u=8 $ Outer hoop 48
170 13 -2.3234 #122 #123 #124 #125 #126 #127 #128
        #129 #130 #131 #132 #133 #134 #135 #136 #137 #138
        #139 #140 #141 #142 #143 #144 #145 #146 #147 #148
        #149 #150 #151 #152 #153 #154 #155 #156 #157 #158
        #159 #160 #161 #162 #163 #164 #165 #166 #167 #168
        #169        fill=9 u=8
171 8 -7.8212 -131   trcl = ( 160.3375 0.0000 0.0000 )    u=9 $ Outer bar 1
172 like 171 but   trcl = ( 159.3293 17.9521 0.0000 )    u=9 $ Outer bar 2
173 like 171 but   trcl = ( 156.3175 35.6785 0.0000 )    u=9 $ Outer bar 3
174 like 171 but   trcl = ( 151.3399 52.9561 0.0000 )    u=9 $ Outer bar 4
175 like 171 but   trcl = ( 144.4591 69.5678 0.0000 )    u=9 $ Outer bar 5
176 like 171 but   trcl = ( 135.7616 85.3047 0.0000 )    u=9 $ Outer bar 6
177 like 171 but   trcl = ( 125.3569 99.9688 0.0000 )    u=9 $ Outer bar 7
178 like 171 but   trcl = ( 113.3757 113.3757 0.0000 )    u=9 $ Outer bar 8
179 like 171 but   trcl = ( 99.9688 125.3569 0.0000 )    u=9 $ Outer bar 9
180 like 171 but   trcl = ( 85.3047 135.7616 0.0000 )    u=9 $ Outer bar 10
181 like 171 but   trcl = ( 69.5678 144.4591 0.0000 )    u=9 $ Outer bar 11
182 like 171 but   trcl = ( 52.9561 151.3399 0.0000 )    u=9 $ Outer bar 12
183 like 171 but   trcl = ( 35.6785 156.3175 0.0000 )    u=9 $ Outer bar 13
184 like 171 but   trcl = ( 17.9521 159.3293 0.0000 )    u=9 $ Outer bar 14
185 like 171 but   trcl = ( 0.0000 160.3375 0.0000 )    u=9 $ Outer bar 15
186 like 171 but   trcl = ( -17.9521 159.3293 0.0000 )    u=9 $ Outer bar 16
187 like 171 but   trcl = ( -35.6785 156.3175 0.0000 )    u=9 $ Outer bar 17
188 like 171 but   trcl = ( -52.9561 151.3399 0.0000 )    u=9 $ Outer bar 18
189 like 171 but   trcl = ( -69.5678 144.4591 0.0000 )    u=9 $ Outer bar 19
190 like 171 but   trcl = ( -85.3047 135.7616 0.0000 )    u=9 $ Outer bar 20
191 like 171 but   trcl = ( -99.9688 125.3569 0.0000 )    u=9 $ Outer bar 21
192 like 171 but   trcl = ( -113.3757 113.3757 0.0000 )    u=9 $ Outer bar 22
193 like 171 but   trcl = ( -125.3569 99.9688 0.0000 )    u=9 $ Outer bar 23
194 like 171 but   trcl = ( -135.7616 85.3047 0.0000 )    u=9 $ Outer bar 24
195 like 171 but   trcl = ( -144.4591 69.5678 0.0000 )    u=9 $ Outer bar 25
196 like 171 but   trcl = ( -151.3399 52.9561 0.0000 )    u=9 $ Outer bar 26
197 like 171 but   trcl = ( -156.3175 35.6785 0.0000 )    u=9 $ Outer bar 27
198 like 171 but   trcl = ( -159.3293 17.9521 0.0000 )    u=9 $ Outer bar 28
199 like 171 but   trcl = ( -160.3375 0.0000 0.0000 )    u=9 $ Outer bar 29
200 like 171 but   trcl = ( -159.3293 -17.9521 0.0000 )    u=9 $ Outer bar 30
201 like 171 but   trcl = ( -156.3175 -35.6785 0.0000 )    u=9 $ Outer bar 31
202 like 171 but   trcl = ( -151.3399 -52.9561 0.0000 )    u=9 $ Outer bar 32
203 like 171 but   trcl = ( -144.4591 -69.5678 0.0000 )    u=9 $ Outer bar 33
204 like 171 but   trcl = ( -135.7616 -85.3047 0.0000 )    u=9 $ Outer bar 34
205 like 171 but   trcl = ( -125.3569 -99.9688 0.0000 )    u=9 $ Outer bar 35
206 like 171 but   trcl = ( -113.3757 -113.3757 0.0000 )    u=9 $ Outer bar 36
207 like 171 but   trcl = ( -99.9688 -125.3569 0.0000 )    u=9 $ Outer bar 37
208 like 171 but   trcl = ( -85.3047 -135.7616 0.0000 )    u=9 $ Outer bar 38
209 like 171 but   trcl = ( -69.5678 -144.4591 0.0000 )    u=9 $ Outer bar 39
210 like 171 but   trcl = ( -52.9561 -151.3399 0.0000 )    u=9 $ Outer bar 40
211 like 171 but   trcl = ( -35.6785 -156.3175 0.0000 )    u=9 $ Outer bar 41
212 like 171 but   trcl = ( -17.9521 -159.3293 0.0000 )    u=9 $ Outer bar 42
213 like 171 but   trcl = ( 0.0000 -160.3375 0.0000 )    u=9 $ Outer bar 43
214 like 171 but   trcl = ( 17.9521 -159.3293 0.0000 )    u=9 $ Outer bar 44
215 like 171 but   trcl = ( 35.6785 -156.3175 0.0000 )    u=9 $ Outer bar 45
216 like 171 but   trcl = ( 52.9561 -151.3399 0.0000 )    u=9 $ Outer bar 46
217 like 171 but   trcl = ( 69.5678 -144.4591 0.0000 )    u=9 $ Outer bar 47
218 like 171 but   trcl = ( 85.3047 -135.7616 0.0000 )    u=9 $ Outer bar 48
219 like 171 but   trcl = ( 99.9688 -125.3569 0.0000 )    u=9 $ Outer bar 49
220 like 171 but   trcl = ( 113.3757 -113.3757 0.0000 )    u=9 $ Outer bar 50
221 like 171 but   trcl = ( 125.3569 -99.9688 0.0000 )    u=9 $ Outer bar 51
222 like 171 but   trcl = ( 135.7616 -85.3047 0.0000 )    u=9 $ Outer bar 52
223 like 171 but   trcl = ( 144.4591 -69.5678 0.0000 )    u=9 $ Outer bar 53
224 like 171 but   trcl = ( 151.3399 -52.9561 0.0000 )    u=9 $ Outer bar 54
225 like 171 but   trcl = ( 156.3175 -35.6785 0.0000 )    u=9 $ Outer bar 55
226 like 171 but   trcl = ( 159.3293 -17.9521 0.0000 )    u=9 $ Outer bar 56
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
227 13 -2.3234 #171 #172 #173
        #174 #175 #176 #177 #178 #179 #180 #181 #182 #183
        #184 #185 #186 #187 #188 #189 #190 #191 #192 #193
        #194 #195 #196 #197 #198 #199 #200 #201 #202 #203
        #204 #205 #206 #207 #208 #209 #210 #211 #212 #213
        #214 #215 #216 #217 #218 #219 #220 #221 #222 #223
        #224 #225 #226        u=9
C VCC Lid Cells - v1.3.1_ng14b
228 13 -2.3234 -133 +132      u=10 $ Lid base
229 13 -2.3234 -135 +136      u=10 $ Lid base disk
230 8 -7.8212 -136 +137 +145 +146    u=10 $ Lid liner
231 8 -7.8212 -139 +140      u=10 $ Anchor steel -x-y
232 8 -7.8212 -141 +142      u=10 $ Anchor steel +x+y
233 8 -7.8212 -134 +133 -143 trcl = ( 71.1200 123.1835 0.0000 )    u=10 $ Lift support
234 like 233 but   trcl = ( -123.1835 71.1200 0.0000 )    u=10 $ Lift support
235 like 233 but   trcl = ( -71.1200 -123.1835 0.0000 )    u=10 $ Lift support
236 like 233 but   trcl = ( 123.1835 -71.1200 0.0000 )    u=10 $ Lift support
237 8 -7.8212 -149 +137 +136     u=10 $ Sectional flange
238 8 -7.8212 (-145 +146 +147 -134 +144) : (-146 +145 +148 -134 +144)  u=10 $ Outlet
steel
239 8 -7.8212 -150       u=10 $ Lid top
240 8 -7.8212 -151 +152      u=10 $ Lid shell
241 13 -2.2432 -152       u=10 $ Lid concrete
242 13 -2.3234 -134 +133 +145 +146 +136 +139 +141 +137
        #233 #234 #235 #236 #237 #239        u=10 $ Concrete
243 13 -2.3234 -132 +135 +138     u=10 $ Lid base void 1
244 8 -7.8212 -132 +135 -138 +137    u=10 $ Lid base void 2
245 0         (-147 +148 -134 +144) : (-148 +147 -134 +144)       u=10 $ Outlet void
246 0         #228 #229 #230 #231 #232 #233 #234 #235 #236
              #237 #238 #239 #240 #241 #242 #243 #244 #245        u=10 $ Outside
C Fuel Assembly Cells - ng14b - v1.1
7 19 -9.6315 -1     u=6 $ Lower Nozzle
8 2 -2.7253 -2 +1    u=6 $ Lower Plenum
9 3 -3.9171 -3 +2    u=6 $ Fuel
10 4 -1.0067 -4 +3    u=6 $ Upper Plenum
11 5 -2.8608 -5 +4    u=6 $ Upper Nozzle
12 0         +5     u=6 $ Outside
C Detector Cells - Radial Biasing
399  0  -399  fill=1  $ Cask
400  0  -400  +399  $ Surface
450  0  -450  +399  +400  $ SurfAzi
500  0  -500  +399  +400  +450  $ 1ft
600  0  -600  +399  +400  +450  +500  $ 1m
700  0  -700  +399  +400  +450  +500  +600  $ 2m
800  0  -800  +399  +400  +450  +500  +600  +700  $ 4m
900  0  +399  +400  +450  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.1
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094       $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 9 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 9 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 9 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.5
23 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1962         $ Lower/upper lid
30 PZ 459.5114         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
C VCC Surfaces - v1.3.1_ng14b
32  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
33  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 63.4999  $ Stand outer
34  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 62.3888  $ Stand inner
35 9 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate A
36 10 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate B
37 9 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall A
38 10 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall B
39  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
40  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 100.3300  $ Connector radius
41  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
42  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 105.41  $ VCC liner outer
43  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 100.965  $ VCC liner inner
44  RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 618.2362 172.7200  $ Concrete
45  RCC 0.0000 0.0000 -132.7660 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
46  RPP -172.7200 172.7200 -63.5000 63.5000 -32.7660 -21.4630   $ Air inlet void X
47  RPP -63.5000 63.5000 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet void Y
48  RPP -172.7200 172.7200 -64.7700 64.7700 -32.7660 -21.4630   $ Air inlet wall X
49  RPP -64.7700 64.7700 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet wall Y
50  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 11.3030 100.3300  $ Air inlet divider
51  RPP -172.7200 172.7200 -64.7700 64.7700 -21.4630 -16.3830   $ Air inlet top X
52  RPP -64.7700 64.7700 -172.7200 172.7200 -21.4630 -16.3830   $ Air inlet top Y
53  RCC 0.0000 0.0000 -21.4630 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
54  RPP -106.6800 106.6800 -5.7150 5.7150 -16.3830 -5.0800   $ Support rail exterior X
55  RPP -106.6800 106.6800 -4.4450 4.4450 -16.3830 -5.0800   $ Support rail interior X
56  RPP -5.7150 5.7150 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail exterior Y
57  RPP -4.4450 4.4450 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail interior Y
58  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 2.5400 115.5700  $ Top flange
59  RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 1
60 11 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 2
61 12 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 3
62 9 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 4
63 13 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 5
64 14 RPP -100.9650 100.9650 -0.4432 0.4432 175.5902 480.3902   $ Standoff outer 6
65  RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 7
66 11 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 8
67 12 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 9
68 9 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 10
69 13 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 11
70 14 RPP -0.4432 0.4432 -100.9650 100.9650 175.5902 480.3902   $ Standoff outer 12
71  RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 1
72 11 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 2
73 12 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 3
74 9 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 4
75 13 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 5
76 14 RPP -93.3450 93.3450 -0.4432 0.4432 175.5902 480.3902   $ Standoff inner 6
77  RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 7
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
78 11 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 8
79 12 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 9
80 9 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 10
81 13 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 11
82 14 RPP -0.4432 0.4432 -93.3450 93.3450 175.5902 480.3902   $ Standoff inner 12
C VCC Rebar Surfaces - v1.3.1_ng14b
83  TZ 0.0000 0.0000 -1.4022 162.2425 0.9525 0.9525   $ Outer hoop 1
84  TZ 0.0000 0.0000 8.4986 162.2425 0.9525 0.9525   $ Outer hoop 2
85  TZ 0.0000 0.0000 18.3994 162.2425 0.9525 0.9525   $ Outer hoop 3
86  TZ 0.0000 0.0000 28.3003 162.2425 0.9525 0.9525   $ Outer hoop 4
87  TZ 0.0000 0.0000 38.2011 162.2425 0.9525 0.9525   $ Outer hoop 5
88  TZ 0.0000 0.0000 48.1019 162.2425 0.9525 0.9525   $ Outer hoop 6
89  TZ 0.0000 0.0000 58.0027 162.2425 0.9525 0.9525   $ Outer hoop 7
90  TZ 0.0000 0.0000 67.9035 162.2425 0.9525 0.9525   $ Outer hoop 8
91  TZ 0.0000 0.0000 77.8043 162.2425 0.9525 0.9525   $ Outer hoop 9
92  TZ 0.0000 0.0000 87.7052 162.2425 0.9525 0.9525   $ Outer hoop 10
93  TZ 0.0000 0.0000 97.6060 162.2425 0.9525 0.9525   $ Outer hoop 11
94  TZ 0.0000 0.0000 107.5068 162.2425 0.9525 0.9525   $ Outer hoop 12
95  TZ 0.0000 0.0000 117.4076 162.2425 0.9525 0.9525   $ Outer hoop 13
96  TZ 0.0000 0.0000 127.3084 162.2425 0.9525 0.9525   $ Outer hoop 14
97  TZ 0.0000 0.0000 137.2092 162.2425 0.9525 0.9525   $ Outer hoop 15
98  TZ 0.0000 0.0000 147.1101 162.2425 0.9525 0.9525   $ Outer hoop 16
99  TZ 0.0000 0.0000 157.0109 162.2425 0.9525 0.9525   $ Outer hoop 17
100  TZ 0.0000 0.0000 166.9117 162.2425 0.9525 0.9525   $ Outer hoop 18
101  TZ 0.0000 0.0000 176.8125 162.2425 0.9525 0.9525   $ Outer hoop 19
102  TZ 0.0000 0.0000 186.7133 162.2425 0.9525 0.9525   $ Outer hoop 20
103  TZ 0.0000 0.0000 196.6141 162.2425 0.9525 0.9525   $ Outer hoop 21
104  TZ 0.0000 0.0000 206.5150 162.2425 0.9525 0.9525   $ Outer hoop 22
105  TZ 0.0000 0.0000 216.4158 162.2425 0.9525 0.9525   $ Outer hoop 23
106  TZ 0.0000 0.0000 226.3166 162.2425 0.9525 0.9525   $ Outer hoop 24
107  TZ 0.0000 0.0000 236.2174 162.2425 0.9525 0.9525   $ Outer hoop 25
108  TZ 0.0000 0.0000 246.1182 162.2425 0.9525 0.9525   $ Outer hoop 26
109  TZ 0.0000 0.0000 256.0190 162.2425 0.9525 0.9525   $ Outer hoop 27
110  TZ 0.0000 0.0000 265.9199 162.2425 0.9525 0.9525   $ Outer hoop 28
111  TZ 0.0000 0.0000 275.8207 162.2425 0.9525 0.9525   $ Outer hoop 29
112  TZ 0.0000 0.0000 285.7215 162.2425 0.9525 0.9525   $ Outer hoop 30
113  TZ 0.0000 0.0000 295.6223 162.2425 0.9525 0.9525   $ Outer hoop 31
114  TZ 0.0000 0.0000 305.5231 162.2425 0.9525 0.9525   $ Outer hoop 32
115  TZ 0.0000 0.0000 315.4239 162.2425 0.9525 0.9525   $ Outer hoop 33
116  TZ 0.0000 0.0000 325.3248 162.2425 0.9525 0.9525   $ Outer hoop 34
117  TZ 0.0000 0.0000 335.2256 162.2425 0.9525 0.9525   $ Outer hoop 35
118  TZ 0.0000 0.0000 345.1264 162.2425 0.9525 0.9525   $ Outer hoop 36
119  TZ 0.0000 0.0000 355.0272 162.2425 0.9525 0.9525   $ Outer hoop 37
120  TZ 0.0000 0.0000 364.9280 162.2425 0.9525 0.9525   $ Outer hoop 38
121  TZ 0.0000 0.0000 374.8288 162.2425 0.9525 0.9525   $ Outer hoop 39
122  TZ 0.0000 0.0000 384.7297 162.2425 0.9525 0.9525   $ Outer hoop 40
123  TZ 0.0000 0.0000 394.6305 162.2425 0.9525 0.9525   $ Outer hoop 41
124  TZ 0.0000 0.0000 404.5313 162.2425 0.9525 0.9525   $ Outer hoop 42
125  TZ 0.0000 0.0000 414.4321 162.2425 0.9525 0.9525   $ Outer hoop 43
126  TZ 0.0000 0.0000 424.3329 162.2425 0.9525 0.9525   $ Outer hoop 44
127  TZ 0.0000 0.0000 434.2337 162.2425 0.9525 0.9525   $ Outer hoop 45
128  TZ 0.0000 0.0000 444.1346 162.2425 0.9525 0.9525   $ Outer hoop 46
129  TZ 0.0000 0.0000 454.0354 162.2425 0.9525 0.9525   $ Outer hoop 47
130  TZ 0.0000 0.0000 463.9362 162.2425 0.9525 0.9525   $ Outer hoop 48
131  RCC 0.0000 0.0000 -11.3030 0.0000 0.0000 485.1400 0.9525  $ Bar
C VCC Lid Surfaces - v1.3.1_ng14b
132  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 116.459  $ Lid base
133  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 3.8100 172.7199  $ Lid base outer
134  RCC 0.0000 0.0000 0.0000 0.0000 0.0000 54.1020 172.7199  $ Lid container
135  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 0.9525 116.4590  $ Lid base disk
136  RCC 0.0000 0.0000 2.8575 0.0000 0.0000 48.7045 101.6  $ Lid liner
137  CZ 100.965        $ Lid liner inner
138  CZ 101.6        $ Lid liner outer
139 9 RPP -15.2400 15.2400 125.5776 161.4424 3.8100 54.1020   $ Anchor cavity outer
140 9 RPP -14.6050 14.6050 126.2126 160.8074 3.8100 54.1020   $ Anchor cavity inner
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
141 9 RPP -15.2400 15.2400 -161.4424 -125.5776 3.8100 54.1020   $ Anchor cavity outer
142 9 RPP -14.6050 14.6050 -160.8074 -126.2126 3.8100 54.1020   $ Anchor cavity inner
143  CZ 5.0800        $ Lifting bar
144  CZ 103.1875        $ Air outlet radius
145  RPP -64.7700 64.7700 -172.7200 172.7200 29.0830 39.1160   $ Air outlet steel X
146  RPP -172.7200 172.7200 -64.7700 64.7700 29.0830 39.1160   $ Air outlet steel Y
147  RPP -64.1350 64.1350 -172.7200 172.7200 29.7180 38.4810   $ Air outlet void X
148  RPP -172.7200 172.7200 -64.1350 64.1350 29.7180 38.4810   $ Air outlet void Y
149  RCC 0.0000 0.0000 51.5620 0.0000 0.0000 2.5400 111.7600  $ Sectional flange
150  RCC 0.0000 0.0000 54.1020 0.0000 0.0000 1.9050 111.7600  $ Lid top
151  RCC 0.0000 0.0000 38.7350 0.0000 0.0000 15.3670 100.3300  $ Lid shell
152  RCC 0.0000 0.0000 39.3700 0.0000 0.0000 14.7320 99.6950  $ Lid concrete
C Storage Cask & Pad Container
399  RCC  0.0000  0.0000  -132.7660  0.0000  0.0000  674.2432  172.7201
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  574.3432  172.8201
401  PZ  15.0959
402  PZ  62.9579
403  PZ  110.8198
404  PZ  158.6817
405  PZ  206.5437
406  PZ  254.4056
407  PZ  302.2675
408  PZ  350.1295
409  PZ  397.9914
410  PZ  445.8533
411  PZ  493.7153
C Radial Detector DRAA (SurfAzi)
450  RCC  0.0000  0.0000  6.9850  0.0000  0.0000  8.0975  172.9201
451     PX  0.0000
452  1  PX  0.0000
453  2  PX  0.0000
454  3  PX  0.0000
455  4  PX  0.0000
456     PY  0.0000
457  5  PX  0.0000
458  6  PX  0.0000
459  7  PX  0.0000
460  8  PX  0.0000
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  604.8232  203.3001
501  PZ  17.6359
502  PZ  68.0379
503  PZ  118.4398
504  PZ  168.8417
505  PZ  219.2437
506  PZ  269.6456
507  PZ  320.0475
508  PZ  370.4495
509  PZ  420.8514
510  PZ  471.2533
511  PZ  521.6553
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  674.3432  272.8201
601  PZ  12.1902
602  PZ  57.1464
603  PZ  102.1026
604  PZ  147.0589
605  PZ  192.0151
606  PZ  236.9713
607  PZ  281.9275
608  PZ  326.8837
609  PZ  371.8399
610  PZ  416.7961
611  PZ  461.7523
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
612  PZ  506.7086
613  PZ  551.6648
614  PZ  596.6210
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  774.3432  372.8201
701  PZ  5.9512
702  PZ  44.6683
703  PZ  83.3855
704  PZ  122.1026
705  PZ  160.8198
706  PZ  199.5370
707  PZ  238.2541
708  PZ  276.9713
709  PZ  315.6884
710  PZ  354.4056
711  PZ  393.1228
712  PZ  431.8399
713  PZ  470.5571
714  PZ  509.2742
715  PZ  547.9914
716  PZ  586.7086
717  PZ  625.4257
718  PZ  664.1429
719  PZ  702.8600
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -32.7660  0.0000  0.0000  974.3432  572.8201
801  PZ  15.9512
802  PZ  64.6683
803  PZ  113.3855
804  PZ  162.1026
805  PZ  210.8198
806  PZ  259.5370
807  PZ  308.2541
808  PZ  356.9713
809  PZ  405.6884
810  PZ  454.4056
811  PZ  503.1228
812  PZ  551.8399
813  PZ  600.5571
814  PZ  649.2742
815  PZ  697.9914
816  PZ  746.7086
817  PZ  795.4257
818  PZ  844.1429
819  PZ  892.8600

C
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
      92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
       8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4    24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
      26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
      40000 -2.1362E-01
C Homogenized Upper Nozzle
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
m5     24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
       28000 -9.5000E-02
C Water
m6     1001 2 8016 1
C Stainless Steel
m7     24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Carbon Steel
m8     26000 -0.99  6012 -0.01
C Neutron Poison
m9     13027 -0.6605 5010 -0.0478 5011 -0.2179
       6012 -0.0737
C Aluminum
m10    13027 -1.0
C Lead
m11    82000 -1.0
C NS-4-FR
m12    5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
       5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
       8016 -4.2500E-01
C Concrete
m13    26000 -0.014 20000 -0.044 14000 -0.337
        1001 -0.010  8016 -0.532 11023 -0.029
       13027 -0.034
C Vent Port Middle Cylinder
m14    24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Balsa
m15    6012 6 1001 10 8016 5
C NS-4-FR (Accident)
m16    5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
       5011 -7.7389E-03
C Copper
m17    29063 -6.8499E-01 29065 -3.1501E-01
C Damaged Fuel
m18    92235 -4.1528E-02
       92238 -7.8904E-01
        8016 -1.1165E-01
       40000 -5.6754E-02
       50000 -8.6669E-04
       26000 -7.2224E-05
       24000 -5.7779E-05
        7014 -2.8890E-05
C Damaged Lower Nozzle
m19    92235 -3.2602E-02
       92238 -6.1944E-01
        8016 -8.7656E-02
       24000 -4.9457E-02
       25055 -5.2060E-03
       26000 -1.8091E-01
       28000 -2.4728E-02
C Damaged Lower Plenum
m20    92235 -3.0443E-02
       92238 -5.7843E-01
        8016 -8.1852E-02
       24000 -3.0928E-04
       26000 -3.8660E-04
       40000 -3.0379E-01
       50000 -4.6392E-03
        7014 -1.5464E-04
C Damaged Upper Plenum
m21    92235 -3.9655E-02
       92238 -7.5344E-01
        8016 -1.0662E-01
       24000 -1.4932E-02
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
      26000 -5.4568E-02
      40000 -2.1423E-02
      50000 -3.2715E-04
       7014 -1.0905E-05
      25055 -1.5695E-03
      28000 -7.4552E-03
C Damaged upper Nozzle
m22   92235 -3.0832E-02
      92238 -5.8581E-01
       8016 -8.2897E-02
      24000 -5.7087E-02
      25055 -6.0091E-03
      26000 -2.0882E-01
      28000 -2.8543E-02
nonu                  $ Disable subcritical multiplication
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:n 1 252r 0
C
C Source Definition - Lower Nozzle Damaged Neutron - ng14b_32b21e4.1y
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=399:120:84:d5:7
si1   -9.85901 9.85901
sp1   0 1
si2   -9.85901 9.85901
sp2   0 1
si3   0.0000 8.0975
sp3   0 1
si4   1.000E-11 7.090E-08 5.500E-07 1.500E-06 4.000E-06 1.600E-05
      4.810E-05 1.660E-04 3.540E-04 9.610E-04 2.950E-03 9.120E-03
      2.480E-02 6.740E-02 1.100E-01 3.900E-01 6.400E-01 1.740E+00
      2.870E+00 3.680E+00 4.720E+00 6.070E+00 7.000E+00 8.250E+00
      1.000E+01 1.125E+01 1.250E+01 1.360E+01 1.460E+01
sp4   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
      0.0000E+00 0.0000E+00 2.0440E+02 8.5840E+06 2.4740E+07 9.4960E+07
      6.0740E+07 2.5550E+07 1.8950E+07 1.1170E+07 3.3370E+06 1.9330E+06
      7.2000E+05 2.2950E+05 6.9100E+04 1.6580E+04 0.0000E+00
C Source Information
si5 1 49 53 75 79
C Source Probability
sp5   1.0 1.0 1.0 1.0
mode n
nps 4000000
C
C ANSI/ANS-6.1.1-1977 - Neutron Flux-to-Dose Conversion Factors
C (mrem/hr)/(neutrons/cm2-sec)
C
de0   2.5E-08 1E-07 0.000001 0.00001 0.0001 0.001 0.01
      0.1 0.5 1 2.5 5 7 10
      14 20
df0   3.67E-03 3.67E-03 4.46E-03 4.54E-03 4.18E-03 3.76E-03 3.56E-03
      2.17E-02 9.26E-02 1.32E-01 1.25E-01 1.56E-01 1.47E-01 1.47E-01
      2.08E-01 2.27E-01
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:n 5 3 5 0 -1 0
mesh geom=cyl ref=89 0 11 origin=0.1 0.1 -134
     imesh 90.2 91.4 101.0 105.4 172.7 672.7
     iints 5 1 1 1 4 1
     jmesh 101 104 112 117 129 141 151 519 550 580 603 658 673 1173
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
     jints 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
wwge:n  1e-5 1e-3 1 20
fc2 Radial Surface Tally
f2:n +400.1
fm2 8.9965E+07
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Radial SurfAzi Tally Q1 (+x+y)
f12:n +450.1
fm12 8.9965E+07
fs12 -451  -456
     +455  +454  +453  +452  T
sd12 4.3989E+03  2.1995E+03  4.3989E+02  4r  8.7979E+03
tf12
fc22 Radial SurfAzi Tally Q2 (-x+y)
f22:n +450.1
fm22 8.9965E+07
fs22 +451  -456
     -460  -459  -458  -457  T
sd22 4.3989E+03  2.1995E+03  4.3989E+02  4r  8.7979E+03
tf22
fc32 Radial SurfAzi Tally Q3 (-x-y)
f32:n +450.1
fm32 8.9965E+07
fs32 +451  +456
     -455  -454  -453  -452  T
sd32 4.3989E+03  2.1995E+03  4.3989E+02  4r  8.7979E+03
tf32
fc42 Radial SurfAzi Tally Q4 (+x-y)
f42:n +450.1
fm42 8.9965E+07
fs42 -451  +456
     +460  +459  +458  +457  T
sd42 4.3989E+03  2.1995E+03  4.3989E+02  4r  8.7979E+03
tf42
fc52 Radial 1ft Tally
f52:n +500.1
fm52 8.9965E+07
fs52  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  T
tf52
fc62 Radial 1m Tally
f62:n +600.1
fm62 8.9965E+07
fs62  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  T
tf62
fc72 Radial 2m Tally
f72:n +700.1
fm72 8.9965E+07
fs72  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf72
fc82 Radial 4m Tally
f82:n +800.1
fm82 8.9965E+07
fs82  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
```

Figure 5.8.8-12 Concrete Cask Sample Input File – Damaged PWR Fuel TSC – Lower End Fitting Damaged Fuel

```
     -819  T
tf82
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 75 165 90 -15 75 90 90 90 0
```

Figure 5.8.8-13 CC4 Sample Input File

```
MAGNASTOR VCC - strShlDryRadFg_ng14b_07g
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng14b - v1.1
1 1 -2.5071 -1     u=6 $ Lower Nozzle
2 2 -2.7253 -2 +1    u=6 $ Lower Plenum
3 3 -3.9171 -3 +2    u=6 $ Fuel
4 4 -1.0067 -4 +3    u=6 $ Upper Plenum
5 5 -2.8608 -5 +4    u=6 $ Upper Nozzle
6 0         +5     u=6 $ Outside
C Cells - Fuel Tube  v1.3
7 8 -7.8212 -8 +7    u=5 $ Tube
8 9 -2.6336 -9 : -10 : -11 : -12     u=5 $ Poison
9 0         #7  #8  -6   u=5 $ Outside below PFE
10 0         #7  #8  +6   u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
11 0         -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )    u=4 $ Assy loc 1
12 like 11 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )    u=4 $ Assy loc 3
13 like 11 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )    u=4 $ Assy loc 4
14 like 11 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )    u=4 $ Assy loc 6
15 like 11 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )    u=4 $ Assy loc 8
16 like 11 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )    u=4 $ Assy loc 9
17 like 11 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )    u=4 $ Assy loc 11
18 like 11 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )    u=4 $ Assy loc 13
19 like 11 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )    u=4 $ Assy loc 15
20 like 11 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )    u=4 $ Assy loc 17
21 like 11 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )    u=4 $ Assy loc 19
22 like 11 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )    u=4 $ Assy loc 21
23 like 11 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 23
24 like 11 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 25
25 like 11 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )    u=4 $ Assy loc 27
26 like 11 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )    u=4 $ Assy loc 29
27 like 11 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 30
28 like 11 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )    u=4 $ Assy loc 32
29 like 11 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )    u=4 $ Assy loc 34
30 like 11 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 35
31 like 11 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )    u=4 $ Assy loc 37
32 8 -7.8212 -15 #19 #26      u=4 $ Side support +x
33 8 -7.8212 -16 #16 #23      u=4 $ Side support -x
34 8 -7.8212 -17 #11 #12      u=4 $ Side support +y
35 8 -7.8212 -18 #30 #31      u=4 $ Side support -y
36 8 -7.8212 -19 +20 +21      u=4 $ Corner
37 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
            #11 #12 #16 #19 #23 #26 #30 #31       u=4 $ Corner diagonal
38 0        -6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
               #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
               #32 #33 #34 #35 #36 #37      u=4 $ Basket below PFE
39 0        +6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
              #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
              #32 #33 #34 #35 #36 #37      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
40 0        -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )    u=3 $ Assy loc 1
41 like 40 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )    u=3 $ Assy loc 2
42 like 40 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )    u=3 $ Assy loc 3
43 like 40 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )    u=3 $ Assy loc 4
44 like 40 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )    u=3 $ Assy loc 5
45 like 40 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )    u=3 $ Assy loc 6
46 like 40 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )    u=3 $ Assy loc 7
47 like 40 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )    u=3 $ Assy loc 8
48 like 40 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )    u=3 $ Assy loc 9
49 like 40 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )    u=3 $ Assy loc 10
50 like 40 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )    u=3 $ Assy loc 11
51 like 40 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )    u=3 $ Assy loc 12
52 like 40 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )    u=3 $ Assy loc 13
53 like 40 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )    u=3 $ Assy loc 14
54 like 40 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )    u=3 $ Assy loc 15
55 like 40 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )    u=3 $ Assy loc 16
56 like 40 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )    u=3 $ Assy loc 17
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
57 like 40 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )     u=3 $ Assy loc 18
58 like 40 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )     u=3 $ Assy loc 19
59 like 40 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )     u=3 $ Assy loc 20
60 like 40 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )     u=3 $ Assy loc 21
61 like 40 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )     u=3 $ Assy loc 22
62 like 40 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )     u=3 $ Assy loc 23
63 like 40 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )     u=3 $ Assy loc 24
64 like 40 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )     u=3 $ Assy loc 25
65 like 40 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )     u=3 $ Assy loc 26
66 like 40 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )     u=3 $ Assy loc 27
67 like 40 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )     u=3 $ Assy loc 28
68 like 40 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )     u=3 $ Assy loc 29
69 like 40 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )     u=3 $ Assy loc 30
70 like 40 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )     u=3 $ Assy loc 31
71 like 40 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )     u=3 $ Assy loc 32
72 like 40 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )     u=3 $ Assy loc 33
73 like 40 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )     u=3 $ Assy loc 34
74 like 40 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )     u=3 $ Assy loc 35
75 like 40 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )     u=3 $ Assy loc 36
76 like 40 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )     u=3 $ Assy loc 37
77 0          #40 #41 #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52
              #53 #54 #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65
              #66 #67 #68 #69 #70 #71 #72 #73 #74 #75 #76      fill=4 u=3 $ Cavity
C Cells - Canister v1.3
78 0          -24 fill=3      u=2 $ Cavity
79 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
80 7 -7.9400 -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )     u=2 $ Bottom Drain Port
81 7 -7.9400 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )     u=2 $ Middle Drain Port
82 7 -7.9400 -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )     u=2 $ Top Drain Port
83 like 80 but   trcl = ( -61.7220 -44.7040 0.0000 )     u=2 $ Bottom Vent Port
84 like 81 but   trcl = ( -61.7220 -44.7040 0.0000 )     u=2 $ Middle Vent Port
85 like 82 but   trcl = ( -61.7220 -44.7040 0.0000 )     u=2 $ Top Vent Port
86 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
87 8 -7.8212 -31 -24.1 +24.2 -29 #80 #81  #83 #84   u=2 $ Lower lid
88 7 -7.9400 -31 -24.1 +29 #81 #82  #84 #85    u=2 $ Upper lid
89 0          +31       u=2 $ Outside
C VCC Cells - v1.0.1_ng14b
90 8 -7.8212 -32       u=1 $ Pedestal plate
91 8 -7.8212 -33 +34      u=1 $ Stand
92 8 -7.8212 -39 +40 +46 +47    u=1 $ Bottom plate outer
93 8 -7.8212 (-40 +41 -35) : (-40 +41 -36)       u=1 $ Bottom plate connector
94 8 -7.8212 -41       u=1 $ Bottom plate inner
95 8 -7.8212 (-34 -60 +61 -43) : (-34 -58 +59 +60 -43)       u=1 $ Support rail inside
stand
96 8 -7.8212 (+33 -60 +61 -43) : (+33 -58 +59 +60 -43)       u=1 $ Support rail outside
stand
97 8 -7.8212 (-51 +53 +35 +36 -44) :
             (-52 +53 +35 +36 -44 +51)       u=1 $ Air inlet top
98 8 -7.8212 (-48 +46 +50 -44 +35 +36 +39) :
             (-49 +47 +50 -44 +35 +36 +39)       u=1 $ Air inlet wall
99 8 -7.8212 (-35 +37 +33 -44 +39) : (-36 +38 +33 -44 +39)       u=1 $ Air inlet angular
wall
100 8 -7.8212 (-50 -48 +46 +35 +36 +47 +39) :
              (-50 -49 +47 +35 +36 +46 +39)       u=1 $ Air inlet remaining wall
101 8 -7.8212 -54 +56 +43 -44    u=1 $ Air outlet steel X
102 8 -7.8212 -55 +57 +43 -44    u=1 $ Air outlet steel Y
103 13 -2.3234 -44 +42 +35 +36 +39 +51 +52 +48 +49 +45 +54 +55 +62
             fill=7 u=1 $ Concrete
104 13 -2.3234 -45       u=1 $ Concrete pad
105 8 -7.8212 -42 +43 +54 +55    u=1 $ Liner
106 8 -7.8212 -62 +42      u=1 $ Top flange
107 8 -7.8212 -63       u=1 $ Lid top
108 13 -2.2432 -64       u=1 $ Lid concrete
109 8 -7.8212 -65 +64      u=1 $ Lid shell
110 8 -7.8212 (-66 +78 -43) :
              (-67 +79 -43) :
              (-68 +80 -43) :
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
                (-69 +81 -43) :
                (-70 +82 -43) :
                (-71 +83 -43) :
                (-72 +84 -43) :
                (-73 +85 -43) :
                (-74 +86 -43) :
                (-75 +87 -43) :
                (-76 +88 -43) :
                (-77 +89 -43)        u=1 $ Standoffs
111 8 -7.8212 -90        u=1 $ -x inlet pipe 1
112 8 -7.8212 -91        u=1 $ -x inlet pipe 2
113 8 -7.8212 -92        u=1 $ -x inlet pipe 3
114 8 -7.8212 -93        u=1 $ -x inlet pipe 4
115 8 -7.8212 -94        u=1 $ -x inlet pipe 5
116 8 -7.8212 -95        u=1 $ -x inlet pipe 6
117 8 -7.8212 -96        u=1 $ -x inlet pipe 7
118 8 -7.8212 -97        u=1 $ -x inlet pipe 8
119 8 -7.8212 -98        u=1 $ -x inlet pipe 9
120 8 -7.8212 -99        u=1 $ -x inlet pipe 10
121 8 -7.8212 -100        u=1 $ -x inlet pipe 11
122 8 -7.8212 -101        u=1 $ -x inlet pipe 12
123 8 -7.8212 -102        u=1 $ -x inlet pipe 13
124 8 -7.8212 -103        u=1 $ -x inlet pipe 14
125 8 -7.8212 -104        u=1 $ -x inlet pipe 15
126 8 -7.8212 -105        u=1 $ -x inlet pipe 16
127 8 -7.8212 -106        u=1 $ -x inlet pipe 17
128 8 -7.8212 -107        u=1 $ +x inlet pipe 1
129 8 -7.8212 -108        u=1 $ +x inlet pipe 2
130 8 -7.8212 -109        u=1 $ +x inlet pipe 3
131 8 -7.8212 -110        u=1 $ +x inlet pipe 4
132 8 -7.8212 -111        u=1 $ +x inlet pipe 5
133 8 -7.8212 -112        u=1 $ +x inlet pipe 6
134 8 -7.8212 -113        u=1 $ +x inlet pipe 7
135 8 -7.8212 -114        u=1 $ +x inlet pipe 8
136 8 -7.8212 -115        u=1 $ +x inlet pipe 9
137 8 -7.8212 -116        u=1 $ +x inlet pipe 10
138 8 -7.8212 -117        u=1 $ +x inlet pipe 11
139 8 -7.8212 -118        u=1 $ +x inlet pipe 12
140 8 -7.8212 -119        u=1 $ +x inlet pipe 13
141 8 -7.8212 -120        u=1 $ +x inlet pipe 14
142 8 -7.8212 -121        u=1 $ +x inlet pipe 15
143 8 -7.8212 -122        u=1 $ +x inlet pipe 16
144 8 -7.8212 -123        u=1 $ +x inlet pipe 17
145 8 -7.8212 -124        u=1 $ -y inlet pipe 1
146 8 -7.8212 -125        u=1 $ -y inlet pipe 2
147 8 -7.8212 -126        u=1 $ -y inlet pipe 3
148 8 -7.8212 -127        u=1 $ -y inlet pipe 4
149 8 -7.8212 -128        u=1 $ -y inlet pipe 5
150 8 -7.8212 -129        u=1 $ -y inlet pipe 6
151 8 -7.8212 -130        u=1 $ -y inlet pipe 7
152 8 -7.8212 -131        u=1 $ -y inlet pipe 8
153 8 -7.8212 -132        u=1 $ -y inlet pipe 9
154 8 -7.8212 -133        u=1 $ -y inlet pipe 10
155 8 -7.8212 -134        u=1 $ -y inlet pipe 11
156 8 -7.8212 -135        u=1 $ -y inlet pipe 12
157 8 -7.8212 -136        u=1 $ -y inlet pipe 13
158 8 -7.8212 -137        u=1 $ -y inlet pipe 14
159 8 -7.8212 -138        u=1 $ -y inlet pipe 15
160 8 -7.8212 -139        u=1 $ -y inlet pipe 16
161 8 -7.8212 -140        u=1 $ -y inlet pipe 17
162 8 -7.8212 -141        u=1 $ +y inlet pipe 1
163 8 -7.8212 -142        u=1 $ +y inlet pipe 2
164 8 -7.8212 -143        u=1 $ +y inlet pipe 3
165 8 -7.8212 -144        u=1 $ +y inlet pipe 4
166 8 -7.8212 -145        u=1 $ +y inlet pipe 5
167 8 -7.8212 -146        u=1 $ +y inlet pipe 6
168 8 -7.8212 -147        u=1 $ +y inlet pipe 7
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
169 8 -7.8212 -148       u=1 $ +y inlet pipe 8
170 8 -7.8212 -149       u=1 $ +y inlet pipe 9
171 8 -7.8212 -150       u=1 $ +y inlet pipe 10
172 8 -7.8212 -151       u=1 $ +y inlet pipe 11
173 8 -7.8212 -152       u=1 $ +y inlet pipe 12
174 8 -7.8212 -153       u=1 $ +y inlet pipe 13
175 8 -7.8212 -154       u=1 $ +y inlet pipe 14
176 8 -7.8212 -155       u=1 $ +y inlet pipe 15
177 8 -7.8212 -156       u=1 $ +y inlet pipe 16
178 8 -7.8212 -157       u=1 $ +y inlet pipe 17
179 0         -39 +40 -46
              +90 +91 +92 +93 +94 +95 +96
              +97 +98 +99 +100 +101 +102 +103
              +104 +105 +106 +107 +108 +109 +110
              +111 +112 +113 +114 +115 +116 +117
              +118 +119 +120 +121 +122 +123       u=1 $ Bottom plate outer void x
180 0         -39 +40 -47
              +124 +125 +126 +127 +128 +129 +130
              +131 +132 +133 +134 +135 +136 +137
              +138 +139 +140 +141 +142 +143 +144
              +145 +146 +147 +148 +149 +150 +151
              +152 +153 +154 +155 +156 +157       u=1 $ Bottom plate outer void y
181 0         -40 +41 +35 +36    u=1 $ Bottom plate connector void
182 0         (-34 -61 -43) : (-34 -59 +60 -43)       u=1 $ Support rail inside stand
void
183 0         (+33 -61 -43) : (+33 -59 +60 -43)       u=1 $ Support rail outside stand
void
184 0         -46 +33 +35 +36 -44 +39
        +90 +91 +92 +93 +94 +95 +96
        +97 +98 +99 +100 +101 +102 +103
        +104 +105 +106 +107 +108 +109 +110
        +111 +112 +113 +114 +115 +116 +117
        +118 +119 +120 +121 +122 +123       u=1 $ Air inlet void x
185 0         -47 +33 +35 +36 -44 +39 +46
              +124 +125 +126 +127 +128 +129 +130
              +131 +132 +133 +134 +135 +136 +137
              +138 +139 +140 +141 +142 +143 +144
              +145 +146 +147 +148 +149 +150 +151
              +152 +153 +154 +155 +156 +157       u=1 $ Air inlet void y
186 0         -53 +33 +35 +36       u=1 $ Air inlet top void
187 0         (-37 +39 +33) : (-38 +39 +33)       u=1 $ Connector void
188 0         -34 +58 +60       u=1 $ Stand void
189 0         -56 +43 -44     u=1 $ Air outlet void X
190 0         -57 +43 -44     u=1 $ Air outlet void Y
191 0         -43 +32 +33 +58 +60 +65 #110
              fill=2 ( 0.0000 0.0000 6.9850 )       u=1 $ Cavity
192 0         +44 +42 +62 63    u=1 $ Outside
C VCC Rebar Cells - v1.0.1_ng14b
193 8 -7.8212 -158       u=7 $ Outer hoop 1
194 8 -7.8212 -159       u=7 $ Outer hoop 2
195 8 -7.8212 -160       u=7 $ Outer hoop 3
196 8 -7.8212 -161       u=7 $ Outer hoop 4
197 8 -7.8212 -162       u=7 $ Outer hoop 5
198 8 -7.8212 -163       u=7 $ Outer hoop 6
199 8 -7.8212 -164       u=7 $ Outer hoop 7
200 8 -7.8212 -165       u=7 $ Outer hoop 8
201 8 -7.8212 -166       u=7 $ Outer hoop 9
202 8 -7.8212 -167       u=7 $ Outer hoop 10
203 8 -7.8212 -168       u=7 $ Outer hoop 11
204 8 -7.8212 -169       u=7 $ Outer hoop 12
205 8 -7.8212 -170       u=7 $ Outer hoop 13
206 8 -7.8212 -171       u=7 $ Outer hoop 14
207 8 -7.8212 -172       u=7 $ Outer hoop 15
208 8 -7.8212 -173       u=7 $ Outer hoop 16
209 8 -7.8212 -174       u=7 $ Outer hoop 17
210 8 -7.8212 -175       u=7 $ Outer hoop 18
211 8 -7.8212 -176       u=7 $ Outer hoop 19
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
212 8 -7.8212 -177        u=7 $ Outer hoop 20
213 8 -7.8212 -178        u=7 $ Outer hoop 21
214 8 -7.8212 -179        u=7 $ Outer hoop 22
215 8 -7.8212 -180        u=7 $ Outer hoop 23
216 8 -7.8212 -181        u=7 $ Outer hoop 24
217 8 -7.8212 -182        u=7 $ Outer hoop 25
218 8 -7.8212 -183        u=7 $ Outer hoop 26
219 8 -7.8212 -184        u=7 $ Outer hoop 27
220 8 -7.8212 -185        u=7 $ Outer hoop 28
221 8 -7.8212 -186        u=7 $ Outer hoop 29
222 8 -7.8212 -187        u=7 $ Outer hoop 30
223 8 -7.8212 -188        u=7 $ Outer hoop 31
224 8 -7.8212 -189        u=7 $ Outer hoop 32
225 8 -7.8212 -190        u=7 $ Outer hoop 33
226 8 -7.8212 -191        u=7 $ Outer hoop 34
227 8 -7.8212 -192        u=7 $ Outer hoop 35
228 8 -7.8212 -193        u=7 $ Outer hoop 36
229 8 -7.8212 -194        u=7 $ Outer hoop 37
230 8 -7.8212 -195        u=7 $ Outer hoop 38
231 8 -7.8212 -196        u=7 $ Outer hoop 39
232 8 -7.8212 -197        u=7 $ Outer hoop 40
233 8 -7.8212 -198        u=7 $ Outer hoop 41
234 8 -7.8212 -199        u=7 $ Outer hoop 42
235 8 -7.8212 -200        u=7 $ Outer hoop 43
236 8 -7.8212 -201        u=7 $ Outer hoop 44
237 8 -7.8212 -202        u=7 $ Outer hoop 45
238 8 -7.8212 -203        u=7 $ Outer hoop 46
239 8 -7.8212 -204        u=7 $ Outer hoop 47
240 8 -7.8212 -205        u=7 $ Outer hoop 48
241 8 -7.8212 -206        u=7 $ Outer hoop 49
242 8 -7.8212 -207        u=7 $ Outer hoop 50
243 13 -2.3234 #193 #194 #195 #196 #197 #198 #199
        #200 #201 #202 #203 #204 #205 #206 #207 #208 #209
        #210 #211 #212 #213 #214 #215 #216 #217 #218 #219
        #220 #221 #222 #223 #224 #225 #226 #227 #228 #229
        #230 #231 #232 #233 #234 #235 #236 #237 #238 #239
        #240 #241 #242        fill=8 u=7
244 8 -7.8212 -208   trcl = ( 160.3375 0.0000 0.0000 )    u=8 $ Outer bar 1
245 like 244 but   trcl = ( 159.3293 17.9521 0.0000 )    u=8 $ Outer bar 2
246 like 244 but   trcl = ( 156.3175 35.6785 0.0000 )    u=8 $ Outer bar 3
247 like 244 but   trcl = ( 151.3399 52.9561 0.0000 )    u=8 $ Outer bar 4
248 like 244 but   trcl = ( 144.4591 69.5678 0.0000 )    u=8 $ Outer bar 5
249 like 244 but   trcl = ( 135.7616 85.3047 0.0000 )    u=8 $ Outer bar 6
250 like 244 but   trcl = ( 125.3569 99.9688 0.0000 )    u=8 $ Outer bar 7
251 like 244 but   trcl = ( 113.3757 113.3757 0.0000 )    u=8 $ Outer bar 8
252 like 244 but   trcl = ( 99.9688 125.3569 0.0000 )    u=8 $ Outer bar 9
253 like 244 but   trcl = ( 85.3047 135.7616 0.0000 )    u=8 $ Outer bar 10
254 like 244 but   trcl = ( 69.5678 144.4591 0.0000 )    u=8 $ Outer bar 11
255 like 244 but   trcl = ( 52.9561 151.3399 0.0000 )    u=8 $ Outer bar 12
256 like 244 but   trcl = ( 35.6785 156.3175 0.0000 )    u=8 $ Outer bar 13
257 like 244 but   trcl = ( 17.9521 159.3293 0.0000 )    u=8 $ Outer bar 14
258 like 244 but   trcl = ( 0.0000 160.3375 0.0000 )    u=8 $ Outer bar 15
259 like 244 but   trcl = ( -17.9521 159.3293 0.0000 )    u=8 $ Outer bar 16
260 like 244 but   trcl = ( -35.6785 156.3175 0.0000 )    u=8 $ Outer bar 17
261 like 244 but   trcl = ( -52.9561 151.3399 0.0000 )    u=8 $ Outer bar 18
262 like 244 but   trcl = ( -69.5678 144.4591 0.0000 )    u=8 $ Outer bar 19
263 like 244 but   trcl = ( -85.3047 135.7616 0.0000 )    u=8 $ Outer bar 20
264 like 244 but   trcl = ( -99.9688 125.3569 0.0000 )    u=8 $ Outer bar 21
265 like 244 but   trcl = ( -113.3757 113.3757 0.0000 )    u=8 $ Outer bar 22
266 like 244 but   trcl = ( -125.3569 99.9688 0.0000 )    u=8 $ Outer bar 23
267 like 244 but   trcl = ( -135.7616 85.3047 0.0000 )    u=8 $ Outer bar 24
268 like 244 but   trcl = ( -144.4591 69.5678 0.0000 )    u=8 $ Outer bar 25
269 like 244 but   trcl = ( -151.3399 52.9561 0.0000 )    u=8 $ Outer bar 26
270 like 244 but   trcl = ( -156.3175 35.6785 0.0000 )    u=8 $ Outer bar 27
271 like 244 but   trcl = ( -159.3293 17.9521 0.0000 )    u=8 $ Outer bar 28
272 like 244 but   trcl = ( -160.3375 0.0000 0.0000 )    u=8 $ Outer bar 29
273 like 244 but   trcl = ( -159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 30
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
274 like 244 but   trcl = ( -156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 31
275 like 244 but   trcl = ( -151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 32
276 like 244 but   trcl = ( -144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 33
277 like 244 but   trcl = ( -135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 34
278 like 244 but   trcl = ( -125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 35
279 like 244 but   trcl = ( -113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 36
280 like 244 but   trcl = ( -99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 37
281 like 244 but   trcl = ( -85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 38
282 like 244 but   trcl = ( -69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 39
283 like 244 but   trcl = ( -52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 40
284 like 244 but   trcl = ( -35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 41
285 like 244 but   trcl = ( -17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 42
286 like 244 but   trcl = ( 0.0000 -160.3375 0.0000 )    u=8 $ Outer bar 43
287 like 244 but   trcl = ( 17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 44
288 like 244 but   trcl = ( 35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 45
289 like 244 but   trcl = ( 52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 46
290 like 244 but   trcl = ( 69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 47
291 like 244 but   trcl = ( 85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 48
292 like 244 but   trcl = ( 99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 49
293 like 244 but   trcl = ( 113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 50
294 like 244 but   trcl = ( 125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 51
295 like 244 but   trcl = ( 135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 52
296 like 244 but   trcl = ( 144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 53
297 like 244 but   trcl = ( 151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 54
298 like 244 but   trcl = ( 156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 55
299 like 244 but   trcl = ( 159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 56
300 13 -2.3234 #244 #245 #246
        #247 #248 #249 #250 #251 #252 #253 #254 #255 #256
        #257 #258 #259 #260 #261 #262 #263 #264 #265 #266
        #267 #268 #269 #270 #271 #272 #273 #274 #275 #276
        #277 #278 #279 #280 #281 #282 #283 #284 #285 #286
        #287 #288 #289 #290 #291 #292 #293 #294 #295 #296
        #297 #298 #299        u=8
C Detector Cells - Radial Biasing
399  0  -399  fill=1  $ Cask
400  0  -400  +399  $ Surface
500  0  -500  +399  +400  $ 1ft
600  0  -600  +399  +400  +500  $ 1m
700  0  -700  +399  +400  +500  +600  $ 2m
800  0  -800  +399  +400  +500  +600  +700  $ 4m
900  0  +399  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.1
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094       $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 9 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 9 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 9 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
C Surfaces - PWR Canister Cavity v1.5
23 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924          $ Bot Cylinder Radius
26 CZ 6.7691          $ Mid Cyclinder Radius
27 CZ 7.4041          $ Top Cylinder Radius
28 PZ 450.8500          $ Port plane bot/mid
29 PZ 452.1962          $ Lower/upper lid
30 PZ 459.5114          $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
C VCC Surfaces - v1.0.1_ng14b
32  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
33  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 63.4999  $ Stand outer
34  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 62.3888  $ Stand inner
35 9 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate A
36 10 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate B
37 9 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall A
38 10 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall B
39  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
40  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 100.3300  $ Connector radius
41  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
42  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 538.0228 105.41  $ VCC liner outer
43  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 538.0228 100.965  $ VCC liner inner
44  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 654.5328 172.7200  $ Concrete
45  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
46  RPP -172.7200 172.7200 -63.5000 63.5000 -33.0200 -21.5900   $ Air inlet void X
47  RPP -63.5000 63.5000 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet void Y
48  RPP -172.7200 172.7200 -64.7700 64.7700 -33.0200 -21.5900   $ Air inlet wall X
49  RPP -64.7700 64.7700 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet wall Y
50  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 11.4300 100.3300  $ Air inlet divider
51  RPP -172.7200 172.7200 -64.7700 64.7700 -21.5900 -16.5100   $ Air inlet top X
52  RPP -64.7700 64.7700 -172.7200 172.7200 -21.5900 -16.5100   $ Air inlet top Y
53  RCC 0.0000 0.0000 -21.5900 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
54  RPP -172.7200 172.7200 -64.7700 64.7700 494.0808 505.0028   $ Air outlet steel X
55  RPP -64.7700 64.7700 -172.7200 172.7200 494.0808 505.0028   $ Air outlet steel Y
56  RPP -172.7200 172.7200 -64.1350 64.1350 494.7158 504.3678   $ Air outlet void X
57  RPP -64.1350 64.1350 -172.7200 172.7200 494.7158 504.3678   $ Air outlet void Y
58  RPP -106.6800 106.6800 -5.7150 5.7150 -16.5100 -5.0800   $ Support rail exterior X
59  RPP -106.6800 106.6800 -4.4450 4.4450 -16.5100 -5.0800   $ Support rail interior X
60  RPP -5.7150 5.7150 -106.6800 106.6800 -16.5100 -5.0800   $ Support rail exterior Y
61  RPP -4.4450 4.4450 -106.6800 106.6800 -16.5100 -5.0800   $ Support rail interior Y
62  RCC 0.0000 0.0000 518.9728 0.0000 0.0000 2.5400 118.7450  $ Top flange
63  RCC 0.0000 0.0000 521.5128 0.0000 0.0000 1.9050 116.2050  $ Lid top
64  RCC 0.0000 0.0000 506.7808 0.0000 0.0000 14.7320 99.6950  $ Lid concrete
65  RCC 0.0000 0.0000 506.1458 0.0000 0.0000 15.3670 100.3300  $ Lid shell
66  RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 1
67 11 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 2
68 12 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 3
69 9 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 4
70 13 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 5
71 14 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 6
72  RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 7
73 11 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 8
74 12 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 9
75 9 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 10
76 13 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 11
77 14 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 12
78  RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 1
79 11 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 2
80 12 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 3
81 9 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 4
82 13 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 5
83 14 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 6
84  RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 7
85 11 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 8
86 12 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 9
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
9 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 10
13 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 11
14 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 12
RCC -146.0500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 1
RCC -146.0500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 2
RCC -146.0500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 3
RCC -146.0500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 4
RCC -146.0500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 5
RCC -146.0500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 6
RCC -133.3500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 7
RCC -133.3500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 8
RCC -133.3500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 9
RCC -133.3500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 10
RCC -133.3500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 11
RCC -133.3500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 12
RCC -120.6500 43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 13
RCC -120.6500 21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 14
RCC -120.6500 -0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 15
RCC -120.6500 -22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 16
RCC -120.6500 -44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 17
RCC 146.0500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 1
RCC 146.0500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 2
RCC 146.0500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 3
RCC 146.0500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 4
RCC 146.0500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 5
RCC 146.0500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 6
RCC 133.3500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 7
RCC 133.3500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 8
RCC 133.3500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 9
RCC 133.3500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 10
RCC 133.3500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 11
RCC 133.3500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 12
RCC 120.6500 -43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 13
RCC 120.6500 -21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 14
RCC 120.6500 0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 15
RCC 120.6500 22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 16
RCC 120.6500 44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 17
RCC -58.4200 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 1
RCC -36.5760 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 2
RCC -14.7320 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 3
RCC 7.1120 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 4
RCC 28.9560 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 5
RCC 50.8000 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 6
RCC -50.8000 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 7
RCC -28.9560 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 8
RCC -7.1120 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 9
RCC 14.7320 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 10
RCC 36.5760 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 11
RCC 58.4200 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 12
RCC -43.1800 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 13
RCC -21.3360 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 14
RCC 0.5080 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 15
RCC 22.3520 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 16
RCC 44.1960 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 17
RCC 58.4200 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 1
RCC 36.5760 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 2
RCC 14.7320 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 3
RCC -7.1120 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 4
RCC -28.9560 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 5
RCC -50.8000 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 6
RCC 50.8000 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 7
RCC 28.9560 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 8
RCC 7.1120 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 9
RCC -14.7320 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 10
RCC -36.5760 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 11
RCC -58.4200 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 12
RCC 43.1800 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 13
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
154  RCC 21.3360 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 14
155  RCC -0.5080 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 15
156  RCC -22.3520 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 16
157  RCC -44.1960 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 17
C VCC Rebar Surfaces - v1.0.1_ng14b
158  TZ 0.0000 0.0000 -1.7182 162.2425 0.9525 0.9525   $ Outer hoop 1
159  TZ 0.0000 0.0000 7.9935 162.2425 0.9525 0.9525   $ Outer hoop 2
160  TZ 0.0000 0.0000 17.7053 162.2425 0.9525 0.9525   $ Outer hoop 3
161  TZ 0.0000 0.0000 27.4171 162.2425 0.9525 0.9525   $ Outer hoop 4
162  TZ 0.0000 0.0000 37.1288 162.2425 0.9525 0.9525   $ Outer hoop 5
163  TZ 0.0000 0.0000 46.8406 162.2425 0.9525 0.9525   $ Outer hoop 6
164  TZ 0.0000 0.0000 56.5524 162.2425 0.9525 0.9525   $ Outer hoop 7
165  TZ 0.0000 0.0000 66.2641 162.2425 0.9525 0.9525   $ Outer hoop 8
166  TZ 0.0000 0.0000 75.9759 162.2425 0.9525 0.9525   $ Outer hoop 9
167  TZ 0.0000 0.0000 85.6876 162.2425 0.9525 0.9525   $ Outer hoop 10
168  TZ 0.0000 0.0000 95.3994 162.2425 0.9525 0.9525   $ Outer hoop 11
169  TZ 0.0000 0.0000 105.1112 162.2425 0.9525 0.9525   $ Outer hoop 12
170  TZ 0.0000 0.0000 114.8229 162.2425 0.9525 0.9525   $ Outer hoop 13
171  TZ 0.0000 0.0000 124.5347 162.2425 0.9525 0.9525   $ Outer hoop 14
172  TZ 0.0000 0.0000 134.2465 162.2425 0.9525 0.9525   $ Outer hoop 15
173  TZ 0.0000 0.0000 143.9582 162.2425 0.9525 0.9525   $ Outer hoop 16
174  TZ 0.0000 0.0000 153.6700 162.2425 0.9525 0.9525   $ Outer hoop 17
175  TZ 0.0000 0.0000 163.3818 162.2425 0.9525 0.9525   $ Outer hoop 18
176  TZ 0.0000 0.0000 173.0935 162.2425 0.9525 0.9525   $ Outer hoop 19
177  TZ 0.0000 0.0000 182.8053 162.2425 0.9525 0.9525   $ Outer hoop 20
178  TZ 0.0000 0.0000 192.5171 162.2425 0.9525 0.9525   $ Outer hoop 21
179  TZ 0.0000 0.0000 202.2288 162.2425 0.9525 0.9525   $ Outer hoop 22
180  TZ 0.0000 0.0000 211.9406 162.2425 0.9525 0.9525   $ Outer hoop 23
181  TZ 0.0000 0.0000 221.6524 162.2425 0.9525 0.9525   $ Outer hoop 24
182  TZ 0.0000 0.0000 231.3641 162.2425 0.9525 0.9525   $ Outer hoop 25
183  TZ 0.0000 0.0000 241.0759 162.2425 0.9525 0.9525   $ Outer hoop 26
184  TZ 0.0000 0.0000 250.7876 162.2425 0.9525 0.9525   $ Outer hoop 27
185  TZ 0.0000 0.0000 260.4994 162.2425 0.9525 0.9525   $ Outer hoop 28
186  TZ 0.0000 0.0000 270.2112 162.2425 0.9525 0.9525   $ Outer hoop 29
187  TZ 0.0000 0.0000 279.9229 162.2425 0.9525 0.9525   $ Outer hoop 30
188  TZ 0.0000 0.0000 289.6347 162.2425 0.9525 0.9525   $ Outer hoop 31
189  TZ 0.0000 0.0000 299.3465 162.2425 0.9525 0.9525   $ Outer hoop 32
190  TZ 0.0000 0.0000 309.0582 162.2425 0.9525 0.9525   $ Outer hoop 33
191  TZ 0.0000 0.0000 318.7700 162.2425 0.9525 0.9525   $ Outer hoop 34
192  TZ 0.0000 0.0000 328.4818 162.2425 0.9525 0.9525   $ Outer hoop 35
193  TZ 0.0000 0.0000 338.1935 162.2425 0.9525 0.9525   $ Outer hoop 36
194  TZ 0.0000 0.0000 347.9053 162.2425 0.9525 0.9525   $ Outer hoop 37
195  TZ 0.0000 0.0000 357.6171 162.2425 0.9525 0.9525   $ Outer hoop 38
196  TZ 0.0000 0.0000 367.3288 162.2425 0.9525 0.9525   $ Outer hoop 39
197  TZ 0.0000 0.0000 377.0406 162.2425 0.9525 0.9525   $ Outer hoop 40
198  TZ 0.0000 0.0000 386.7524 162.2425 0.9525 0.9525   $ Outer hoop 41
199  TZ 0.0000 0.0000 396.4641 162.2425 0.9525 0.9525   $ Outer hoop 42
200  TZ 0.0000 0.0000 406.1759 162.2425 0.9525 0.9525   $ Outer hoop 43
201  TZ 0.0000 0.0000 415.8876 162.2425 0.9525 0.9525   $ Outer hoop 44
202  TZ 0.0000 0.0000 425.5994 162.2425 0.9525 0.9525   $ Outer hoop 45
203  TZ 0.0000 0.0000 435.3112 162.2425 0.9525 0.9525   $ Outer hoop 46
204  TZ 0.0000 0.0000 445.0229 162.2425 0.9525 0.9525   $ Outer hoop 47
205  TZ 0.0000 0.0000 454.7347 162.2425 0.9525 0.9525   $ Outer hoop 48
206  TZ 0.0000 0.0000 464.4465 162.2425 0.9525 0.9525   $ Outer hoop 49
207  TZ 0.0000 0.0000 474.1582 162.2425 0.9525 0.9525   $ Outer hoop 50
208  RCC 0.0000 0.0000 -11.4300 0.0000 0.0000 495.3000 0.9525  $ Bar
C Storage Cask & Pad Container
399  RCC  0.0000  0.0000  -133.0200  0.0000  0.0000  656.4378  172.7201
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  556.5378  172.8201
401  PZ  13.3582
402  PZ  59.7363
403  PZ  106.1145
404  PZ  152.4926
405  PZ  198.8708
406  PZ  245.2489
407  PZ  291.6271
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
408  PZ  338.0052
409  PZ  384.3834
410  PZ  430.7615
411  PZ  477.1397
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  587.0178  203.3001
501  PZ  15.8982
502  PZ  64.8163
503  PZ  113.7345
504  PZ  162.6526
505  PZ  211.5708
506  PZ  260.4889
507  PZ  309.4071
508  PZ  358.3252
509  PZ  407.2434
510  PZ  456.1615
511  PZ  505.0797
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  656.5378  272.8201
601  PZ  10.7492
602  PZ  54.5184
603  PZ  98.2876
604  PZ  142.0567
605  PZ  185.8259
606  PZ  229.5951
607  PZ  273.3643
608  PZ  317.1335
609  PZ  360.9027
610  PZ  404.6719
611  PZ  448.4411
612  PZ  492.2102
613  PZ  535.9794
614  PZ  579.7486
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  756.5378  372.8201
701  PZ  4.8069
702  PZ  42.6338
703  PZ  80.4607
704  PZ  118.2876
705  PZ  156.1145
706  PZ  193.9413
707  PZ  231.7682
708  PZ  269.5951
709  PZ  307.4220
710  PZ  345.2489
711  PZ  383.0758
712  PZ  420.9027
713  PZ  458.7296
714  PZ  496.5565
715  PZ  534.3834
716  PZ  572.2102
717  PZ  610.0371
718  PZ  647.8640
719  PZ  685.6909
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  956.5378  572.8201
801  PZ  14.8069
802  PZ  62.6338
803  PZ  110.4607
804  PZ  158.2876
805  PZ  206.1145
806  PZ  253.9413
807  PZ  301.7682
808  PZ  349.5951
809  PZ  397.4220
810  PZ  445.2489
811  PZ  493.0758
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
812  PZ  540.9027
813  PZ  588.7296
814  PZ  636.5565
815  PZ  684.3834
816  PZ  732.2102
817  PZ  780.0371
818  PZ  827.8640
819  PZ  875.6909

C
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
      92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
       8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4    24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
      26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
      40000 -2.1362E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Neutron Poison
m9    13027 -0.6605 5010 -0.0478 5011 -0.2179
      6012 -0.0737
C Aluminum
m10   13027 -1.0
C Lead
m11   82000 -1.0
C NS-4-FR
m12   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m13   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Balsa
m15   6012 6 1001 10 8016 5
C NS-4-FR (Accident)
m16   5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
      5011 -7.7389E-03
C Copper
m17   29063 -6.8499E-01 29065 -3.1501E-01
C Damaged Fuel
m18   92235 -4.4075E-02 92238 -8.3742E-01  8016 -1.1850E-01
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
C
imp:p 1 305r 0
C
C Source Definition - Fuel Gamma Response to Group 7
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=399:191:78:d5:3
si1   -9.85901 9.85901
sp1   0 1
si2   -9.85901 9.85901
sp2   0 1
si3 a 9.8374 19.0576 28.2778 37.4980 46.7182 55.9384 65.1586
      323.3242 332.5444 341.7646 350.9848 360.2050 369.4252 378.6454
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
sb3 d 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
si4   3.000E+00 4.000E+00
sp4   0 1
C Source Information
si5 l       40 41 42
         43 44 45 46 47
      48 49 50 51 52 53 54
      55 56 57 58 59 60 61
      62 63 64 65 66 67 68
         69 70 71 72 73
            74 75 76
C Source Probability
sp5           1.0 1.0 1.0
           1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
      1.0 1.0 1.0 1.0 1.0 1.0 1.0
           1.0 1.0 1.0 1.0 1.0
               1.0 1.0 1.0
mode p
nps 4000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=89 0 201 origin=0.1 0.1 -134
     imesh 90.2 91.4 101.0 105.4 172.7 672.7
     iints 5 1 1 1 5 1
     jmesh 101 104 112 118 129 141 151 520 550 581 603 640 656 1156
     jints 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
C wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +400.1
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
fm2 3.7000E+01
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Radial 1ft Tally
f12:p +500.1
fm12 3.7000E+01
fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  T
tf12
fc22 Radial 1m Tally
f22:p +600.1
fm22 3.7000E+01
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  T
tf22
fc32 Radial 2m Tally
f32:p +700.1
fm32 3.7000E+01
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf32
fc42 Radial 4m Tally
f42:p +800.1
fm42 3.7000E+01
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
```

Figure 5.8.8-13 CC4 Sample Input File (cont'd)

```
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 75 165 90 -15 75 90 90 90 0
```

5.8.9 Cool-Time Tables

5.8.9.1 PWR

PWR system performance is evaluated for a cask heat load of 35.5 kW with preferential (1.2 kW max) and uniform (959 W/assy) heat load patterns. Minimum cool times are summarized for the uniform and preferential heat load patterns.

Allowed low burnup (up to 30,000 MWd/MTU) fuel loadings are shown in Table 5.8.9-1. Note that the listed minimum cool times at each burnup step are bounding for all fuel types and initial enrichments above the minimum enrichment specified. Collapsing the fuel type and initial enrichment-dependent minimum cool time matrix to a single value may result in a minimum cool time longer than individual values presented for higher burnups in the detailed tables that follow.

The minimum cool time tables account for potential uncertainties in the source generation abilities of SAS2H at burnups greater than 45 GWd/MTU by reducing allowed heat loads by 5 percent. Fuel assembly loading tables at greater than 45 GWd/MTU are, therefore, generated for a cask heat load of 33.725 kW with preferential (1.14 kW max) and uniform (911 W/assy) heat load patterns.

The 5% penalty adjusted three-zone preferential loading pattern is as follows.

Zone Description	Designator	Heat Load [W/assy]	# Assemblies
Inner Ring	A	876	9
Middle Ring	B	1,140	12
Outer Ring	C	760	16

Table 5.8.9-2 contains the minimum cool times for a uniform heat load of 959 W/assy (≤ 45 GWd/MTU) PWR fuel. Greater than 45 GWd/MTU uniform heat load minimum cool times are listed in Table 5.8.9-6. Table 5.8.9-3 through Table 5.8.9-5 contain the minimum cool times for the preferential loading of ≤ 45 GWd/MTU with higher burnup fuel cool times listed in Table 5.8.9-7 through Table 5.8.9-9.

Decay heat associated with loading nonfuel components requires an increase in the minimum fuel assembly cool time. The incremental cool time increase required to load nonfuel components are documented in Sections 5.8.5, 5.8.6, and 5.8.7.

Table 5.8.9-1 Low Burnup PWR Fuel Loading Table

Max. Assembly Avg. Burnup (MWd/MTU)	Min. Assembly Avg. Initial Enrichment (wt% ^{235}U)	Minimum Cool Time (yrs)			
Heat Load per Assy	--	959 W	800 W	922 W	1,200 W
10,000	1.3	4.0	4.0	4.0	4.0
15,000	1.5	4.0	4.0	4.0	4.0
20,000	1.7	4.0	4.0	4.0	4.0
25,000	1.9	4.0	4.3	4.0	4.0
30,000	2.1	4.4	5.2	4.5	4.0

Table 5.8.9-2 Loading Table for PWR Fuel – 959 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.1	4.1	4.6	4.7	4.4	4.7	4.7
2.3 ≤ E < 2.5	4.0	4.1	4.5	4.7	4.4	4.6	4.6
2.5 ≤ E < 2.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
2.7 ≤ E < 2.9	4.0	4.0	4.5	4.5	4.3	4.5	4.5
2.9 ≤ E < 3.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.1 ≤ E < 3.3	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.3 ≤ E < 3.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
3.5 ≤ E < 3.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.7 ≤ E < 3.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.9 ≤ E < 4.1	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.1 ≤ E < 4.3	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.3 ≤ E < 4.5	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.5 ≤ E < 4.7	4.0	4.0	4.1	4.2	4.0	4.2	4.2
4.7 ≤ E < 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2
E ≥ 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.3	4.4	5.0	5.1	4.7	5.0	5.0
2.5 ≤ E < 2.7	4.3	4.4	4.9	5.0	4.7	5.0	5.0
2.7 ≤ E < 2.9	4.2	4.3	4.8	5.0	4.6	4.9	4.9
2.9 ≤ E < 3.1	4.2	4.3	4.8	4.9	4.6	4.9	4.9
3.1 ≤ E < 3.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.3 ≤ E < 3.5	4.1	4.2	4.7	4.8	4.5	4.8	4.8
3.5 ≤ E < 3.7	4.1	4.1	4.6	4.8	4.4	4.7	4.7
3.7 ≤ E < 3.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.9 ≤ E < 4.1	4.0	4.1	4.6	4.7	4.4	4.7	4.7
4.1 ≤ E < 4.3	4.0	4.0	4.5	4.7	4.3	4.6	4.6
4.3 ≤ E < 4.5	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.5 ≤ E < 4.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.7 ≤ E < 4.9	4.0	4.0	4.4	4.6	4.3	4.5	4.5
E ≥ 4.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5

Table 5.8.9-2 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
2.5 ≤ E < 2.7	4.6	4.7	5.4	5.6	5.1	5.5	5.5
2.7 ≤ E < 2.9	4.6	4.7	5.3	5.5	5.0	5.4	5.4
2.9 ≤ E < 3.1	4.5	4.6	5.3	5.4	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.5	5.2	5.4	4.9	5.3	5.3
3.3 ≤ E < 3.5	4.4	4.5	5.1	5.3	4.9	5.2	5.2
3.5 ≤ E < 3.7	4.4	4.5	5.0	5.2	4.8	5.2	5.2
3.7 ≤ E < 3.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1
3.9 ≤ E < 4.1	4.3	4.4	5.0	5.1	4.7	5.1	5.1
4.1 ≤ E < 4.3	4.3	4.4	4.9	5.1	4.7	5.0	5.0
4.3 ≤ E < 4.5	4.2	4.3	4.9	5.0	4.7	5.0	5.0
4.5 ≤ E < 4.7	4.2	4.3	4.9	5.0	4.6	5.0	5.0
4.7 ≤ E < 4.9	4.2	4.3	4.8	5.0	4.6	4.9	4.9
E ≥ 4.9	4.1	4.2	4.8	4.9	4.5	4.9	4.9
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.0	5.2	5.9	6.1	5.6	6.0	6.0
2.7 ≤ E < 2.9	5.0	5.1	5.9	6.0	5.5	5.9	5.9
2.9 ≤ E < 3.1	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.1 ≤ E < 3.3	4.9	4.9	5.7	5.9	5.4	5.8	5.8
3.3 ≤ E < 3.5	4.8	4.9	5.7	5.8	5.3	5.7	5.7
3.5 ≤ E < 3.7	4.7	4.8	5.6	5.8	5.2	5.7	5.7
3.7 ≤ E < 3.9	4.7	4.8	5.5	5.7	5.2	5.6	5.6
3.9 ≤ E < 4.1	4.6	4.8	5.5	5.7	5.1	5.6	5.6
4.1 ≤ E < 4.3	4.6	4.7	5.4	5.6	5.1	5.5	5.5
4.3 ≤ E < 4.5	4.5	4.7	5.4	5.6	5.0	5.5	5.5
4.5 ≤ E < 4.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
4.7 ≤ E < 4.9	4.5	4.6	5.3	5.5	5.0	5.4	5.4
E ≥ 4.9	4.5	4.5	5.2	5.4	4.9	5.4	5.4

Table 5.8.9-2 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.3	5.4	6.2	6.4	5.8	6.3	6.3
2.7 ≤ E < 2.9	5.2	5.3	6.1	6.3	5.7	6.2	6.2
2.9 ≤ E < 3.1	5.1	5.2	6.0	6.2	5.7	6.1	6.1
3.1 ≤ E < 3.3	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.3 ≤ E < 3.5	4.9	5.1	5.9	6.0	5.5	5.9	5.9
3.5 ≤ E < 3.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.8	4.9	5.7	5.9	5.4	5.8	5.8
3.9 ≤ E < 4.1	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.1 ≤ E < 4.3	4.7	4.9	5.6	5.8	5.3	5.7	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.5 ≤ E < 4.7	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.6	4.7	5.5	5.6	5.1	5.6	5.6
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.5	5.6	6.5	6.7	6.0	6.6	6.6
2.7 ≤ E < 2.9	5.4	5.5	6.4	6.6	5.9	6.5	6.5
2.9 ≤ E < 3.1	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.1 ≤ E < 3.3	5.2	5.3	6.2	6.4	5.8	6.3	6.3
3.3 ≤ E < 3.5	5.1	5.3	6.1	6.3	5.7	6.2	6.2
3.5 ≤ E < 3.7	5.0	5.2	6.0	6.2	5.7	6.1	6.1
3.7 ≤ E < 3.9	5.0	5.1	5.9	6.2	5.6	6.0	6.0
3.9 ≤ E < 4.1	4.9	5.1	5.9	6.1	5.5	6.0	6.0
4.1 ≤ E < 4.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.3 ≤ E < 4.5	4.9	5.0	5.8	6.0	5.4	5.9	5.9
4.5 ≤ E < 4.7	4.8	4.9	5.7	5.9	5.4	5.8	5.8
4.7 ≤ E < 4.9	4.8	4.9	5.7	5.9	5.3	5.8	5.8
E ≥ 4.9	4.7	4.9	5.7	5.9	5.3	5.8	5.8

Table 5.8.9-2 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	5.8	6.8	7.0	6.3	6.9	6.9
2.7 ≤ E < 2.9	5.6	5.7	6.7	6.9	6.2	6.8	6.8
2.9 ≤ E < 3.1	5.5	5.6	6.6	6.8	6.0	6.7	6.7
3.1 ≤ E < 3.3	5.4	5.6	6.5	6.7	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.5 ≤ E < 3.7	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.7 ≤ E < 3.9	5.2	5.3	6.2	6.5	5.8	6.3	6.3
3.9 ≤ E < 4.1	5.1	5.3	6.1	6.4	5.7	6.2	6.2
4.1 ≤ E < 4.3	5.0	5.2	6.0	6.3	5.7	6.2	6.1
4.3 ≤ E < 4.5	5.0	5.2	6.0	6.2	5.6	6.1	6.1
4.5 ≤ E < 4.7	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.7 ≤ E < 4.9	4.9	5.0	5.9	6.1	5.5	6.0	6.0
E ≥ 4.9	4.9	5.0	5.8	6.0	5.5	6.0	5.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.9	6.0	7.1	7.4	6.6	7.2	7.2
2.7 ≤ E < 2.9	5.8	5.9	7.0	7.3	6.5	7.0	7.0
2.9 ≤ E < 3.1	5.7	5.8	6.9	7.1	6.4	6.9	6.9
3.1 ≤ E < 3.3	5.6	5.8	6.8	7.0	6.2	6.8	6.8
3.3 ≤ E < 3.5	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.5 ≤ E < 3.7	5.5	5.6	6.6	6.8	6.0	6.7	6.7
3.7 ≤ E < 3.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
3.9 ≤ E < 4.1	5.3	5.5	6.4	6.7	5.9	6.5	6.5
4.1 ≤ E < 4.3	5.3	5.4	6.3	6.6	5.9	6.4	6.4
4.3 ≤ E < 4.5	5.2	5.4	6.2	6.5	5.8	6.4	6.4
4.5 ≤ E < 4.7	5.1	5.3	6.2	6.5	5.8	6.3	6.3
4.7 ≤ E < 4.9	5.1	5.3	6.1	6.4	5.7	6.2	6.2
E ≥ 4.9	5.0	5.2	6.0	6.3	5.7	6.2	6.2

Table 5.8.9-2 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.0	6.2	7.3	7.7	6.7	7.4	7.4
2.9 ≤ E < 3.1	5.9	6.0	7.2	7.6	6.6	7.3	7.3
3.1 ≤ E < 3.3	5.8	6.0	7.0	7.4	6.5	7.2	7.1
3.3 ≤ E < 3.5	5.7	5.9	6.9	7.3	6.4	7.0	7.0
3.5 ≤ E < 3.7	5.7	5.8	6.8	7.2	6.3	6.9	6.9
3.7 ≤ E < 3.9	5.6	5.8	6.8	7.0	6.2	6.9	6.9
3.9 ≤ E < 4.1	5.5	5.7	6.7	7.0	6.2	6.8	6.8
4.1 ≤ E < 4.3	5.5	5.6	6.6	6.9	6.1	6.7	6.7
4.3 ≤ E < 4.5	5.4	5.6	6.5	6.8	6.0	6.7	6.6
4.5 ≤ E < 4.7	5.3	5.5	6.5	6.7	6.0	6.6	6.6
4.7 ≤ E < 4.9	5.3	5.5	6.4	6.7	5.9	6.5	6.5
E ≥ 4.9	5.2	5.4	6.3	6.6	5.9	6.5	6.5

Note: Burnups greater than 45 GWd/MTU have been deleted from this table.

Table 5.8.9-3 Loading Table for PWR Fuel – 1,200 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.1	4.0	4.1	4.1
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.1	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.8.9-3 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
2.5 ≤ E < 2.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
2.7 ≤ E < 2.9	4.0	4.0	4.2	4.3	4.1	4.3	4.3
2.9 ≤ E < 3.1	4.0	4.0	4.2	4.3	4.0	4.3	4.3
3.1 ≤ E < 3.3	4.0	4.0	4.1	4.2	4.0	4.2	4.2
3.3 ≤ E < 3.5	4.0	4.0	4.1	4.2	4.0	4.2	4.2
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.2	4.0	4.2	4.2
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.1	4.0	4.1	4.1
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.1	4.0	4.1	4.1
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.0	4.1	4.6	4.8	4.4	4.7	4.7
2.7 ≤ E < 2.9	4.0	4.0	4.6	4.7	4.4	4.7	4.7
2.9 ≤ E < 3.1	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.1 ≤ E < 3.3	4.0	4.0	4.5	4.6	4.3	4.5	4.5
3.3 ≤ E < 3.5	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.5 ≤ E < 3.7	4.0	4.0	4.4	4.5	4.2	4.5	4.4
3.7 ≤ E < 3.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.9 ≤ E < 4.1	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.1 ≤ E < 4.3	4.0	4.0	4.2	4.3	4.1	4.3	4.3
4.3 ≤ E < 4.5	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.5 ≤ E < 4.7	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.7 ≤ E < 4.9	4.0	4.0	4.1	4.3	4.0	4.3	4.3
E ≥ 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2

Table 5.8.9-3 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.2	4.2	4.8	4.9	4.5	4.9	4.9
2.7 ≤ E < 2.9	4.1	4.2	4.7	4.8	4.5	4.8	4.8
2.9 ≤ E < 3.1	4.0	4.1	4.7	4.8	4.4	4.8	4.7
3.1 ≤ E < 3.3	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.3 ≤ E < 3.5	4.0	4.0	4.5	4.7	4.4	4.6	4.6
3.5 ≤ E < 3.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.7 ≤ E < 3.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.9 ≤ E < 4.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.1 ≤ E < 4.3	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.3 ≤ E < 4.5	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.5 ≤ E < 4.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.7 ≤ E < 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
E ≥ 4.9	4.0	4.0	4.2	4.3	4.0	4.4	4.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.3	4.4	4.9	5.1	4.7	5.0	5.0
2.7 ≤ E < 2.9	4.2	4.3	4.9	5.0	4.6	5.0	5.0
2.9 ≤ E < 3.1	4.2	4.2	4.8	4.9	4.6	4.9	4.9
3.1 ≤ E < 3.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.3 ≤ E < 3.5	4.0	4.1	4.7	4.8	4.5	4.8	4.8
3.5 ≤ E < 3.7	4.0	4.1	4.6	4.8	4.4	4.7	4.7
3.7 ≤ E < 3.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.9 ≤ E < 4.1	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.1 ≤ E < 4.3	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.3 ≤ E < 4.5	4.0	4.0	4.4	4.6	4.3	4.5	4.5
4.5 ≤ E < 4.7	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.7 ≤ E < 4.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
E ≥ 4.9	4.0	4.0	4.3	4.5	4.2	4.5	4.5

Table 5.8.9-3 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.4	4.5	5.1	5.3	4.9	5.2	5.2
2.7 ≤ E < 2.9	4.4	4.4	5.0	5.2	4.8	5.1	5.1
2.9 ≤ E < 3.1	4.3	4.4	5.0	5.1	4.7	5.0	5.0
3.1 ≤ E < 3.3	4.2	4.3	4.9	5.0	4.7	5.0	5.0
3.3 ≤ E < 3.5	4.2	4.3	4.8	5.0	4.6	4.9	4.9
3.5 ≤ E < 3.7	4.1	4.2	4.8	4.9	4.5	4.9	4.9
3.7 ≤ E < 3.9	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.9 ≤ E < 4.1	4.0	4.1	4.7	4.8	4.4	4.8	4.8
4.1 ≤ E < 4.3	4.0	4.1	4.6	4.8	4.4	4.7	4.7
4.3 ≤ E < 4.5	4.0	4.0	4.6	4.7	4.4	4.7	4.7
4.5 ≤ E < 4.7	4.0	4.0	4.5	4.7	4.3	4.7	4.6
4.7 ≤ E < 4.9	4.0	4.0	4.5	4.6	4.3	4.6	4.6
E ≥ 4.9	4.0	4.0	4.4	4.6	4.3	4.6	4.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
2.7 ≤ E < 2.9	4.5	4.6	5.2	5.4	4.9	5.3	5.3
2.9 ≤ E < 3.1	4.4	4.5	5.1	5.3	4.9	5.2	5.2
3.1 ≤ E < 3.3	4.4	4.4	5.0	5.2	4.8	5.2	5.2
3.3 ≤ E < 3.5	4.3	4.4	5.0	5.1	4.7	5.1	5.1
3.5 ≤ E < 3.7	4.2	4.3	4.9	5.1	4.7	5.0	5.0
3.7 ≤ E < 3.9	4.2	4.3	4.9	5.0	4.6	5.0	5.0
3.9 ≤ E < 4.1	4.1	4.3	4.8	5.0	4.6	4.9	4.9
4.1 ≤ E < 4.3	4.1	4.2	4.8	4.9	4.5	4.9	4.9
4.3 ≤ E < 4.5	4.1	4.2	4.7	4.9	4.5	4.8	4.8
4.5 ≤ E < 4.7	4.0	4.2	4.7	4.8	4.5	4.8	4.8
4.7 ≤ E < 4.9	4.0	4.1	4.6	4.8	4.4	4.8	4.7
E ≥ 4.9	4.0	4.1	4.6	4.8	4.4	4.7	4.7

Table 5.8.9-3 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	4.6	4.7	5.4	5.6	5.1	5.5	5.5
2.9 ≤ E < 3.1	4.5	4.6	5.3	5.5	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.6	5.2	5.4	4.9	5.4	5.4
3.3 ≤ E < 3.5	4.4	4.5	5.2	5.4	4.9	5.3	5.3
3.5 ≤ E < 3.7	4.4	4.5	5.1	5.3	4.8	5.2	5.2
3.7 ≤ E < 3.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1
3.9 ≤ E < 4.1	4.3	4.4	5.0	5.1	4.7	5.1	5.1
4.1 ≤ E < 4.3	4.2	4.3	4.9	5.1	4.7	5.0	5.0
4.3 ≤ E < 4.5	4.2	4.3	4.9	5.0	4.6	5.0	5.0
4.5 ≤ E < 4.7	4.1	4.2	4.8	5.0	4.6	4.9	4.9
4.7 ≤ E < 4.9	4.1	4.2	4.8	4.9	4.5	4.9	4.9
E ≥ 4.9	4.0	4.2	4.7	4.9	4.5	4.9	4.8

Note: Burnups greater than 45 GWd/MTU have been deleted from this table.

Table 5.8.9-4 Loading Table for PWR Fuel – 922 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.2	4.3	4.8	4.9	4.6	4.9	4.9
2.3 ≤ E < 2.5	4.2	4.2	4.7	4.8	4.5	4.8	4.8
2.5 ≤ E < 2.7	4.1	4.2	4.7	4.8	4.5	4.8	4.8
2.7 ≤ E < 2.9	4.1	4.1	4.6	4.7	4.4	4.7	4.7
2.9 ≤ E < 3.1	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.1 ≤ E < 3.3	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.3 ≤ E < 3.5	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.5 ≤ E < 3.7	4.0	4.0	4.5	4.5	4.3	4.5	4.5
3.7 ≤ E < 3.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.9 ≤ E < 4.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.1 ≤ E < 4.3	4.0	4.0	4.4	4.5	4.2	4.4	4.4
4.3 ≤ E < 4.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
4.5 ≤ E < 4.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.7 ≤ E < 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
E ≥ 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	**WE 14×14**	**WE 15×15**	**B&W 15×15**	**CE 16×16**	**WE 17×17**	**B&W 17×17**
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.5	4.6	5.2	5.3	4.9	5.3	5.3
2.5 ≤ E < 2.7	4.4	4.5	5.1	5.3	4.9	5.2	5.2
2.7 ≤ E < 2.9	4.4	4.5	5.0	5.2	4.8	5.1	5.1
2.9 ≤ E < 3.1	4.4	4.4	5.0	5.1	4.8	5.1	5.1
3.1 ≤ E < 3.3	4.3	4.4	4.9	5.0	4.7	5.0	5.0
3.3 ≤ E < 3.5	4.3	4.3	4.9	5.0	4.7	5.0	5.0
3.5 ≤ E < 3.7	4.2	4.3	4.8	5.0	4.6	4.9	4.9
3.7 ≤ E < 3.9	4.2	4.3	4.8	4.9	4.6	4.9	4.9
3.9 ≤ E < 4.1	4.1	4.2	4.8	4.9	4.5	4.9	4.9
4.1 ≤ E < 4.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
4.3 ≤ E < 4.5	4.1	4.2	4.7	4.8	4.5	4.8	4.8
4.5 ≤ E < 4.7	4.0	4.1	4.7	4.8	4.5	4.8	4.8
4.7 ≤ E < 4.9	4.0	4.1	4.6	4.8	4.4	4.7	4.7
E ≥ 4.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7

Table 5.8.9-4 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.9	5.0	5.7	5.9	5.4	5.8	5.8
2.5 ≤ E < 2.7	4.8	4.9	5.7	5.8	5.3	5.7	5.7
2.7 ≤ E < 2.9	4.8	4.9	5.6	5.8	5.3	5.7	5.7
2.9 ≤ E < 3.1	4.7	4.8	5.5	5.7	5.2	5.6	5.6
3.1 ≤ E < 3.3	4.6	4.7	5.4	5.6	5.1	5.5	5.5
3.3 ≤ E < 3.5	4.6	4.7	5.4	5.6	5.0	5.5	5.5
3.5 ≤ E < 3.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
3.7 ≤ E < 3.9	4.5	4.6	5.3	5.4	5.0	5.4	5.4
3.9 ≤ E < 4.1	4.5	4.6	5.2	5.4	4.9	5.3	5.3
4.1 ≤ E < 4.3	4.4	4.5	5.2	5.4	4.9	5.3	5.3
4.3 ≤ E < 4.5	4.4	4.5	5.1	5.3	4.9	5.2	5.2
4.5 ≤ E < 4.7	4.4	4.5	5.1	5.3	4.8	5.2	5.2
4.7 ≤ E < 4.9	4.3	4.4	5.0	5.2	4.8	5.2	5.2
E ≥ 4.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.3	5.4	6.2	6.5	5.9	6.3	6.3
2.7 ≤ E < 2.9	5.2	5.3	6.1	6.4	5.8	6.2	6.2
2.9 ≤ E < 3.1	5.1	5.3	6.0	6.3	5.7	6.1	6.1
3.1 ≤ E < 3.3	5.0	5.2	6.0	6.2	5.6	6.0	6.0
3.3 ≤ E < 3.5	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.5 ≤ E < 3.7	4.9	5.0	5.9	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.9 ≤ E < 4.1	4.8	5.0	5.7	5.9	5.4	5.8	5.8
4.1 ≤ E < 4.3	4.8	4.9	5.7	5.9	5.4	5.8	5.8
4.3 ≤ E < 4.5	4.8	4.9	5.7	5.8	5.3	5.8	5.7
4.5 ≤ E < 4.7	4.7	4.8	5.6	5.8	5.3	5.7	5.7
4.7 ≤ E < 4.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7
E ≥ 4.9	4.6	4.8	5.5	5.7	5.2	5.6	5.6

Table 5.8.9-4 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.5	5.6	6.6	6.8	6.0	6.6	6.6
2.7 ≤ E < 2.9	5.4	5.6	6.4	6.7	6.0	6.5	6.5
2.9 ≤ E < 3.1	5.3	5.5	6.3	6.6	5.9	6.4	6.4
3.1 ≤ E < 3.3	5.3	5.4	6.2	6.5	5.8	6.3	6.3
3.3 ≤ E < 3.5	5.2	5.3	6.1	6.4	5.8	6.3	6.2
3.5 ≤ E < 3.7	5.1	5.3	6.1	6.3	5.7	6.2	6.2
3.7 ≤ E < 3.9	5.0	5.2	6.0	6.2	5.7	6.1	6.1
3.9 ≤ E < 4.1	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.1 ≤ E < 4.3	5.0	5.1	5.9	6.1	5.6	6.0	6.0
4.3 ≤ E < 4.5	4.9	5.0	5.9	6.0	5.5	5.9	5.9
4.5 ≤ E < 4.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.7 ≤ E < 4.9	4.8	5.0	5.8	6.0	5.4	5.9	5.9
E ≥ 4.9	4.8	4.9	5.7	5.9	5.4	5.8	5.8
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	5.9	6.9	7.1	6.4	6.9	6.9
2.7 ≤ E < 2.9	5.6	5.8	6.7	7.0	6.2	6.8	6.8
2.9 ≤ E < 3.1	5.6	5.7	6.6	6.9	6.1	6.7	6.7
3.1 ≤ E < 3.3	5.5	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.4	5.5	6.4	6.7	6.0	6.6	6.5
3.5 ≤ E < 3.7	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.7 ≤ E < 3.9	5.3	5.4	6.3	6.6	5.9	6.4	6.4
3.9 ≤ E < 4.1	5.2	5.4	6.2	6.5	5.8	6.3	6.3
4.1 ≤ E < 4.3	5.1	5.3	6.1	6.4	5.8	6.3	6.2
4.3 ≤ E < 4.5	5.1	5.2	6.0	6.3	5.7	6.2	6.2
4.5 ≤ E < 4.7	5.0	5.2	6.0	6.3	5.7	6.1	6.1
4.7 ≤ E < 4.9	5.0	5.1	6.0	6.2	5.6	6.1	6.1
E ≥ 4.9	4.9	5.1	5.9	6.2	5.6	6.0	6.0

Table 5.8.9-4 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.9	6.1	7.2	7.5	6.7	7.3	7.3
2.7 ≤ E < 2.9	5.8	6.0	7.0	7.4	6.5	7.1	7.1
2.9 ≤ E < 3.1	5.8	5.9	6.9	7.3	6.4	7.0	7.0
3.1 ≤ E < 3.3	5.7	5.8	6.8	7.1	6.3	6.9	6.9
3.3 ≤ E < 3.5	5.6	5.8	6.7	7.0	6.2	6.8	6.8
3.5 ≤ E < 3.7	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.7 ≤ E < 3.9	5.5	5.6	6.6	6.8	6.1	6.7	6.7
3.9 ≤ E < 4.1	5.4	5.6	6.5	6.8	6.0	6.6	6.6
4.1 ≤ E < 4.3	5.3	5.5	6.4	6.7	6.0	6.5	6.5
4.3 ≤ E < 4.5	5.3	5.5	6.4	6.6	5.9	6.5	6.5
4.5 ≤ E < 4.7	5.2	5.4	6.3	6.6	5.9	6.4	6.4
4.7 ≤ E < 4.9	5.2	5.3	6.2	6.5	5.8	6.4	6.4
E ≥ 4.9	5.1	5.3	6.2	6.5	5.8	6.3	6.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.2	6.4	7.6	8.0	6.9	7.7	7.7
2.7 ≤ E < 2.9	6.0	6.2	7.4	7.8	6.8	7.5	7.5
2.9 ≤ E < 3.1	6.0	6.1	7.3	7.7	6.7	7.4	7.4
3.1 ≤ E < 3.3	5.9	6.0	7.2	7.5	6.6	7.3	7.3
3.3 ≤ E < 3.5	5.8	6.0	7.0	7.4	6.5	7.1	7.1
3.5 ≤ E < 3.7	5.8	5.9	6.9	7.3	6.4	7.0	7.0
3.7 ≤ E < 3.9	5.7	5.8	6.9	7.2	6.3	7.0	7.0
3.9 ≤ E < 4.1	5.6	5.8	6.8	7.1	6.3	6.9	6.9
4.1 ≤ E < 4.3	5.5	5.7	6.7	7.0	6.2	6.8	6.8
4.3 ≤ E < 4.5	5.5	5.7	6.7	6.9	6.1	6.8	6.8
4.5 ≤ E < 4.7	5.4	5.6	6.6	6.9	6.0	6.7	6.7
4.7 ≤ E < 4.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
E ≥ 4.9	5.3	5.5	6.5	6.8	6.0	6.6	6.6

Table 5.8.9-4 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.3	6.6	7.8	8.3	7.1	7.9	7.9
2.9 ≤ E < 3.1	6.2	6.4	7.7	8.1	7.0	7.8	7.8
3.1 ≤ E < 3.3	6.1	6.3	7.6	7.9	6.9	7.7	7.7
3.3 ≤ E < 3.5	6.0	6.2	7.4	7.8	6.8	7.5	7.5
3.5 ≤ E < 3.7	5.9	6.1	7.3	7.7	6.7	7.4	7.4
3.7 ≤ E < 3.9	5.9	6.0	7.2	7.6	6.6	7.3	7.3
3.9 ≤ E < 4.1	5.8	6.0	7.1	7.5	6.6	7.2	7.2
4.1 ≤ E < 4.3	5.7	5.9	7.0	7.4	6.5	7.1	7.1
4.3 ≤ E < 4.5	5.7	5.9	6.9	7.3	6.4	7.0	7.0
4.5 ≤ E < 4.7	5.6	5.8	6.9	7.2	6.3	7.0	7.0
4.7 ≤ E < 4.9	5.6	5.8	6.8	7.1	6.3	6.9	6.9
E ≥ 4.9	5.5	5.7	6.7	7.0	6.2	6.9	6.9

Note: Burnups greater than 45 GWd/MTU have been deleted from this table.

Table 5.8.9-5 Loading Table for PWR Fuel – 800 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.8	4.9	5.6	5.7	5.2	5.6	5.6
2.3 ≤ E < 2.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
2.5 ≤ E < 2.7	4.7	4.8	5.4	5.6	5.1	5.5	5.5
2.7 ≤ E < 2.9	4.6	4.7	5.4	5.5	5.0	5.5	5.5
2.9 ≤ E < 3.1	4.6	4.7	5.3	5.5	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.6	5.3	5.4	5.0	5.3	5.3
3.3 ≤ E < 3.5	4.5	4.6	5.2	5.4	4.9	5.3	5.3
3.5 ≤ E < 3.7	4.5	4.5	5.1	5.3	4.9	5.2	5.2
3.7 ≤ E < 3.9	4.4	4.5	5.1	5.3	4.8	5.2	5.2
3.9 ≤ E < 4.1	4.4	4.5	5.0	5.2	4.8	5.2	5.1
4.1 ≤ E < 4.3	4.4	4.4	5.0	5.2	4.8	5.1	5.1
4.3 ≤ E < 4.5	4.3	4.4	5.0	5.1	4.8	5.1	5.1
4.5 ≤ E < 4.7	4.3	4.4	5.0	5.1	4.7	5.0	5.0
4.7 ≤ E < 4.9	4.3	4.4	4.9	5.1	4.7	5.0	5.0
E ≥ 4.9	4.3	4.3	4.9	5.0	4.7	5.0	5.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	**WE 14×14**	**WE 15×15**	**B&W 15×15**	**CE 16×16**	**WE 17×17**	**B&W 17×17**
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.2	5.3	6.0	6.3	5.7	6.1	6.1
2.5 ≤ E < 2.7	5.1	5.2	6.0	6.2	5.7	6.0	6.0
2.7 ≤ E < 2.9	5.0	5.2	5.9	6.1	5.6	6.0	6.0
2.9 ≤ E < 3.1	5.0	5.1	5.9	6.0	5.5	5.9	5.9
3.1 ≤ E < 3.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.3 ≤ E < 3.5	4.9	5.0	5.8	5.9	5.4	5.8	5.8
3.5 ≤ E < 3.7	4.9	4.9	5.7	5.9	5.4	5.8	5.8
3.7 ≤ E < 3.9	4.8	4.9	5.7	5.8	5.3	5.8	5.8
3.9 ≤ E < 4.1	4.8	4.9	5.6	5.8	5.3	5.7	5.7
4.1 ≤ E < 4.3	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.5 ≤ E < 4.7	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.6	4.7	5.4	5.6	5.1	5.5	5.5

Table 5.8.9-5 Loading Table for PWR Fuel – 800 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.8	5.9	6.9	7.1	6.4	6.9	6.9
2.5 ≤ E < 2.7	5.7	5.8	6.8	7.0	6.3	6.8	6.8
2.7 ≤ E < 2.9	5.6	5.7	6.7	6.9	6.2	6.7	6.7
2.9 ≤ E < 3.1	5.5	5.7	6.6	6.8	6.1	6.7	6.7
3.1 ≤ E < 3.3	5.5	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.4	5.5	6.4	6.7	6.0	6.5	6.5
3.5 ≤ E < 3.7	5.3	5.5	6.3	6.6	5.9	6.5	6.4
3.7 ≤ E < 3.9	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.9 ≤ E < 4.1	5.2	5.4	6.2	6.5	5.8	6.3	6.3
4.1 ≤ E < 4.3	5.2	5.3	6.1	6.4	5.8	6.3	6.3
4.3 ≤ E < 4.5	5.1	5.3	6.1	6.4	5.7	6.2	6.2
4.5 ≤ E < 4.7	5.1	5.2	6.0	6.3	5.7	6.2	6.2
4.7 ≤ E < 4.9	5.0	5.2	6.0	6.3	5.7	6.1	6.1
E ≥ 4.9	5.0	5.1	6.0	6.2	5.6	6.1	6.1
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.3	6.5	7.7	8.1	7.0	7.8	7.8
2.7 ≤ E < 2.9	6.2	6.4	7.6	8.0	6.9	7.7	7.7
2.9 ≤ E < 3.1	6.1	6.3	7.5	7.8	6.9	7.6	7.6
3.1 ≤ E < 3.3	6.0	6.2	7.4	7.7	6.8	7.4	7.4
3.3 ≤ E < 3.5	5.9	6.1	7.2	7.6	6.7	7.3	7.3
3.5 ≤ E < 3.7	5.9	6.0	7.1	7.5	6.6	7.3	7.2
3.7 ≤ E < 3.9	5.8	6.0	7.1	7.4	6.5	7.2	7.1
3.9 ≤ E < 4.1	5.8	5.9	7.0	7.4	6.5	7.1	7.1
4.1 ≤ E < 4.3	5.7	5.9	6.9	7.3	6.4	7.0	7.0
4.3 ≤ E < 4.5	5.7	5.8	6.9	7.2	6.4	7.0	7.0
4.5 ≤ E < 4.7	5.6	5.8	6.8	7.1	6.3	6.9	6.9
4.7 ≤ E < 4.9	5.6	5.7	6.8	7.1	6.3	6.9	6.9
E ≥ 4.9	5.5	5.7	6.7	7.0	6.2	6.8	6.8

Table 5.8.9-5 Loading Table for PWR Fuel – 800 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.6	6.8	8.2	8.7	7.4	8.3	8.3
2.7 ≤ E < 2.9	6.5	6.7	8.0	8.5	7.3	8.1	8.1
2.9 ≤ E < 3.1	6.4	6.6	7.9	8.3	7.2	8.0	8.0
3.1 ≤ E < 3.3	6.3	6.5	7.8	8.2	7.1	7.9	7.9
3.3 ≤ E < 3.5	6.2	6.4	7.7	8.0	7.0	7.8	7.8
3.5 ≤ E < 3.7	6.1	6.3	7.6	8.0	6.9	7.7	7.7
3.7 ≤ E < 3.9	6.0	6.2	7.5	7.9	6.8	7.6	7.6
3.9 ≤ E < 4.1	6.0	6.1	7.4	7.8	6.8	7.5	7.5
4.1 ≤ E < 4.3	5.9	6.1	7.3	7.7	6.7	7.4	7.4
4.3 ≤ E < 4.5	5.9	6.0	7.2	7.6	6.7	7.4	7.3
4.5 ≤ E < 4.7	5.8	6.0	7.1	7.6	6.6	7.3	7.3
4.7 ≤ E < 4.9	5.8	5.9	7.1	7.5	6.6	7.2	7.2
E ≥ 4.9	5.7	5.9	7.0	7.4	6.5	7.2	7.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.9	7.1	8.7	9.3	7.8	8.8	8.8
2.7 ≤ E < 2.9	6.8	7.0	8.6	9.0	7.7	8.6	8.6
2.9 ≤ E < 3.1	6.7	6.9	8.4	8.9	7.6	8.5	8.5
3.1 ≤ E < 3.3	6.6	6.8	8.2	8.7	7.5	8.3	8.3
3.3 ≤ E < 3.5	6.5	6.7	8.1	8.6	7.3	8.2	8.2
3.5 ≤ E < 3.7	6.4	6.6	8.0	8.5	7.2	8.1	8.1
3.7 ≤ E < 3.9	6.3	6.5	7.9	8.3	7.1	8.0	8.0
3.9 ≤ E < 4.1	6.2	6.5	7.8	8.2	7.1	7.9	7.9
4.1 ≤ E < 4.3	6.1	6.4	7.7	8.1	7.0	7.8	7.8
4.3 ≤ E < 4.5	6.1	6.3	7.6	8.0	6.9	7.8	7.7
4.5 ≤ E < 4.7	6.0	6.3	7.6	8.0	6.9	7.7	7.7
4.7 ≤ E < 4.9	6.0	6.2	7.5	7.9	6.8	7.6	7.6
E ≥ 4.9	5.9	6.1	7.4	7.8	6.8	7.6	7.6

Table 5.8.9-5 Loading Table for PWR Fuel – 800 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.3	7.5	9.3	9.9	8.3	9.4	9.4
2.7 ≤ E < 2.9	7.1	7.4	9.1	9.7	8.1	9.2	9.2
2.9 ≤ E < 3.1	7.0	7.2	8.9	9.5	8.0	9.0	9.0
3.1 ≤ E < 3.3	6.9	7.1	8.8	9.3	7.9	8.9	8.8
3.3 ≤ E < 3.5	6.8	7.0	8.6	9.2	7.8	8.7	8.7
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.0	7.7	8.6	8.6
3.7 ≤ E < 3.9	6.6	6.8	8.4	8.9	7.6	8.5	8.5
3.9 ≤ E < 4.1	6.5	6.8	8.2	8.8	7.5	8.4	8.4
4.1 ≤ E < 4.3	6.5	6.7	8.1	8.7	7.4	8.3	8.3
4.3 ≤ E < 4.5	6.4	6.6	8.0	8.6	7.3	8.2	8.2
4.5 ≤ E < 4.7	6.3	6.6	8.0	8.5	7.2	8.1	8.1
4.7 ≤ E < 4.9	6.2	6.5	7.9	8.4	7.2	8.0	8.0
E ≥ 4.9	6.2	6.4	7.8	8.3	7.1	8.0	8.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.7	8.0	10.0	10.8	8.8	10.0	10.1
2.7 ≤ E < 2.9	7.5	7.8	9.7	10.5	8.7	9.9	9.8
2.9 ≤ E < 3.1	7.4	7.7	9.5	10.2	8.5	9.7	9.6
3.1 ≤ E < 3.3	7.2	7.5	9.3	10.0	8.3	9.5	9.4
3.3 ≤ E < 3.5	7.1	7.4	9.2	9.8	8.2	9.3	9.3
3.5 ≤ E < 3.7	7.1	7.3	9.0	9.7	8.0	9.1	9.1
3.7 ≤ E < 3.9	6.9	7.2	8.9	9.5	8.0	9.0	9.0
3.9 ≤ E < 4.1	6.8	7.1	8.8	9.4	7.9	8.9	8.9
4.1 ≤ E < 4.3	6.7	7.0	8.7	9.2	7.8	8.8	8.8
4.3 ≤ E < 4.5	6.7	6.9	8.5	9.1	7.7	8.7	8.7
4.5 ≤ E < 4.7	6.6	6.9	8.5	9.0	7.6	8.6	8.6
4.7 ≤ E < 4.9	6.6	6.8	8.4	8.9	7.6	8.5	8.5
E ≥ 4.9	6.5	6.8	8.3	8.9	7.5	8.5	8.4

Table 5.8.9-5 Loading Table for PWR Fuel – 800 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.9	8.2	10.5	11.4	9.2	10.6	10.6
2.9 ≤ E < 3.1	7.8	8.1	10.2	11.1	9.0	10.4	10.4
3.1 ≤ E < 3.3	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.3 ≤ E < 3.5	7.5	7.8	9.8	10.6	8.7	9.9	9.9
3.5 ≤ E < 3.7	7.3	7.7	9.6	10.4	8.6	9.8	9.8
3.7 ≤ E < 3.9	7.2	7.6	9.5	10.2	8.4	9.6	9.6
3.9 ≤ E < 4.1	7.1	7.5	9.3	10.0	8.3	9.5	9.5
4.1 ≤ E < 4.3	7.0	7.4	9.2	9.9	8.2	9.4	9.3
4.3 ≤ E < 4.5	7.0	7.3	9.1	9.8	8.1	9.2	9.2
4.5 ≤ E < 4.7	6.9	7.2	9.0	9.7	8.0	9.1	9.1
4.7 ≤ E < 4.9	6.8	7.1	8.9	9.6	7.9	9.0	9.0
E ≥ 4.9	6.8	7.0	8.8	9.5	7.9	9.0	8.9

Note: Burnups greater than 45 GWd/MTU have been deleted from this table.

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.7	6.9	8.5	9.0	7.7	8.6	8.6
2.9 ≤ E < 3.1	6.6	6.8	8.3	8.8	7.5	8.4	8.4
3.1 ≤ E < 3.3	6.5	6.7	8.1	8.6	7.4	8.2	8.2
3.3 ≤ E < 3.5	6.4	6.6	8.0	8.5	7.3	8.1	8.1
3.5 ≤ E < 3.7	6.3	6.5	7.8	8.3	7.1	8.0	7.9
3.7 ≤ E < 3.9	6.2	6.4	7.7	8.2	7.0	7.8	7.8
3.9 ≤ E < 4.1	6.1	6.3	7.6	8.0	6.9	7.7	7.7
4.1 ≤ E < 4.3	6.0	6.2	7.5	7.9	6.9	7.7	7.6
4.3 ≤ E < 4.5	6.0	6.2	7.4	7.8	6.8	7.6	7.6
4.5 ≤ E < 4.7	5.9	6.1	7.3	7.8	6.7	7.5	7.5
4.7 ≤ E < 4.9	5.9	6.0	7.2	7.7	6.7	7.4	7.4
E ≥ 4.9	5.8	6.0	7.2	7.6	6.6	7.3	7.3

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.0	7.3	9.0	9.6	8.0	9.1	9.1
2.9 ≤ E < 3.1	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.1 ≤ E < 3.3	6.8	7.0	8.6	9.2	7.8	8.7	8.7
3.3 ≤ E < 3.5	6.7	6.9	8.4	9.0	7.6	8.6	8.6
3.5 ≤ E < 3.7	6.6	6.8	8.3	8.8	7.5	8.4	8.4
3.7 ≤ E < 3.9	6.5	6.7	8.1	8.7	7.4	8.3	8.3
3.9 ≤ E < 4.1	6.4	6.6	8.0	8.5	7.3	8.1	8.1
4.1 ≤ E < 4.3	6.3	6.5	7.9	8.4	7.2	8.0	8.0
4.3 ≤ E < 4.5	6.2	6.5	7.8	8.3	7.1	7.9	7.9
4.5 ≤ E < 4.7	6.1	6.4	7.7	8.2	7.0	7.9	7.8
4.7 ≤ E < 4.9	6.0	6.3	7.6	8.1	6.9	7.8	7.8
E ≥ 4.9	6.0	6.2	7.6	8.0	6.9	7.7	7.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.4	7.7	9.6	10.3	8.6	9.7	9.7
2.9 ≤ E < 3.1	7.2	7.6	9.4	10.0	8.4	9.5	9.5
3.1 ≤ E < 3.3	7.1	7.4	9.1	9.8	8.2	9.3	9.3
3.3 ≤ E < 3.5	7.0	7.2	8.9	9.6	8.0	9.1	9.0
3.5 ≤ E < 3.7	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.7 ≤ E < 3.9	6.7	7.0	8.6	9.2	7.8	8.8	8.7
3.9 ≤ E < 4.1	6.7	6.9	8.5	9.0	7.6	8.6	8.6
4.1 ≤ E < 4.3	6.6	6.8	8.4	8.9	7.6	8.5	8.5
4.3 ≤ E < 4.5	6.5	6.7	8.2	8.8	7.4	8.4	8.4
4.5 ≤ E < 4.7	6.4	6.7	8.1	8.7	7.4	8.3	8.3
4.7 ≤ E < 4.9	6.3	6.6	8.0	8.6	7.3	8.2	8.2
E ≥ 4.9	6.2	6.5	7.9	8.5	7.2	8.1	8.1

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.8	8.1	10.2	11.1	9.0	10.4	10.4
2.9 ≤ E < 3.1	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.1 ≤ E < 3.3	7.5	7.8	9.7	10.5	8.6	9.9	9.8
3.3 ≤ E < 3.5	7.3	7.6	9.5	10.2	8.5	9.7	9.6
3.5 ≤ E < 3.7	7.2	7.5	9.3	10.0	8.3	9.5	9.4
3.7 ≤ E < 3.9	7.0	7.4	9.1	9.8	8.2	9.3	9.3
3.9 ≤ E < 4.1	6.9	7.2	9.0	9.6	8.0	9.1	9.1
4.1 ≤ E < 4.3	6.8	7.1	8.8	9.5	7.9	9.0	9.0
4.3 ≤ E < 4.5	6.8	7.0	8.7	9.3	7.8	8.9	8.9
4.5 ≤ E < 4.7	6.7	6.9	8.6	9.2	7.7	8.8	8.7
4.7 ≤ E < 4.9	6.6	6.9	8.5	9.1	7.6	8.7	8.6
E ≥ 4.9	6.5	6.8	8.4	9.0	7.6	8.6	8.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.0	8.3	10.7	11.6	9.4	10.9	10.9
3.1 ≤ E < 3.3	7.8	8.1	10.4	11.3	9.1	10.6	10.6
3.3 ≤ E < 3.5	7.7	7.9	10.1	11.0	9.0	10.3	10.3
3.5 ≤ E < 3.7	7.5	7.8	9.9	10.8	8.8	10.0	10.0
3.7 ≤ E < 3.9	7.4	7.6	9.7	10.5	8.6	9.9	9.9
3.9 ≤ E < 4.1	7.3	7.5	9.5	10.3	8.5	9.7	9.7
4.1 ≤ E < 4.3	7.1	7.4	9.4	10.1	8.3	9.6	9.5
4.3 ≤ E < 4.5	7.0	7.3	9.2	9.9	8.2	9.4	9.4
4.5 ≤ E < 4.7	6.9	7.2	9.1	9.8	8.1	9.3	9.2
4.7 ≤ E < 4.9	6.9	7.1	9.0	9.6	8.0	9.1	9.1
E ≥ 4.9	6.8	7.0	8.9	9.5	7.9	9.0	9.0

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.3	8.7	11.5	12.3	10.0	11.6	11.6
3.1 ≤ E < 3.3	8.0	8.5	11.2	12.0	9.8	11.3	11.3
3.3 ≤ E < 3.5	7.9	8.3	10.9	11.7	9.5	11.1	11.1
3.5 ≤ E < 3.7	7.8	8.1	10.6	11.5	9.3	10.8	10.8
3.7 ≤ E < 3.9	7.6	8.0	10.4	11.3	9.1	10.6	10.6
3.9 ≤ E < 4.1	7.5	7.9	10.1	11.1	9.0	10.4	10.4
4.1 ≤ E < 4.3	7.4	7.8	10.0	10.9	8.8	10.2	10.1
4.3 ≤ E < 4.5	7.3	7.6	9.8	10.6	8.7	10.0	10.0
4.5 ≤ E < 4.7	7.1	7.5	9.7	10.5	8.6	9.8	9.8
4.7 ≤ E < 4.9	7.0	7.4	9.5	10.3	8.5	9.7	9.7
E ≥ 4.9	7.0	7.3	9.4	10.1	8.3	9.6	9.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.8	9.3	12.2	13.0	10.7	12.4	12.4
3.1 ≤ E < 3.3	8.5	9.0	11.9	12.6	10.4	12.1	12.0
3.3 ≤ E < 3.5	8.3	8.8	11.6	12.3	10.1	11.8	11.8
3.5 ≤ E < 3.7	8.1	8.6	11.4	11.9	9.9	11.6	11.5
3.7 ≤ E < 3.9	8.0	8.5	11.1	11.7	9.7	11.3	11.3
3.9 ≤ E < 4.1	7.9	8.3	10.9	11.5	9.5	11.1	11.1
4.1 ≤ E < 4.3	7.7	8.1	10.7	11.3	9.3	10.9	10.9
4.3 ≤ E < 4.5	7.6	8.0	10.5	11.1	9.2	10.7	10.7
4.5 ≤ E < 4.7	7.5	7.9	10.3	11.0	9.0	10.5	10.5
4.7 ≤ E < 4.9	7.4	7.8	10.1	10.8	8.9	10.3	10.3
E ≥ 4.9	7.3	7.7	10.0	10.6	8.8	10.2	10.2

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.3	9.8	12.8	13.8	11.4	13.3	13.3
3.1 ≤ E < 3.3	9.0	9.6	12.4	13.5	11.2	13.0	13.0
3.3 ≤ E < 3.5	8.8	9.3	12.1	13.2	10.9	12.6	12.6
3.5 ≤ E < 3.7	8.6	9.1	11.8	12.8	10.6	12.3	12.3
3.7 ≤ E < 3.9	8.4	9.0	11.5	12.6	10.3	12.0	12.0
3.9 ≤ E < 4.1	8.2	8.8	11.3	12.3	10.1	11.8	11.8
4.1 ≤ E < 4.3	8.1	8.6	11.1	12.0	9.9	11.6	11.6
4.3 ≤ E < 4.5	8.0	8.5	10.9	11.8	9.7	11.4	11.4
4.5 ≤ E < 4.7	7.9	8.3	10.7	11.7	9.6	11.2	11.2
4.7 ≤ E < 4.9	7.8	8.2	10.6	11.5	9.4	11.1	11.0
E ≥ 4.9	7.7	8.1	10.4	11.3	9.3	10.9	10.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.8	10.5	13.6	14.9	12.2	14.2	14.2
3.1 ≤ E < 3.3	9.6	10.2	13.3	14.4	11.8	13.8	13.8
3.3 ≤ E < 3.5	9.3	9.9	12.9	14.0	11.6	13.5	13.5
3.5 ≤ E < 3.7	9.1	9.7	12.6	13.7	11.3	13.2	13.2
3.7 ≤ E < 3.9	8.9	9.5	12.3	13.4	11.0	12.9	12.9
3.9 ≤ E < 4.1	8.7	9.3	12.0	13.2	10.8	12.6	12.6
4.1 ≤ E < 4.3	8.6	9.1	11.8	12.9	10.6	12.4	12.4
4.3 ≤ E < 4.5	8.4	8.9	11.6	12.6	10.4	12.1	12.1
4.5 ≤ E < 4.7	8.3	8.8	11.4	12.4	10.1	11.9	11.9
4.7 ≤ E < 4.9	8.1	8.7	11.3	12.2	10.0	11.8	11.7
E ≥ 4.9	8.0	8.8	11.1	12.0	9.9	11.6	11.6

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	10.1	10.9	14.1	15.4	12.7	14.8	14.8
3.3 ≤ E < 3.5	9.9	10.6	13.8	15.0	12.3	14.4	14.4
3.5 ≤ E < 3.7	9.6	10.3	13.5	14.7	12.0	14.0	14.0
3.7 ≤ E < 3.9	9.4	10.1	13.1	14.3	11.8	13.8	13.8
3.9 ≤ E < 4.1	9.2	9.8	12.9	14.0	11.5	13.5	13.5
4.1 ≤ E < 4.3	9.0	9.7	12.6	13.8	11.3	13.3	13.2
4.3 ≤ E < 4.5	8.9	9.5	12.3	13.5	11.1	13.0	13.0
4.5 ≤ E < 4.7	8.7	9.3	12.1	13.3	10.9	12.8	12.7
4.7 ≤ E < 4.9	8.6	9.1	11.9	13.1	10.7	12.6	12.5
E ≥ 4.9	8.5	9.0	11.7	12.9	10.5	12.3	12.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	10.9	11.6	15.1	16.5	13.1	15.8	15.8
3.3 ≤ E < 3.5	10.5	11.3	14.7	16.0	12.8	15.4	15.4
3.5 ≤ E < 3.7	10.2	11.0	14.3	15.7	12.4	15.1	15.0
3.7 ≤ E < 3.9	9.9	10.8	14.0	15.3	12.1	14.7	14.7
3.9 ≤ E < 4.1	9.7	10.5	13.7	15.0	11.9	14.4	14.4
4.1 ≤ E < 4.3	9.5	10.2	13.4	14.7	11.7	14.1	14.1
4.3 ≤ E < 4.5	9.3	10.0	13.2	14.5	11.4	13.8	13.8
4.5 ≤ E < 4.7	9.2	9.9	12.9	14.2	11.2	13.6	13.6
4.7 ≤ E < 4.9	9.0	9.7	12.7	13.9	11.1	13.4	13.4
E ≥ 4.9	8.9	9.5	12.5	13.8	10.9	13.2	13.2

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.5	12.3	16.0	17.4	14.0	16.8	16.8
3.3 ≤ E < 3.5	11.2	12.0	15.6	17.1	13.6	16.4	16.4
3.5 ≤ E < 3.7	10.9	11.7	15.3	16.7	13.3	16.0	16.0
3.7 ≤ E < 3.9	10.6	11.4	14.9	16.3	13.0	15.7	15.6
3.9 ≤ E < 4.1	10.3	11.2	14.6	16.0	12.6	15.4	15.3
4.1 ≤ E < 4.3	10.1	10.9	14.2	15.7	12.4	15.1	15.1
4.3 ≤ E < 4.5	9.9	10.7	14.0	15.4	12.1	14.8	14.8
4.5 ≤ E < 4.7	9.7	10.5	13.8	15.2	11.9	14.5	14.5
4.7 ≤ E < 4.9	9.5	10.3	13.6	14.9	11.7	14.2	14.2
E ≥ 4.9	9.4	10.1	13.4	14.7	11.5	14.0	14.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.2	13.2	17.0	18.5	14.9	17.8	17.7
3.3 ≤ E < 3.5	11.9	12.8	16.7	18.1	14.5	17.4	17.4
3.5 ≤ E < 3.7	11.6	12.4	16.2	17.7	14.1	17.0	17.0
3.7 ≤ E < 3.9	11.3	12.1	15.9	17.3	13.8	16.7	16.6
3.9 ≤ E < 4.1	11.0	11.9	15.6	17.0	13.5	16.3	16.3
4.1 ≤ E < 4.3	10.7	11.6	15.3	16.7	13.2	16.0	16.0
4.3 ≤ E < 4.5	10.5	11.4	15.0	16.4	12.9	15.7	15.7
4.5 ≤ E < 4.7	10.3	11.2	14.7	16.1	12.7	15.5	15.4
4.7 ≤ E < 4.9	10.0	10.9	14.4	15.8	12.4	15.2	15.2
E ≥ 4.9	9.9	10.8	14.2	15.6	12.2	15.0	14.9

Table 5.8.9-6 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	13.0	14.0	18.0	19.5	15.8	18.8	18.8
3.3 ≤ E < 3.5	12.6	13.6	17.6	19.1	15.4	18.4	18.4
3.5 ≤ E < 3.7	12.2	13.3	17.2	18.7	15.0	18.0	18.0
3.7 ≤ E < 3.9	11.9	12.9	16.9	18.3	14.6	17.7	17.7
3.9 ≤ E < 4.1	11.6	12.6	16.5	18.0	14.3	17.4	17.3
4.1 ≤ E < 4.3	11.4	12.3	16.2	17.7	14.0	17.0	17.0
4.3 ≤ E < 4.5	11.1	12.0	15.9	17.4	13.7	16.7	16.7
4.5 ≤ E < 4.7	10.9	11.8	15.6	17.1	13.5	16.4	16.4
4.7 ≤ E < 4.9	10.7	11.6	15.4	16.8	13.2	16.1	16.1
E ≥ 4.9	10.5	11.4	15.1	16.6	13.0	15.9	15.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	13.4	14.4	18.6	20.1	16.3	19.0	19.0
3.5 ≤ E < 3.7	13.0	14.1	18.2	19.7	15.9	18.6	18.5
3.7 ≤ E < 3.9	12.7	13.7	17.8	19.4	15.5	18.2	18.1
3.9 ≤ E < 4.1	12.3	13.4	17.5	19.0	15.2	17.9	17.8
4.1 ≤ E < 4.3	12.0	13.1	17.1	18.7	14.9	17.5	17.5
4.3 ≤ E < 4.5	11.8	12.8	16.8	18.4	14.6	17.2	17.2
4.5 ≤ E < 4.7	11.6	12.6	16.5	18.0	14.3	16.9	16.9
4.7 ≤ E < 4.9	11.3	12.3	16.2	17.8	14.0	16.6	16.6
E ≥ 4.9	11.2	12.1	16.0	17.6	13.8	16.4	16.3

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.0	5.2	6.0	6.2	5.6	6.0	6.0
2.9 ≤ E < 3.1	5.0	5.1	5.9	6.0	5.5	6.0	6.0
3.1 ≤ E < 3.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.3 ≤ E < 3.5	4.8	4.9	5.7	5.9	5.4	5.8	5.8
3.5 ≤ E < 3.7	4.8	4.9	5.6	5.8	5.3	5.7	5.7
3.7 ≤ E < 3.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7
3.9 ≤ E < 4.1	4.6	4.8	5.5	5.7	5.1	5.6	5.6
4.1 ≤ E < 4.3	4.6	4.7	5.4	5.6	5.1	5.5	5.6
4.3 ≤ E < 4.5	4.5	4.6	5.4	5.6	5.0	5.5	5.5
4.5 ≤ E < 4.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
4.7 ≤ E < 4.9	4.4	4.6	5.3	5.5	4.9	5.4	5.4
E ≥ 4.9	4.4	4.5	5.2	5.4	4.9	5.4	5.3

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.2	5.4	6.2	6.5	5.8	6.3	6.3
2.9 ≤ E < 3.1	5.1	5.3	6.1	6.4	5.7	6.2	6.2
3.1 ≤ E < 3.3	5.0	5.2	6.0	6.2	5.6	6.1	6.1
3.3 ≤ E < 3.5	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.5 ≤ E < 3.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.8	5.0	5.8	6.0	5.4	5.9	5.9
3.9 ≤ E < 4.1	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.1 ≤ E < 4.3	4.7	4.8	5.6	5.8	5.3	5.8	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.5 ≤ E < 4.7	4.6	4.7	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.5	4.7	5.4	5.6	5.0	5.5	5.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
2.9 ≤ E < 3.1	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.1 ≤ E < 3.3	5.2	5.4	6.2	6.5	5.8	6.4	6.4
3.3 ≤ E < 3.5	5.1	5.3	6.1	6.4	5.8	6.2	6.2
3.5 ≤ E < 3.7	5.0	5.2	6.0	6.3	5.7	6.2	6.1
3.7 ≤ E < 3.9	5.0	5.1	5.9	6.2	5.6	6.0	6.0
3.9 ≤ E < 4.1	4.9	5.0	5.9	6.1	5.5	6.0	6.0
4.1 ≤ E < 4.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.3 ≤ E < 4.5	4.8	4.9	5.8	6.0	5.4	5.9	5.9
4.5 ≤ E < 4.7	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.7 ≤ E < 4.9	4.7	4.9	5.7	5.8	5.3	5.8	5.8
E ≥ 4.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.6	5.8	6.8	7.0	6.3	6.9	6.9
2.9 ≤ E < 3.1	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.1 ≤ E < 3.3	5.4	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.3	5.5	6.4	6.7	5.9	6.5	6.5
3.5 ≤ E < 3.7	5.2	5.4	6.3	6.6	5.9	6.4	6.4
3.7 ≤ E < 3.9	5.2	5.3	6.2	6.5	5.8	6.3	6.3
3.9 ≤ E < 4.1	5.1	5.2	6.1	6.4	5.7	6.2	6.2
4.1 ≤ E < 4.3	5.0	5.2	6.0	6.3	5.7	6.1	6.1
4.3 ≤ E < 4.5	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.5 ≤ E < 4.7	4.9	5.0	5.9	6.1	5.5	6.0	6.0
4.7 ≤ E < 4.9	4.8	5.0	5.8	6.0	5.5	5.9	5.9
E ≥ 4.9	4.8	4.9	5.8	6.0	5.4	5.9	5.9
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	5.7	5.8	6.9	7.3	6.4	7.0	7.0
3.1 ≤ E < 3.3	5.6	5.7	6.8	7.1	6.3	6.9	6.9
3.3 ≤ E < 3.5	5.5	5.6	6.7	7.0	6.2	6.8	6.8
3.5 ≤ E < 3.7	5.4	5.5	6.6	6.9	6.0	6.7	6.7
3.7 ≤ E < 3.9	5.4	5.5	6.5	6.8	6.0	6.6	6.6
3.9 ≤ E < 4.1	5.3	5.4	6.4	6.7	5.9	6.5	6.5
4.1 ≤ E < 4.3	5.2	5.3	6.3	6.6	5.8	6.4	6.4
4.3 ≤ E < 4.5	5.1	5.2	6.2	6.5	5.8	6.3	6.3
4.5 ≤ E < 4.7	5.0	5.2	6.1	6.4	5.7	6.2	6.2
4.7 ≤ E < 4.9	5.0	5.1	6.0	6.3	5.7	6.2	6.2
E ≥ 4.9	4.9	5.0	6.0	6.2	5.6	6.1	6.1

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	5.8	6.0	7.3	7.6	6.7	7.4	7.4
3.1 ≤ E < 3.3	5.8	5.9	7.1	7.5	6.6	7.2	7.2
3.3 ≤ E < 3.5	5.7	5.8	7.0	7.3	6.4	7.1	7.0
3.5 ≤ E < 3.7	5.6	5.7	6.8	7.2	6.3	6.9	6.9
3.7 ≤ E < 3.9	5.5	5.7	6.7	7.0	6.2	6.9	6.8
3.9 ≤ E < 4.1	5.4	5.6	6.6	6.9	6.1	6.8	6.8
4.1 ≤ E < 4.3	5.3	5.5	6.5	6.8	6.0	6.7	6.7
4.3 ≤ E < 4.5	5.2	5.4	6.4	6.8	6.0	6.6	6.6
4.5 ≤ E < 4.7	5.2	5.4	6.4	6.7	5.9	6.5	6.5
4.7 ≤ E < 4.9	5.1	5.3	6.3	6.6	5.8	6.4	6.4
E ≥ 4.9	5.0	5.2	6.2	6.5	5.8	6.4	6.3
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.0	6.3	7.6	7.9	6.9	7.7	7.7
3.1 ≤ E < 3.3	5.9	6.1	7.5	7.7	6.8	7.6	7.6
3.3 ≤ E < 3.5	5.8	6.0	7.3	7.6	6.7	7.4	7.4
3.5 ≤ E < 3.7	5.8	5.9	7.1	7.4	6.6	7.3	7.3
3.7 ≤ E < 3.9	5.7	5.9	7.0	7.3	6.5	7.1	7.1
3.9 ≤ E < 4.1	5.6	5.8	6.9	7.1	6.4	7.0	7.0
4.1 ≤ E < 4.3	5.5	5.7	6.8	7.0	6.3	6.9	6.9
4.3 ≤ E < 4.5	5.4	5.6	6.7	6.9	6.2	6.8	6.8
4.5 ≤ E < 4.7	5.4	5.6	6.6	6.8	6.1	6.8	6.8
4.7 ≤ E < 4.9	5.3	5.5	6.5	6.8	6.0	6.7	6.7
E ≥ 4.9	5.2	5.4	6.5	6.7	6.0	6.6	6.6

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.3	6.5	7.9	8.3	7.3	8.1	8.1
3.1 ≤ E < 3.3	6.2	6.4	7.7	8.1	7.1	7.9	7.9
3.3 ≤ E < 3.5	6.0	6.3	7.5	7.9	7.0	7.8	7.8
3.5 ≤ E < 3.7	5.9	6.1	7.4	7.8	6.9	7.6	7.6
3.7 ≤ E < 3.9	5.8	6.1	7.2	7.6	6.7	7.5	7.5
3.9 ≤ E < 4.1	5.8	6.0	7.1	7.5	6.6	7.4	7.3
4.1 ≤ E < 4.3	5.7	5.9	7.0	7.4	6.5	7.2	7.2
4.3 ≤ E < 4.5	5.6	5.8	6.9	7.2	6.4	7.1	7.1
4.5 ≤ E < 4.7	5.5	5.7	6.8	7.1	6.4	7.0	7.0
4.7 ≤ E < 4.9	5.5	5.7	6.7	7.0	6.3	6.9	6.9
E ≥ 4.9	5.4	5.6	6.6	6.9	6.2	6.9	6.9
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.6	6.8	8.3	8.8	7.6	8.6	8.6
3.1 ≤ E < 3.3	6.4	6.7	8.0	8.6	7.5	8.3	8.3
3.3 ≤ E < 3.5	6.3	6.5	7.9	8.3	7.3	8.2	8.1
3.5 ≤ E < 3.7	6.1	6.4	7.7	8.1	7.1	8.0	8.0
3.7 ≤ E < 3.9	6.0	6.3	7.6	8.0	7.0	7.9	7.8
3.9 ≤ E < 4.1	5.9	6.2	7.4	7.8	6.9	7.7	7.7
4.1 ≤ E < 4.3	5.9	6.1	7.3	7.7	6.8	7.6	7.6
4.3 ≤ E < 4.5	5.8	6.0	7.2	7.6	6.7	7.5	7.5
4.5 ≤ E < 4.7	5.7	5.9	7.0	7.5	6.6	7.4	7.3
4.7 ≤ E < 4.9	5.7	5.9	7.0	7.4	6.5	7.2	7.2
E ≥ 4.9	5.6	5.9	6.9	7.3	6.4	7.1	7.1

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	6.7	6.9	8.5	9.0	7.8	8.8	8.8
3.3 ≤ E < 3.5	6.6	6.8	8.3	8.8	7.6	8.6	8.6
3.5 ≤ E < 3.7	6.4	6.7	8.1	8.6	7.5	8.4	8.4
3.7 ≤ E < 3.9	6.3	6.6	7.9	8.4	7.3	8.2	8.2
3.9 ≤ E < 4.1	6.2	6.5	7.8	8.2	7.2	8.0	8.0
4.1 ≤ E < 4.3	6.1	6.3	7.6	8.1	7.0	7.9	7.9
4.3 ≤ E < 4.5	6.0	6.2	7.5	7.9	7.0	7.8	7.8
4.5 ≤ E < 4.7	5.9	6.1	7.4	7.8	6.9	7.7	7.7
4.7 ≤ E < 4.9	5.9	6.0	7.3	7.7	6.8	7.6	7.6
E ≥ 4.9	5.8	6.0	7.2	7.6	6.7	7.5	7.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	6.9	7.3	8.9	9.6	8.0	9.3	9.3
3.3 ≤ E < 3.5	6.8	7.1	8.7	9.3	7.8	9.0	9.0
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.1	7.7	8.8	8.9
3.7 ≤ E < 3.9	6.6	6.8	8.3	8.9	7.5	8.7	8.7
3.9 ≤ E < 4.1	6.4	6.7	8.1	8.7	7.4	8.5	8.5
4.1 ≤ E < 4.3	6.3	6.6	8.0	8.5	7.2	8.3	8.3
4.3 ≤ E < 4.5	6.2	6.5	7.9	8.4	7.1	8.2	8.1
4.5 ≤ E < 4.7	6.1	6.4	7.7	8.2	7.0	8.0	8.0
4.7 ≤ E < 4.9	6.0	6.3	7.6	8.1	6.9	7.9	7.9
E ≥ 4.9	6.0	6.2	7.5	8.0	6.8	7.8	7.8

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.3	7.6	9.4	10.1	8.4	9.8	9.8
3.3 ≤ E < 3.5	7.1	7.4	9.2	9.9	8.2	9.6	9.6
3.5 ≤ E < 3.7	6.9	7.3	9.0	9.6	8.0	9.4	9.3
3.7 ≤ E < 3.9	6.8	7.1	8.8	9.4	7.9	9.1	9.1
3.9 ≤ E < 4.1	6.7	7.0	8.6	9.2	7.7	8.9	8.9
4.1 ≤ E < 4.3	6.6	6.9	8.4	9.0	7.6	8.8	8.8
4.3 ≤ E < 4.5	6.5	6.8	8.2	8.8	7.5	8.6	8.6
4.5 ≤ E < 4.7	6.4	6.7	8.1	8.7	7.3	8.5	8.4
4.7 ≤ E < 4.9	6.3	6.6	8.0	8.5	7.2	8.3	8.3
E ≥ 4.9	6.2	6.5	7.8	8.4	7.1	8.2	8.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.6	8.0	10.0	10.8	8.9	10.5	10.4
3.3 ≤ E < 3.5	7.4	7.8	9.7	10.5	8.7	10.2	10.1
3.5 ≤ E < 3.7	7.2	7.6	9.5	10.2	8.4	9.9	9.9
3.7 ≤ E < 3.9	7.1	7.5	9.3	9.9	8.2	9.7	9.6
3.9 ≤ E < 4.1	6.9	7.3	9.0	9.7	8.1	9.5	9.4
4.1 ≤ E < 4.3	6.8	7.1	8.8	9.5	7.9	9.2	9.2
4.3 ≤ E < 4.5	6.7	7.0	8.7	9.3	7.8	9.0	9.0
4.5 ≤ E < 4.7	6.6	6.9	8.5	9.1	7.7	8.9	8.9
4.7 ≤ E < 4.9	6.5	6.8	8.4	8.9	7.5	8.7	8.7
E ≥ 4.9	6.4	6.7	8.2	8.8	7.4	8.6	8.6

Table 5.8.9-7 Loading Table for PWR Fuel – 1,140 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.9	8.4	10.7	11.5	9.4	11.1	11.1
3.3 ≤ E < 3.5	7.8	8.2	10.3	11.2	9.1	10.8	10.8
3.5 ≤ E < 3.7	7.6	8.0	10.0	10.9	8.9	10.5	10.5
3.7 ≤ E < 3.9	7.4	7.8	9.8	10.6	8.7	10.2	10.2
3.9 ≤ E < 4.1	7.2	7.6	9.5	10.3	8.5	10.0	9.9
4.1 ≤ E < 4.3	7.1	7.5	9.3	10.0	8.3	9.8	9.7
4.3 ≤ E < 4.5	7.0	7.3	9.1	9.8	8.1	9.6	9.5
4.5 ≤ E < 4.7	6.9	7.2	8.9	9.6	8.0	9.4	9.4
4.7 ≤ E < 4.9	6.8	7.1	8.8	9.5	7.9	9.2	9.2
E ≥ 4.9	6.7	7.0	8.7	9.3	7.8	9.0	9.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	8.1	8.6	11.0	11.8	9.6	11.2	11.2
3.5 ≤ E < 3.7	7.9	8.4	10.7	11.5	9.4	10.9	10.8
3.7 ≤ E < 3.9	7.7	8.2	10.3	11.2	9.1	10.6	10.5
3.9 ≤ E < 4.1	7.6	8.0	10.1	11.0	8.9	10.3	10.3
4.1 ≤ E < 4.3	7.4	7.8	9.8	10.7	8.7	10.0	10.0
4.3 ≤ E < 4.5	7.3	7.7	9.6	10.4	8.5	9.8	9.8
4.5 ≤ E < 4.7	7.1	7.6	9.4	10.2	8.4	9.7	9.6
4.7 ≤ E < 4.9	7.0	7.4	9.2	10.0	8.2	9.5	9.4
E ≥ 4.9	6.9	7.3	9.1	9.8	8.1	9.3	9.3

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.1	7.4	9.2	9.8	8.2	9.3	9.3
2.9 ≤ E < 3.1	7.0	7.3	9.0	9.6	8.0	9.1	9.0
3.1 ≤ E < 3.3	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.3 ≤ E < 3.5	6.8	7.0	8.6	9.1	7.8	8.7	8.7
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.0	7.6	8.6	8.6
3.7 ≤ E < 3.9	6.6	6.8	8.3	8.9	7.5	8.5	8.4
3.9 ≤ E < 4.1	6.5	6.7	8.2	8.7	7.4	8.3	8.3
4.1 ≤ E < 4.3	6.4	6.6	8.1	8.6	7.3	8.2	8.2
4.3 ≤ E < 4.5	6.3	6.6	8.0	8.5	7.2	8.1	8.1
4.5 ≤ E < 4.7	6.2	6.5	7.9	8.4	7.2	8.0	8.0
4.7 ≤ E < 4.9	6.2	6.4	7.8	8.3	7.1	8.0	7.9
E ≥ 4.9	6.1	6.4	7.7	8.2	7.0	7.9	7.9

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.5	7.8	9.8	10.5	8.7	9.9	9.9
2.9 ≤ E < 3.1	7.4	7.7	9.6	10.3	8.5	9.7	9.7
3.1 ≤ E < 3.3	7.2	7.5	9.3	10.0	8.3	9.5	9.5
3.3 ≤ E < 3.5	7.1	7.4	9.1	9.8	8.1	9.3	9.3
3.5 ≤ E < 3.7	7.0	7.2	9.0	9.6	8.0	9.1	9.1
3.7 ≤ E < 3.9	6.9	7.1	8.8	9.4	7.9	9.0	8.9
3.9 ≤ E < 4.1	6.8	7.0	8.7	9.3	7.8	8.8	8.8
4.1 ≤ E < 4.3	6.7	6.9	8.6	9.1	7.7	8.7	8.7
4.3 ≤ E < 4.5	6.6	6.9	8.4	9.0	7.6	8.6	8.6
4.5 ≤ E < 4.7	6.5	6.8	8.3	8.9	7.5	8.5	8.5
4.7 ≤ E < 4.9	6.5	6.7	8.2	8.8	7.5	8.4	8.4
E ≥ 4.9	6.4	6.7	8.1	8.7	7.4	8.3	8.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.9	8.3	10.5	11.3	9.2	10.7	10.6
2.9 ≤ E < 3.1	7.7	8.1	10.2	11.1	9.0	10.4	10.3
3.1 ≤ E < 3.3	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.3 ≤ E < 3.5	7.4	7.8	9.7	10.5	8.7	9.9	9.9
3.5 ≤ E < 3.7	7.3	7.6	9.6	10.3	8.5	9.7	9.7
3.7 ≤ E < 3.9	7.2	7.5	9.4	10.1	8.4	9.5	9.5
3.9 ≤ E < 4.1	7.0	7.4	9.2	9.9	8.2	9.4	9.4
4.1 ≤ E < 4.3	7.0	7.3	9.0	9.7	8.1	9.2	9.2
4.3 ≤ E < 4.5	6.9	7.2	8.9	9.6	8.0	9.1	9.1
4.5 ≤ E < 4.7	6.8	7.1	8.8	9.5	7.9	9.0	9.0
4.7 ≤ E < 4.9	6.7	7.0	8.7	9.4	7.8	8.9	8.9
E ≥ 4.9	6.7	6.9	8.6	9.2	7.7	8.8	8.8

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	8.4	8.8	11.3	12.1	9.9	11.4	11.4
2.9 ≤ E < 3.1	8.2	8.6	11.0	11.8	9.6	11.1	11.1
3.1 ≤ E < 3.3	8.0	8.4	10.7	11.6	9.4	10.9	10.8
3.3 ≤ E < 3.5	7.8	8.2	10.4	11.3	9.2	10.6	10.6
3.5 ≤ E < 3.7	7.7	8.0	10.2	11.1	9.0	10.4	10.4
3.7 ≤ E < 3.9	7.6	7.9	10.0	10.8	8.8	10.2	10.1
3.9 ≤ E < 4.1	7.4	7.8	9.8	10.6	8.7	10.0	9.9
4.1 ≤ E < 4.3	7.3	7.7	9.7	10.4	8.6	9.8	9.8
4.3 ≤ E < 4.5	7.2	7.6	9.5	10.3	8.4	9.7	9.7
4.5 ≤ E < 4.7	7.1	7.5	9.4	10.1	8.3	9.6	9.5
4.7 ≤ E < 4.9	7.0	7.4	9.2	10.0	8.2	9.4	9.4
E ≥ 4.9	6.9	7.3	9.1	9.8	8.1	9.3	9.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.7	8.9	11.8	12.7	10.2	11.9	11.9
3.1 ≤ E < 3.3	8.4	8.7	11.5	12.4	10.0	11.7	11.6
3.3 ≤ E < 3.5	8.2	8.5	11.2	12.1	9.8	11.4	11.4
3.5 ≤ E < 3.7	8.1	8.4	11.0	11.8	9.6	11.2	11.1
3.7 ≤ E < 3.9	7.9	8.2	10.7	11.6	9.4	10.9	10.9
3.9 ≤ E < 4.1	7.8	8.0	10.5	11.4	9.2	10.7	10.7
4.1 ≤ E < 4.3	7.7	7.9	10.3	11.2	9.0	10.5	10.5
4.3 ≤ E < 4.5	7.6	7.8	10.1	11.0	8.9	10.4	10.3
4.5 ≤ E < 4.7	7.5	7.7	9.9	10.9	8.8	10.2	10.1
4.7 ≤ E < 4.9	7.4	7.6	9.8	10.7	8.7	10.0	10.0
E ≥ 4.9	7.3	7.6	9.7	10.5	8.6	9.9	9.9

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.9	9.5	12.6	13.7	11.0	12.8	12.8
3.1 ≤ E < 3.3	8.7	9.3	12.2	13.3	10.7	12.5	12.4
3.3 ≤ E < 3.5	8.5	9.0	11.9	13.0	10.5	12.1	12.1
3.5 ≤ E < 3.7	8.4	8.8	11.7	12.7	10.2	11.9	11.9
3.7 ≤ E < 3.9	8.2	8.7	11.5	12.4	10.0	11.7	11.6
3.9 ≤ E < 4.1	8.0	8.5	11.2	12.2	9.8	11.5	11.4
4.1 ≤ E < 4.3	7.9	8.4	11.0	11.9	9.6	11.3	11.2
4.3 ≤ E < 4.5	7.8	8.2	10.9	11.8	9.5	11.1	11.0
4.5 ≤ E < 4.7	7.7	8.1	10.7	11.6	9.3	10.9	10.9
4.7 ≤ E < 4.9	7.6	8.0	10.5	11.4	9.2	10.8	10.7
E ≥ 4.9	7.5	7.9	10.4	11.3	9.1	10.6	10.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.5	10.1	13.5	14.3	11.7	13.7	13.7
3.1 ≤ E < 3.3	9.2	9.8	13.2	13.9	11.5	13.4	13.4
3.3 ≤ E < 3.5	9.0	9.6	12.8	13.6	11.2	13.1	13.0
3.5 ≤ E < 3.7	8.8	9.4	12.5	13.3	10.9	12.8	12.7
3.7 ≤ E < 3.9	8.7	9.2	12.2	13.0	10.7	12.5	12.4
3.9 ≤ E < 4.1	8.5	9.0	12.0	12.8	10.4	12.2	12.2
4.1 ≤ E < 4.3	8.3	8.9	11.8	12.5	10.2	12.0	11.9
4.3 ≤ E < 4.5	8.2	8.7	11.6	12.3	10.0	11.8	11.8
4.5 ≤ E < 4.7	8.1	8.6	11.4	12.1	9.9	11.6	11.6
4.7 ≤ E < 4.9	8.0	8.5	11.2	11.9	9.8	11.5	11.5
E ≥ 4.9	7.9	8.3	11.1	11.8	9.6	11.3	11.3

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.1	10.9	14.0	15.3	12.6	14.7	14.7
3.1 ≤ E < 3.3	9.8	10.5	13.7	14.9	12.2	14.3	14.3
3.3 ≤ E < 3.5	9.6	10.2	13.4	14.6	11.9	14.0	13.9
3.5 ≤ E < 3.7	9.3	10.0	13.1	14.2	11.6	13.7	13.6
3.7 ≤ E < 3.9	9.1	9.9	12.8	13.9	11.4	13.4	13.3
3.9 ≤ E < 4.1	8.9	9.6	12.5	13.7	11.2	13.1	13.1
4.1 ≤ E < 4.3	8.8	9.4	12.2	13.4	11.0	12.9	12.8
4.3 ≤ E < 4.5	8.7	9.2	12.0	13.2	10.8	12.6	12.6
4.5 ≤ E < 4.7	8.5	9.0	11.8	13.0	10.6	12.4	12.4
4.7 ≤ E < 4.9	8.4	8.9	11.7	12.8	10.4	12.2	12.2
E ≥ 4.9	8.3	8.8	11.5	12.6	10.2	12.0	12.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.8	11.6	15.1	16.4	13.5	15.7	15.6
3.1 ≤ E < 3.3	10.5	11.3	14.6	15.9	13.1	15.3	15.3
3.3 ≤ E < 3.5	10.1	11.0	14.2	15.6	12.7	14.9	14.9
3.5 ≤ E < 3.7	9.9	10.7	13.9	15.2	12.4	14.6	14.6
3.7 ≤ E < 3.9	9.7	10.4	13.6	14.9	12.1	14.3	14.2
3.9 ≤ E < 4.1	9.5	10.2	13.4	14.6	11.9	14.0	14.0
4.1 ≤ E < 4.3	9.3	9.9	13.1	14.3	11.7	13.7	13.7
4.3 ≤ E < 4.5	9.1	9.8	12.9	14.0	11.5	13.5	13.5
4.5 ≤ E < 4.7	9.0	9.6	12.6	13.8	11.3	13.3	13.3
4.7 ≤ E < 4.9	8.8	9.5	12.4	13.6	11.1	13.1	13.1
E ≥ 4.9	8.7	9.6	12.2	13.4	10.9	12.9	12.9

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.2	12.0	15.6	17.0	13.9	16.3	16.3
3.3 ≤ E < 3.5	10.9	11.7	15.2	16.6	13.6	15.9	15.9
3.5 ≤ E < 3.7	10.6	11.4	14.9	16.2	13.3	15.6	15.6
3.7 ≤ E < 3.9	10.3	11.2	14.5	15.9	13.0	15.3	15.3
3.9 ≤ E < 4.1	10.0	10.9	14.2	15.6	12.7	15.0	14.9
4.1 ≤ E < 4.3	9.9	10.7	13.9	15.3	12.4	14.7	14.6
4.3 ≤ E < 4.5	9.7	10.5	13.7	15.1	12.2	14.4	14.4
4.5 ≤ E < 4.7	9.5	10.2	13.5	14.8	12.0	14.1	14.1
4.7 ≤ E < 4.9	9.3	10.0	13.3	14.6	11.8	13.9	13.9
E ≥ 4.9	9.2	9.9	13.1	14.3	11.6	13.8	13.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.9	12.8	16.6	18.1	14.5	17.4	17.3
3.3 ≤ E < 3.5	11.5	12.5	16.2	17.6	14.1	17.0	16.9
3.5 ≤ E < 3.7	11.3	12.1	15.8	17.3	13.7	16.6	16.6
3.7 ≤ E < 3.9	11.0	11.8	15.5	17.0	13.4	16.3	16.2
3.9 ≤ E < 4.1	10.7	11.6	15.2	16.6	13.2	15.9	15.9
4.1 ≤ E < 4.3	10.5	11.3	14.9	16.3	12.9	15.7	15.6
4.3 ≤ E < 4.5	10.2	11.1	14.6	16.0	12.6	15.4	15.3
4.5 ≤ E < 4.7	10.0	10.9	14.3	15.8	12.4	15.2	15.1
4.7 ≤ E < 4.9	9.9	10.7	14.1	15.6	12.2	14.9	14.9
E ≥ 4.9	9.7	10.5	13.9	15.3	12.0	14.7	14.6

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.6	13.6	17.6	19.1	15.5	18.4	18.4
3.3 ≤ E < 3.5	12.3	13.3	17.2	18.7	15.0	18.0	18.0
3.5 ≤ E < 3.7	11.9	13.0	16.8	18.4	14.6	17.7	17.6
3.7 ≤ E < 3.9	11.7	12.6	16.5	18.0	14.3	17.3	17.3
3.9 ≤ E < 4.1	11.4	12.3	16.1	17.7	14.0	17.0	17.0
4.1 ≤ E < 4.3	11.2	12.0	15.8	17.4	13.7	16.7	16.7
4.3 ≤ E < 4.5	10.9	11.8	15.5	17.1	13.5	16.4	16.4
4.5 ≤ E < 4.7	10.7	11.6	15.3	16.8	13.2	16.1	16.1
4.7 ≤ E < 4.9	10.5	11.4	15.1	16.6	13.0	15.8	15.8
E ≥ 4.9	10.3	11.2	14.8	16.3	12.8	15.7	15.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	13.5	14.5	18.7	20.1	16.4	19.5	19.4
3.3 ≤ E < 3.5	13.1	14.1	18.3	19.8	15.9	19.1	19.0
3.5 ≤ E < 3.7	12.7	13.8	17.9	19.4	15.6	18.7	18.7
3.7 ≤ E < 3.9	12.4	13.4	17.5	19.0	15.3	18.4	18.3
3.9 ≤ E < 4.1	12.1	13.1	17.2	18.7	14.9	18.0	18.0
4.1 ≤ E < 4.3	11.8	12.9	16.9	18.4	14.6	17.7	17.7
4.3 ≤ E < 4.5	11.6	12.6	16.5	18.1	14.3	17.4	17.4
4.5 ≤ E < 4.7	11.4	12.3	16.3	17.8	14.0	17.2	17.1
4.7 ≤ E < 4.9	11.1	12.1	16.0	17.5	13.8	16.9	16.8
E ≥ 4.9	11.0	11.9	15.8	17.3	13.6	16.7	16.6

Table 5.8.9-8 Loading Table for PWR Fuel – 876 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	14.3	15.4	19.7	21.2	17.4	20.5	20.5
3.3 ≤ E < 3.5	13.9	15.0	19.3	20.8	16.9	20.1	20.1
3.5 ≤ E < 3.7	13.5	14.7	18.9	20.4	16.6	19.8	19.7
3.7 ≤ E < 3.9	13.2	14.3	18.5	20.1	16.1	19.4	19.4
3.9 ≤ E < 4.1	12.9	14.0	18.2	19.7	15.8	19.1	19.0
4.1 ≤ E < 4.3	12.6	13.7	17.8	19.4	15.5	18.8	18.7
4.3 ≤ E < 4.5	12.2	13.4	17.6	19.1	15.2	18.4	18.4
4.5 ≤ E < 4.7	12.0	13.1	17.3	18.9	14.9	18.2	18.1
4.7 ≤ E < 4.9	11.8	12.9	17.0	18.6	14.7	17.9	17.8
E ≥ 4.9	11.6	12.7	16.8	18.4	14.5	17.6	17.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	14.7	15.9	20.2	21.9	17.9	20.7	20.6
3.5 ≤ E < 3.7	14.3	15.6	19.9	21.5	17.5	20.3	20.2
3.7 ≤ E < 3.9	13.9	15.2	19.5	21.1	17.1	19.9	19.9
3.9 ≤ E < 4.1	13.6	14.9	19.2	20.8	16.8	19.6	19.5
4.1 ≤ E < 4.3	13.3	14.5	18.8	20.5	16.4	19.3	19.2
4.3 ≤ E < 4.5	13.1	14.2	18.5	20.2	16.1	18.9	18.9
4.5 ≤ E < 4.7	12.8	13.9	18.2	19.9	15.8	18.7	18.6
4.7 ≤ E < 4.9	12.5	13.7	18.0	19.6	15.6	18.4	18.3
E ≥ 4.9	12.3	13.5	17.7	19.4	15.4	18.2	18.1

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.2	9.8	12.8	13.9	11.2	13.0	13.0
2.9 ≤ E < 3.1	9.0	9.6	12.5	13.6	10.9	12.7	12.7
3.1 ≤ E < 3.3	8.9	9.4	12.1	13.3	10.6	12.4	12.4
3.3 ≤ E < 3.5	8.7	9.1	11.9	13.0	10.4	12.1	12.1
3.5 ≤ E < 3.7	8.6	9.0	11.8	12.8	10.2	11.9	11.9
3.7 ≤ E < 3.9	8.4	8.8	11.6	12.5	10.0	11.8	11.7
3.9 ≤ E < 4.1	8.3	8.7	11.4	12.3	9.9	11.6	11.5
4.1 ≤ E < 4.3	8.1	8.6	11.2	12.2	9.7	11.4	11.4
4.3 ≤ E < 4.5	8.0	8.5	11.1	12.0	9.6	11.3	11.3
4.5 ≤ E < 4.7	7.9	8.4	10.9	11.9	9.5	11.2	11.1
4.7 ≤ E < 4.9	7.9	8.3	10.8	11.7	9.4	11.0	11.0
E ≥ 4.9	7.8	8.2	10.7	11.6	9.3	10.9	10.9

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.9	10.6	13.8	15.0	12.0	13.9	13.9
2.9 ≤ E < 3.1	9.7	10.3	13.5	14.7	11.7	13.7	13.7
3.1 ≤ E < 3.3	9.4	10.0	13.2	14.4	11.4	13.4	13.4
3.3 ≤ E < 3.5	9.2	9.8	12.9	14.0	11.2	13.1	13.1
3.5 ≤ E < 3.7	9.0	9.6	12.7	13.8	11.0	12.9	12.8
3.7 ≤ E < 3.9	8.9	9.4	12.4	13.6	10.8	12.6	12.6
3.9 ≤ E < 4.1	8.8	9.3	12.2	13.4	10.6	12.5	12.4
4.1 ≤ E < 4.3	8.6	9.1	12.0	13.2	10.4	12.2	12.2
4.3 ≤ E < 4.5	8.5	9.0	11.8	13.0	10.3	12.1	12.0
4.5 ≤ E < 4.7	8.4	8.9	11.7	12.8	10.1	11.9	11.9
4.7 ≤ E < 4.9	8.3	8.8	11.6	12.7	10.0	11.8	11.8
E ≥ 4.9	8.2	8.7	11.5	12.5	9.9	11.7	11.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	10.6	11.4	14.9	16.1	12.9	15.1	15.1
2.9 ≤ E < 3.1	10.4	11.1	14.5	15.8	12.5	14.7	14.7
3.1 ≤ E < 3.3	10.0	10.8	14.1	15.5	12.2	14.4	14.4
3.3 ≤ E < 3.5	9.9	10.5	13.9	15.2	12.0	14.1	14.0
3.5 ≤ E < 3.7	9.6	10.3	13.6	14.9	11.8	13.8	13.8
3.7 ≤ E < 3.9	9.5	10.1	13.4	14.6	11.6	13.6	13.6
3.9 ≤ E < 4.1	9.3	9.9	13.2	14.4	11.4	13.4	13.4
4.1 ≤ E < 4.3	9.1	9.8	13.0	14.1	11.2	13.2	13.2
4.3 ≤ E < 4.5	9.0	9.6	12.8	14.0	11.1	13.0	13.0
4.5 ≤ E < 4.7	8.9	9.5	12.6	13.8	10.9	12.9	12.8
4.7 ≤ E < 4.9	8.8	9.3	12.4	13.6	10.8	12.7	12.7
E ≥ 4.9	8.7	9.2	12.3	13.5	10.7	12.5	12.5

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	11.4	12.2	16.0	17.3	13.9	16.2	16.2
2.9 ≤ E < 3.1	11.1	11.8	15.6	17.0	13.5	15.8	15.8
3.1 ≤ E < 3.3	10.8	11.6	15.3	16.6	13.2	15.5	15.5
3.3 ≤ E < 3.5	10.6	11.3	14.9	16.3	12.9	15.2	15.2
3.5 ≤ E < 3.7	10.3	11.1	14.7	16.0	12.7	14.9	14.9
3.7 ≤ E < 3.9	10.1	10.9	14.4	15.7	12.4	14.6	14.6
3.9 ≤ E < 4.1	9.9	10.7	14.1	15.5	12.1	14.4	14.4
4.1 ≤ E < 4.3	9.7	10.4	13.9	15.2	12.0	14.1	14.1
4.3 ≤ E < 4.5	9.6	10.2	13.7	15.0	11.8	13.9	13.9
4.5 ≤ E < 4.7	9.5	10.1	13.5	14.9	11.7	13.8	13.8
4.7 ≤ E < 4.9	9.3	9.9	13.4	14.6	11.5	13.6	13.6
E ≥ 4.9	9.2	9.8	13.2	14.5	11.4	13.5	13.5
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.9	12.4	16.8	18.2	14.5	17.0	17.0
3.1 ≤ E < 3.3	11.6	12.1	16.4	17.8	14.1	16.6	16.6
3.3 ≤ E < 3.5	11.3	11.8	16.0	17.5	13.8	16.3	16.2
3.5 ≤ E < 3.7	11.1	11.6	15.7	17.2	13.6	16.0	16.0
3.7 ≤ E < 3.9	10.8	11.4	15.5	16.9	13.3	15.7	15.7
3.9 ≤ E < 4.1	10.6	11.2	15.2	16.6	13.1	15.5	15.5
4.1 ≤ E < 4.3	10.4	11.0	14.9	16.3	12.9	15.3	15.2
4.3 ≤ E < 4.5	10.2	10.8	14.7	16.1	12.7	15.0	15.0
4.5 ≤ E < 4.7	10.1	10.6	14.5	15.9	12.5	14.9	14.8
4.7 ≤ E < 4.9	9.9	10.5	14.3	15.7	12.3	14.6	14.6
E ≥ 4.9	9.8	10.3	14.1	15.5	12.2	14.5	14.5

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	12.4	13.4	17.8	19.3	15.6	18.1	18.1
3.1 ≤ E < 3.3	12.1	13.1	17.5	19.0	15.2	17.8	17.8
3.3 ≤ E < 3.5	11.8	12.7	17.2	18.7	14.9	17.4	17.4
3.5 ≤ E < 3.7	11.5	12.4	16.8	18.3	14.5	17.2	17.1
3.7 ≤ E < 3.9	11.3	12.1	16.5	18.0	14.3	16.9	16.8
3.9 ≤ E < 4.1	11.1	11.9	16.2	17.7	14.0	16.6	16.5
4.1 ≤ E < 4.3	10.9	11.7	16.0	17.5	13.8	16.3	16.3
4.3 ≤ E < 4.5	10.7	11.5	15.8	17.3	13.6	16.1	16.0
4.5 ≤ E < 4.7	10.5	11.4	15.5	17.1	13.4	15.8	15.9
4.7 ≤ E < 4.9	10.4	11.2	15.3	16.8	13.2	15.7	15.7
E ≥ 4.9	10.2	11.1	15.2	16.7	13.1	15.5	15.5
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	13.3	14.3	19.0	20.1	16.7	19.4	19.3
3.1 ≤ E < 3.3	12.9	14.0	18.6	19.7	16.3	19.0	18.9
3.3 ≤ E < 3.5	12.6	13.6	18.2	19.4	15.9	18.6	18.6
3.5 ≤ E < 3.7	12.3	13.3	17.9	19.1	15.6	18.3	18.3
3.7 ≤ E < 3.9	12.0	13.1	17.6	18.8	15.3	18.0	17.9
3.9 ≤ E < 4.1	11.8	12.8	17.4	18.5	15.0	17.7	17.7
4.1 ≤ E < 4.3	11.6	12.5	17.1	18.2	14.8	17.5	17.4
4.3 ≤ E < 4.5	11.4	12.3	16.8	18.0	14.5	17.3	17.2
4.5 ≤ E < 4.7	11.2	12.1	16.6	17.7	14.4	17.0	17.0
4.7 ≤ E < 4.9	11.1	11.9	16.4	17.5	14.1	16.8	16.8
E ≥ 4.9	10.9	11.8	16.2	17.4	13.9	16.6	16.5

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	14.2	15.3	19.7	21.3	17.8	20.5	20.5
3.1 ≤ E < 3.3	13.8	15.0	19.3	20.9	17.4	20.1	20.1
3.3 ≤ E < 3.5	13.5	14.6	18.9	20.6	17.1	19.8	19.7
3.5 ≤ E < 3.7	13.1	14.3	18.6	20.3	16.7	19.5	19.4
3.7 ≤ E < 3.9	12.9	14.2	18.3	19.9	16.4	19.2	19.1
3.9 ≤ E < 4.1	12.6	13.7	18.0	19.6	16.0	18.9	18.8
4.1 ≤ E < 4.3	12.3	13.5	17.7	19.4	15.8	18.6	18.5
4.3 ≤ E < 4.5	12.1	13.2	17.5	19.1	15.6	18.4	18.3
4.5 ≤ E < 4.7	11.9	13.0	17.3	18.8	15.3	18.2	18.1
4.7 ≤ E < 4.9	11.8	12.8	17.0	18.7	15.2	17.9	17.8
E ≥ 4.9	11.6	12.6	16.9	18.5	14.9	17.7	17.7
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	15.2	16.4	20.9	22.5	18.9	21.7	21.6
3.1 ≤ E < 3.3	14.8	16.0	20.4	22.1	18.5	21.3	21.3
3.3 ≤ E < 3.5	14.4	15.6	20.0	21.8	18.1	21.0	20.9
3.5 ≤ E < 3.7	14.0	15.2	19.7	21.4	17.7	20.6	20.6
3.7 ≤ E < 3.9	13.7	14.9	19.4	21.1	17.4	20.3	20.3
3.9 ≤ E < 4.1	13.4	14.6	19.1	20.8	17.2	20.1	20.0
4.1 ≤ E < 4.3	13.2	14.4	18.9	20.5	16.9	19.8	19.7
4.3 ≤ E < 4.5	12.9	14.1	18.6	20.3	16.6	19.5	19.5
4.5 ≤ E < 4.7	12.7	13.9	18.3	20.1	16.4	19.3	19.2
4.7 ≤ E < 4.9	12.5	13.6	18.1	19.8	16.1	19.0	19.0
E ≥ 4.9	12.4	13.9	17.9	19.6	15.9	18.8	18.8

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.7	17.1	21.6	23.2	19.6	22.5	22.4
3.3 ≤ E < 3.5	15.4	17.7	21.2	22.9	19.2	22.1	22.1
3.5 ≤ E < 3.7	15.0	16.3	20.9	22.6	18.9	21.8	21.8
3.7 ≤ E < 3.9	14.6	16.0	20.6	22.2	18.5	21.5	21.5
3.9 ≤ E < 4.1	14.4	15.7	20.2	21.9	18.3	21.2	21.2
4.1 ≤ E < 4.3	14.1	15.4	19.9	21.7	18.0	20.9	20.9
4.3 ≤ E < 4.5	13.8	15.1	19.7	21.4	17.7	20.7	20.6
4.5 ≤ E < 4.7	13.6	14.9	19.4	21.2	17.5	20.5	20.4
4.7 ≤ E < 4.9	13.4	14.6	19.2	21.0	17.2	20.2	20.1
E ≥ 4.9	13.2	14.4	19.0	20.7	17.0	19.9	19.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	16.8	18.1	22.7	24.4	20.2	23.6	23.6
3.3 ≤ E < 3.5	16.3	17.7	22.4	24.1	19.8	23.3	23.3
3.5 ≤ E < 3.7	15.9	17.3	21.9	23.7	19.5	23.0	22.9
3.7 ≤ E < 3.9	15.6	17.0	21.7	23.4	19.2	22.6	22.6
3.9 ≤ E < 4.1	15.3	16.7	21.4	23.1	18.8	22.4	22.3
4.1 ≤ E < 4.3	15.0	16.4	21.0	22.9	18.5	22.1	22.0
4.3 ≤ E < 4.5	14.8	16.1	20.8	22.6	18.3	21.8	21.8
4.5 ≤ E < 4.7	14.5	15.8	20.5	22.4	17.9	21.6	21.5
4.7 ≤ E < 4.9	14.3	15.6	20.3	22.2	17.8	21.3	21.3
E ≥ 4.9	14.0	15.4	20.0	21.9	17.6	21.1	21.1

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	17.7	19.2	23.8	25.6	21.3	24.7	24.7
3.3 ≤ E < 3.5	17.3	18.8	23.4	25.2	20.9	24.4	24.4
3.5 ≤ E < 3.7	16.9	18.4	23.1	24.9	20.5	24.0	24.0
3.7 ≤ E < 3.9	16.6	18.1	22.7	24.6	20.2	23.7	23.7
3.9 ≤ E < 4.1	16.2	17.7	22.4	24.3	19.9	23.5	23.5
4.1 ≤ E < 4.3	15.9	17.4	22.2	24.0	19.6	23.2	23.2
4.3 ≤ E < 4.5	15.7	17.1	21.9	23.8	19.3	23.0	22.9
4.5 ≤ E < 4.7	15.4	16.8	21.6	23.5	19.1	22.7	22.6
4.7 ≤ E < 4.9	15.2	16.6	21.4	23.3	18.8	22.5	22.4
E ≥ 4.9	15.0	16.4	21.2	23.0	18.6	22.2	22.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	18.8	20.2	24.9	26.7	22.3	25.8	25.8
3.3 ≤ E < 3.5	18.3	19.9	24.6	26.3	22.0	25.5	25.5
3.5 ≤ E < 3.7	17.9	19.5	24.2	26.0	21.6	25.2	25.2
3.7 ≤ E < 3.9	17.6	19.1	23.9	25.7	21.3	24.9	24.8
3.9 ≤ E < 4.1	17.3	18.8	23.6	25.4	20.9	24.6	24.6
4.1 ≤ E < 4.3	16.9	18.4	23.3	25.1	20.6	24.4	24.3
4.3 ≤ E < 4.5	16.6	18.1	23.0	24.9	20.4	24.1	24.0
4.5 ≤ E < 4.7	16.3	17.9	22.8	24.6	20.0	23.8	23.8
4.7 ≤ E < 4.9	16.1	17.6	22.5	24.4	19.9	23.6	23.6
E ≥ 4.9	15.8	17.4	22.3	24.2	19.7	23.4	23.3

Table 5.8.9-9 Loading Table for PWR Fuel – 760 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	19.8	21.3	25.9	27.7	23.4	26.9	26.9
3.3 ≤ E < 3.5	19.3	20.9	25.6	27.4	23.0	26.7	26.6
3.5 ≤ E < 3.7	18.9	20.5	25.3	27.1	22.7	26.3	26.2
3.7 ≤ E < 3.9	18.6	20.2	24.9	26.8	22.3	26.0	25.9
3.9 ≤ E < 4.1	18.2	19.8	24.6	26.5	22.0	25.7	25.7
4.1 ≤ E < 4.3	17.9	19.5	24.3	26.2	21.7	25.5	25.4
4.3 ≤ E < 4.5	17.6	19.2	24.1	26.0	21.4	25.2	25.2
4.5 ≤ E < 4.7	17.3	18.9	23.9	25.8	21.2	25.0	24.9
4.7 ≤ E < 4.9	17.1	18.7	23.6	25.5	20.9	24.7	24.7
E ≥ 4.9	16.8	18.4	23.4	25.3	20.7	24.5	24.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	20.3	22.0	26.7	28.4	24.1	27.2	27.1
3.5 ≤ E < 3.7	20.0	21.5	26.4	28.1	23.7	26.8	26.7
3.7 ≤ E < 3.9	19.6	21.2	26.0	27.8	23.4	26.5	26.5
3.9 ≤ E < 4.1	19.3	20.8	25.7	27.6	23.1	26.2	26.2
4.1 ≤ E < 4.3	18.9	20.5	25.4	27.3	22.7	26.0	25.9
4.3 ≤ E < 4.5	18.6	20.2	25.2	27.1	22.5	25.7	25.6
4.5 ≤ E < 4.7	18.3	20.0	24.9	26.8	22.2	25.5	25.4
4.7 ≤ E < 4.9	18.0	19.7	24.7	26.6	22.0	25.2	25.2
E ≥ 4.9	17.7	19.5	24.4	26.4	21.7	25.0	24.9

5.8.9.2 BWR

Thermal analysis limits the BWR cask heat load to below that used in the cask shielding analysis. Minimum fuel assembly cool times are, therefore, required for a 33 kW cask heat load (379 W/assembly). Due to potential uncertainties in the source generation abilities of SAS2H, allowed heat load is reduced by an additional 5%, to 360 W/assembly, for fuel with burnups greater than 45 GWd/MTU. Minimum cool times for fuel with burnup greater than 30 GWd/MTU, but ≤ 45 GWd/MTU, are listed in Table 5.8.9-11 with high burnup fuel cool times shown in Table 5.8.9-12.

Allowed low burnup (up to 30,000 MWd/MTU) fuel loadings are shown in Table 5.8.9-10. Note that the listed minimum cool times at each burnup step are bounding for all fuel types and initial enrichments above the minimum enrichment specified. Collapsing the fuel type and initial enrichment dependent minimum cool time matrix to a single value may result in a minimum cool time longer than individual values presented for higher burnups.

Table 5.8.9-10 Low Burnup BWR Fuel Loading Table

Max. Assembly Avg. Burnup (MWd/MTU)	Min. Assembly Avg. Initial Enrichment (wt% ^{235}U)	Minimum Cool Time (yrs)
5,000	0.7	4.0
10,000	1.3	4.0
15,000	1.5	4.0
20,000	1.7	4.0
25,000	1.9	4.0
30,000	2.1	4.3

Table 5.8.9-11 Loading Table for BWR Fuel – 379 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	4.3	4.6	4.0	4.5	4.0	4.5	4.4
2.3 ≤ E < 2.5	4.2	4.6	4.0	4.5	4.0	4.4	4.4
2.5 ≤ E < 2.7	4.2	4.5	4.0	4.4	4.0	4.4	4.3
2.7 ≤ E < 2.9	4.1	4.5	4.0	4.4	4.0	4.3	4.3
2.9 ≤ E < 3.1	4.1	4.4	4.0	4.3	4.0	4.3	4.2
3.1 ≤ E < 3.3	4.0	4.4	4.0	4.3	4.0	4.2	4.2
3.3 ≤ E < 3.5	4.0	4.3	4.0	4.2	4.0	4.2	4.1
3.5 ≤ E < 3.7	4.0	4.3	4.0	4.2	4.0	4.2	4.1
3.7 ≤ E < 3.9	4.0	4.3	4.0	4.2	4.0	4.1	4.0
3.9 ≤ E < 4.1	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.1 ≤ E < 4.3	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.3 ≤ E < 4.5	4.0	4.2	4.0	4.1	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.1	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.1	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.1	4.0	4.0	4.0	4.0	4.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.7	5.0	4.3	4.9	4.0	4.9	4.8
2.5 ≤ E < 2.7	4.6	4.9	4.3	4.8	4.0	4.8	4.7
2.7 ≤ E < 2.9	4.5	4.9	4.2	4.8	4.0	4.7	4.6
2.9 ≤ E < 3.1	4.5	4.8	4.2	4.7	4.0	4.7	4.6
3.1 ≤ E < 3.3	4.4	4.8	4.1	4.7	4.0	4.6	4.5
3.3 ≤ E < 3.5	4.4	4.7	4.0	4.6	4.0	4.6	4.5
3.5 ≤ E < 3.7	4.3	4.7	4.0	4.6	4.0	4.5	4.5
3.7 ≤ E < 3.9	4.3	4.6	4.0	4.5	4.0	4.5	4.4
3.9 ≤ E < 4.1	4.2	4.6	4.0	4.5	4.0	4.5	4.4
4.1 ≤ E < 4.3	4.2	4.5	4.0	4.5	4.0	4.4	4.3
4.3 ≤ E < 4.5	4.2	4.5	4.0	4.4	4.0	4.4	4.3
4.5 ≤ E < 4.7	4.1	4.5	4.0	4.4	4.0	4.4	4.3
4.7 ≤ E < 4.9	4.1	4.5	4.0	4.4	4.0	4.3	4.2
E ≥ 4.9	4.1	4.4	4.0	4.3	4.0	4.3	4.2

Table 5.8.9-11 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.2	5.6	4.7	5.4	4.4	5.4	5.2
2.5 ≤ E < 2.7	5.1	5.5	4.7	5.3	4.3	5.3	5.2
2.7 ≤ E < 2.9	5.0	5.4	4.6	5.3	4.3	5.2	5.1
2.9 ≤ E < 3.1	4.9	5.4	4.5	5.2	4.2	5.1	5.0
3.1 ≤ E < 3.3	4.9	5.3	4.5	5.1	4.1	5.1	4.9
3.3 ≤ E < 3.5	4.8	5.2	4.4	5.0	4.1	5.0	4.9
3.5 ≤ E < 3.7	4.8	5.1	4.4	5.0	4.0	4.9	4.8
3.7 ≤ E < 3.9	4.7	5.1	4.3	4.9	4.0	4.9	4.8
3.9 ≤ E < 4.1	4.6	5.0	4.3	4.9	4.0	4.9	4.7
4.1 ≤ E < 4.3	4.6	5.0	4.3	4.9	4.0	4.8	4.7
4.3 ≤ E < 4.5	4.6	4.9	4.2	4.8	4.0	4.8	4.7
4.5 ≤ E < 4.7	4.5	4.9	4.2	4.8	4.0	4.7	4.6
4.7 ≤ E < 4.9	4.5	4.9	4.1	4.7	4.0	4.7	4.6
E ≥ 4.9	4.5	4.9	4.1	4.7	4.0	4.7	4.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	6.1	5.2	5.9	4.7	5.9	5.7
2.7 ≤ E < 2.9	5.6	6.0	5.1	5.8	4.6	5.8	5.7
2.9 ≤ E < 3.1	5.5	5.9	5.0	5.8	4.6	5.7	5.6
3.1 ≤ E < 3.3	5.5	5.9	4.9	5.7	4.5	5.6	5.5
3.3 ≤ E < 3.5	5.4	5.8	4.9	5.6	4.4	5.6	5.4
3.5 ≤ E < 3.7	5.3	5.7	4.8	5.6	4.4	5.5	5.4
3.7 ≤ E < 3.9	5.2	5.7	4.7	5.5	4.3	5.4	5.3
3.9 ≤ E < 4.1	5.2	5.6	4.7	5.4	4.3	5.4	5.2
4.1 ≤ E < 4.3	5.1	5.6	4.6	5.4	4.3	5.3	5.2
4.3 ≤ E < 4.5	5.0	5.5	4.6	5.3	4.2	5.3	5.1
4.5 ≤ E < 4.7	5.0	5.5	4.5	5.3	4.2	5.2	5.0
4.7 ≤ E < 4.9	5.0	5.4	4.5	5.2	4.1	5.2	5.0
E ≥ 4.9	4.9	5.4	4.5	5.2	4.1	5.1	5.0

Table 5.8.9-11 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.0	6.5	5.4	6.2	4.9	6.1	6.0
2.7 ≤ E < 2.9	5.9	6.4	5.3	6.1	4.8	6.0	5.9
2.9 ≤ E < 3.1	5.8	6.2	5.2	6.0	4.7	5.9	5.8
3.1 ≤ E < 3.3	5.7	6.1	5.1	5.9	4.7	5.9	5.7
3.3 ≤ E < 3.5	5.6	6.0	5.0	5.9	4.6	5.8	5.6
3.5 ≤ E < 3.7	5.5	6.0	5.0	5.8	4.5	5.7	5.6
3.7 ≤ E < 3.9	5.5	5.9	4.9	5.7	4.5	5.7	5.5
3.9 ≤ E < 4.1	5.4	5.9	4.9	5.7	4.4	5.6	5.5
4.1 ≤ E < 4.3	5.3	5.8	4.8	5.6	4.4	5.5	5.4
4.3 ≤ E < 4.5	5.3	5.8	4.8	5.6	4.4	5.5	5.3
4.5 ≤ E < 4.7	5.2	5.7	4.7	5.5	4.3	5.4	5.3
4.7 ≤ E < 4.9	5.2	5.7	4.7	5.5	4.3	5.4	5.2
E ≥ 4.9	5.1	5.6	4.6	5.4	4.2	5.4	5.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.3	6.8	5.6	6.5	5.1	6.4	6.2
2.7 ≤ E < 2.9	6.2	6.7	5.5	6.4	5.0	6.3	6.1
2.9 ≤ E < 3.1	6.0	6.6	5.5	6.3	4.9	6.2	6.0
3.1 ≤ E < 3.3	6.0	6.5	5.4	6.2	4.8	6.1	5.9
3.3 ≤ E < 3.5	5.9	6.4	5.3	6.1	4.8	6.0	5.9
3.5 ≤ E < 3.7	5.8	6.3	5.2	6.0	4.7	5.9	5.8
3.7 ≤ E < 3.9	5.7	6.2	5.1	5.9	4.6	5.9	5.7
3.9 ≤ E < 4.1	5.6	6.1	5.0	5.9	4.6	5.8	5.7
4.1 ≤ E < 4.3	5.6	6.0	5.0	5.8	4.5	5.8	5.6
4.3 ≤ E < 4.5	5.5	6.0	4.9	5.8	4.5	5.7	5.6
4.5 ≤ E < 4.7	5.5	5.9	4.9	5.7	4.5	5.7	5.5
4.7 ≤ E < 4.9	5.4	5.9	4.9	5.7	4.4	5.6	5.5
E ≥ 4.9	5.4	5.8	4.8	5.6	4.4	5.6	5.4

Table 5.8.9-11 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.6	7.1	5.9	6.8	5.3	6.8	6.6
2.7 ≤ E < 2.9	6.5	7.0	5.8	6.7	5.2	6.6	6.4
2.9 ≤ E < 3.1	6.4	6.9	5.7	6.6	5.1	6.5	6.3
3.1 ≤ E < 3.3	6.3	6.8	5.6	6.5	5.0	6.4	6.2
3.3 ≤ E < 3.5	6.1	6.7	5.5	6.4	4.9	6.3	6.1
3.5 ≤ E < 3.7	6.0	6.6	5.4	6.3	4.9	6.2	6.0
3.7 ≤ E < 3.9	6.0	6.5	5.4	6.2	4.8	6.1	5.9
3.9 ≤ E < 4.1	5.9	6.4	5.3	6.1	4.8	6.0	5.9
4.1 ≤ E < 4.3	5.8	6.3	5.2	6.0	4.7	6.0	5.8
4.3 ≤ E < 4.5	5.8	6.3	5.1	6.0	4.6	5.9	5.8
4.5 ≤ E < 4.7	5.7	6.2	5.1	6.0	4.6	5.9	5.7
4.7 ≤ E < 4.9	5.7	6.1	5.0	5.9	4.6	5.9	5.7
E ≥ 4.9	5.6	6.1	5.0	5.9	4.5	5.8	5.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.0	7.6	6.1	7.2	5.5	7.1	6.9
2.7 ≤ E < 2.9	6.8	7.4	6.0	7.0	5.4	6.9	6.7
2.9 ≤ E < 3.1	6.7	7.3	5.9	6.9	5.3	6.8	6.6
3.1 ≤ E < 3.3	6.6	7.1	5.8	6.8	5.2	6.7	6.5
3.3 ≤ E < 3.5	6.5	7.0	5.7	6.7	5.1	6.6	6.4
3.5 ≤ E < 3.7	6.4	6.9	5.7	6.6	5.0	6.5	6.3
3.7 ≤ E < 3.9	6.3	6.8	5.6	6.5	5.0	6.5	6.2
3.9 ≤ E < 4.1	6.2	6.7	5.5	6.4	4.9	6.4	6.1
4.1 ≤ E < 4.3	6.1	6.7	5.5	6.4	4.9	6.3	6.0
4.3 ≤ E < 4.5	6.0	6.6	5.4	6.3	4.8	6.2	6.0
4.5 ≤ E < 4.7	5.9	6.5	5.3	6.2	4.8	6.1	5.9
4.7 ≤ E < 4.9	5.9	6.5	5.3	6.2	4.7	6.1	5.9
E ≥ 4.9	5.8	6.4	5.2	6.1	4.7	6.0	5.9

Table 5.8.9-11 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.2	7.9	6.3	7.5	5.6	7.4	7.1
2.9 ≤ E < 3.1	7.0	7.7	6.2	7.3	5.5	7.2	6.9
3.1 ≤ E < 3.3	6.9	7.6	6.1	7.1	5.4	7.0	6.8
3.3 ≤ E < 3.5	6.8	7.4	6.0	7.0	5.4	6.9	6.7
3.5 ≤ E < 3.7	6.7	7.3	5.9	6.9	5.3	6.9	6.6
3.7 ≤ E < 3.9	6.6	7.2	5.8	6.8	5.2	6.8	6.5
3.9 ≤ E < 4.1	6.5	7.1	5.8	6.8	5.1	6.7	6.4
4.1 ≤ E < 4.3	6.4	7.0	5.7	6.7	5.0	6.6	6.3
4.3 ≤ E < 4.5	6.3	6.9	5.6	6.6	5.0	6.5	6.3
4.5 ≤ E < 4.7	6.3	6.8	5.6	6.5	4.9	6.4	6.2
4.7 ≤ E < 4.9	6.2	6.8	5.5	6.5	4.9	6.4	6.1
E ≥ 4.9	6.1	6.7	5.4	6.4	4.8	6.3	6.1

Note: Burnups greater than 45 MWd/MTU have been deleted from this table.

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	8.5	9.3	7.3	8.8	6.3	8.6	8.2
2.9 ≤ E < 3.1	8.3	9.0	7.1	8.6	6.2	8.4	8.0
3.1 ≤ E < 3.3	8.1	8.9	7.0	8.4	6.0	8.2	7.9
3.3 ≤ E < 3.5	8.0	8.8	6.8	8.2	6.0	8.0	7.7
3.5 ≤ E < 3.7	7.9	8.6	6.7	8.0	5.9	7.9	7.6
3.7 ≤ E < 3.9	7.7	8.4	6.7	7.9	5.8	7.8	7.5
3.9 ≤ E < 4.1	7.6	8.3	6.6	7.8	5.8	7.7	7.4
4.1 ≤ E < 4.3	7.5	8.2	6.5	7.7	5.7	7.6	7.3
4.3 ≤ E < 4.5	7.4	8.1	6.4	7.6	5.6	7.5	7.2
4.5 ≤ E < 4.7	7.3	8.0	6.3	7.6	5.6	7.4	7.1
4.7 ≤ E < 4.9	7.2	7.9	6.2	7.5	5.5	7.4	7.0
E ≥ 4.9	7.1	7.8	6.1	7.4	5.4	7.3	7.0

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.1	10.0	7.7	9.3	6.7	9.2	8.7
2.9 ≤ E < 3.1	8.9	9.8	7.5	9.1	6.5	8.9	8.5
3.1 ≤ E < 3.3	8.7	9.5	7.4	8.9	6.4	8.8	8.3
3.3 ≤ E < 3.5	8.5	9.3	7.2	8.7	6.2	8.6	8.2
3.5 ≤ E < 3.7	8.3	9.1	7.0	8.6	6.1	8.4	8.0
3.7 ≤ E < 3.9	8.2	9.0	7.0	8.4	6.0	8.3	7.9
3.9 ≤ E < 4.1	8.0	8.8	6.9	8.3	6.0	8.1	7.8
4.1 ≤ E < 4.3	7.9	8.7	6.8	8.2	5.9	8.0	7.7
4.3 ≤ E < 4.5	7.8	8.6	6.7	8.1	5.8	7.9	7.6
4.5 ≤ E < 4.7	7.7	8.5	6.6	8.0	5.8	7.9	7.5
4.7 ≤ E < 4.9	7.6	8.4	6.5	7.9	5.7	7.8	7.4
E ≥ 4.9	7.5	8.3	6.5	7.8	5.7	7.7	7.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.8	10.7	8.2	9.9	6.9	9.8	9.3
2.9 ≤ E < 3.1	9.6	10.5	8.0	9.7	6.8	9.5	9.1
3.1 ≤ E < 3.3	9.3	10.2	7.8	9.5	6.7	9.3	8.9
3.3 ≤ E < 3.5	9.1	9.9	7.7	9.3	6.6	9.2	8.7
3.5 ≤ E < 3.7	8.9	9.7	7.5	9.1	6.5	9.0	8.5
3.7 ≤ E < 3.9	8.7	9.6	7.4	8.9	6.3	8.8	8.4
3.9 ≤ E < 4.1	8.6	9.4	7.2	8.8	6.2	8.7	8.2
4.1 ≤ E < 4.3	8.4	9.3	7.1	8.7	6.1	8.6	8.1
4.3 ≤ E < 4.5	8.3	9.1	7.0	8.6	6.0	8.4	8.0
4.5 ≤ E < 4.7	8.1	9.0	6.9	8.5	6.0	8.3	7.9
4.7 ≤ E < 4.9	8.0	8.9	6.9	8.3	5.9	8.2	7.8
E ≥ 4.9	7.9	8.8	6.8	8.2	5.9	8.1	7.8

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	10.5	11.6	8.7	10.8	7.3	10.6	9.9
2.9 ≤ E < 3.1	10.2	11.3	8.5	10.4	7.1	10.2	9.7
3.1 ≤ E < 3.3	10.0	11.0	8.3	10.1	7.0	9.9	9.4
3.3 ≤ E < 3.5	9.7	10.7	8.1	9.9	6.9	9.8	9.2
3.5 ≤ E < 3.7	9.5	10.5	7.9	9.7	6.8	9.6	9.0
3.7 ≤ E < 3.9	9.3	10.3	7.8	9.5	6.7	9.4	8.9
3.9 ≤ E < 4.1	9.1	10.1	7.7	9.4	6.5	9.2	8.7
4.1 ≤ E < 4.3	9.0	9.9	7.5	9.2	6.4	9.0	8.6
4.3 ≤ E < 4.5	8.8	9.7	7.4	9.1	6.3	8.9	8.5
4.5 ≤ E < 4.7	8.7	9.6	7.3	8.9	6.3	8.8	8.4
4.7 ≤ E < 4.9	8.6	9.5	7.2	8.9	6.2	8.7	8.3
E ≥ 4.9	8.5	9.3	7.1	8.8	6.1	8.6	8.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.0	12.0	9.0	11.2	7.6	11.0	10.3
3.1 ≤ E < 3.3	10.7	11.7	8.8	10.9	7.4	10.7	10.1
3.3 ≤ E < 3.5	10.4	11.5	8.6	10.7	7.2	10.4	9.8
3.5 ≤ E < 3.7	10.2	11.3	8.4	10.4	7.0	10.2	9.7
3.7 ≤ E < 3.9	10.0	11.0	8.2	10.2	7.0	10.0	9.5
3.9 ≤ E < 4.1	9.7	10.8	8.0	10.0	6.8	9.8	9.3
4.1 ≤ E < 4.3	9.6	10.6	7.9	9.8	6.7	9.7	9.1
4.3 ≤ E < 4.5	9.4	10.4	7.8	9.7	6.7	9.5	9.0
4.5 ≤ E < 4.7	9.3	10.2	7.7	9.5	6.6	9.4	8.9
4.7 ≤ E < 4.9	9.1	10.1	7.6	9.4	6.5	9.2	8.7
E ≥ 4.9	9.0	10.0	7.5	9.3	6.4	9.1	8.6

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.8	12.9	9.6	12.0	8.0	11.8	11.1
3.1 ≤ E < 3.3	11.5	12.6	9.4	11.7	7.8	11.5	10.9
3.3 ≤ E < 3.5	11.2	12.3	9.1	11.5	7.6	11.2	10.6
3.5 ≤ E < 3.7	10.9	11.9	8.9	11.1	7.5	11.0	10.3
3.7 ≤ E < 3.9	10.7	11.8	8.7	10.9	7.3	10.7	10.0
3.9 ≤ E < 4.1	10.4	11.6	8.6	10.7	7.2	10.5	9.9
4.1 ≤ E < 4.3	10.3	11.3	8.4	10.5	7.0	10.3	9.7
4.3 ≤ E < 4.5	10.0	11.2	8.3	10.4	7.0	10.1	9.6
4.5 ≤ E < 4.7	9.9	11.0	8.1	10.1	6.8	9.9	9.4
4.7 ≤ E < 4.9	9.8	10.9	8.0	10.0	6.8	9.8	9.3
E ≥ 4.9	9.6	10.7	7.9	9.9	6.7	9.7	9.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	12.7	13.9	10.3	12.9	8.4	12.6	11.9
3.1 ≤ E < 3.3	12.3	13.4	10.0	12.5	8.2	12.3	11.6
3.3 ≤ E < 3.5	11.9	13.2	9.8	12.1	8.0	11.9	11.3
3.5 ≤ E < 3.7	11.7	12.9	9.5	11.9	7.9	11.7	11.0
3.7 ≤ E < 3.9	11.5	12.6	9.3	11.7	7.7	11.4	10.8
3.9 ≤ E < 4.1	11.2	12.4	9.1	11.5	7.6	11.3	10.5
4.1 ≤ E < 4.3	11.0	12.1	8.9	11.3	7.4	11.0	10.3
4.3 ≤ E < 4.5	10.8	11.8	8.8	11.1	7.3	10.9	10.2
4.5 ≤ E < 4.7	10.6	11.7	8.7	10.9	7.2	10.7	10.0
4.7 ≤ E < 4.9	10.5	11.6	8.5	10.7	7.1	10.5	9.9
E ≥ 4.9	10.2	11.4	8.4	10.6	7.0	10.4	9.8

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	13.6	14.8	11.0	13.7	8.9	13.4	12.7
3.1 ≤ E < 3.3	13.2	14.5	10.7	13.3	8.7	13.1	12.4
3.3 ≤ E < 3.5	12.8	14.1	10.4	13.0	8.5	12.8	12.0
3.5 ≤ E < 3.7	12.6	13.8	10.1	12.7	8.3	12.5	11.8
3.7 ≤ E < 3.9	12.2	13.5	9.8	12.4	8.1	12.2	11.5
3.9 ≤ E < 4.1	11.9	13.2	9.7	12.2	7.9	12.0	11.3
4.1 ≤ E < 4.3	11.7	13.0	9.5	12.0	7.8	11.8	11.1
4.3 ≤ E < 4.5	11.6	12.7	9.3	11.8	7.7	11.5	10.9
4.5 ≤ E < 4.7	11.4	12.5	9.2	11.6	7.6	11.4	10.7
4.7 ≤ E < 4.9	11.2	12.4	9.0	11.5	7.5	11.3	10.5
E ≥ 4.9	11.0	12.1	8.9	11.3	7.4	11.1	10.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	14.5	15.8	11.8	14.6	9.5	14.4	13.6
3.1 ≤ E < 3.3	14.1	15.4	11.4	14.3	9.2	14.0	13.2
3.3 ≤ E < 3.5	13.8	15.1	11.1	13.9	8.9	13.6	12.8
3.5 ≤ E < 3.7	13.4	14.7	10.9	13.6	8.7	13.4	12.6
3.7 ≤ E < 3.9	13.1	14.4	10.6	13.3	8.6	13.1	12.2
3.9 ≤ E < 4.1	12.9	14.1	10.4	13.1	8.4	12.8	12.0
4.1 ≤ E < 4.3	12.6	13.9	10.1	12.8	8.2	12.5	11.8
4.3 ≤ E < 4.5	12.4	13.6	9.9	12.6	8.1	12.3	11.6
4.5 ≤ E < 4.7	12.1	13.4	9.7	12.3	7.9	12.1	11.4
4.7 ≤ E < 4.9	11.9	13.2	9.6	12.2	7.9	11.9	11.2
E ≥ 4.9	11.7	13.1	9.4	12.0	7.8	11.7	11.1

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.0	16.4	12.1	15.2	9.8	14.9	14.1
3.3 ≤ E < 3.5	14.7	16.0	11.9	14.9	9.5	14.6	13.7
3.5 ≤ E < 3.7	14.3	15.7	11.5	14.5	9.3	14.2	13.4
3.7 ≤ E < 3.9	13.9	15.4	11.3	14.2	9.0	13.9	13.1
3.9 ≤ E < 4.1	13.6	15.1	11.1	13.9	8.9	13.6	12.8
4.1 ≤ E < 4.3	13.3	14.7	10.8	13.6	8.7	13.4	12.5
4.3 ≤ E < 4.5	13.1	14.5	10.5	13.4	8.5	13.1	12.3
4.5 ≤ E < 4.7	12.9	14.3	10.4	13.2	8.4	13.0	12.1
4.7 ≤ E < 4.9	12.8	14.1	10.2	13.0	8.3	12.8	11.9
E ≥ 4.9	12.5	13.9	10.0	12.8	8.1	12.5	11.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.8	17.5	13.1	16.2	10.4	15.9	15.0
3.3 ≤ E < 3.5	15.5	17.1	12.7	15.8	10.1	15.5	14.6
3.5 ≤ E < 3.7	15.1	16.7	12.3	15.5	9.9	15.2	14.3
3.7 ≤ E < 3.9	14.7	16.3	12.0	15.1	9.7	14.8	13.9
3.9 ≤ E < 4.1	14.4	16.0	11.8	14.9	9.4	14.6	13.6
4.1 ≤ E < 4.3	14.0	15.7	11.5	14.5	9.2	14.3	13.4
4.3 ≤ E < 4.5	13.8	15.4	11.3	14.3	9.0	14.0	13.1
4.5 ≤ E < 4.7	13.7	15.2	11.1	14.1	8.8	13.8	12.9
4.7 ≤ E < 4.9	13.4	15.0	10.9	13.9	8.7	13.7	12.8
E ≥ 4.9	13.3	14.8	10.7	13.7	8.6	13.4	12.5

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	16.8	18.4	13.8	17.2	11.1	16.9	16.0
3.3 ≤ E < 3.5	16.5	18.1	13.5	16.8	10.9	16.4	15.5
3.5 ≤ E < 3.7	16.0	17.7	13.1	16.4	10.5	16.2	15.2
3.7 ≤ E < 3.9	15.7	17.3	12.9	16.1	10.2	15.7	14.8
3.9 ≤ E < 4.1	15.4	17.1	12.5	15.8	10.0	15.4	14.5
4.1 ≤ E < 4.3	15.1	16.8	12.2	15.4	9.8	15.2	14.3
4.3 ≤ E < 4.5	14.8	16.4	12.0	15.2	9.6	14.8	14.0
4.5 ≤ E < 4.7	14.6	16.2	11.8	15.0	9.4	14.7	13.8
4.7 ≤ E < 4.9	14.3	15.9	11.6	14.7	9.2	14.4	13.5
E ≥ 4.9	14.0	15.7	11.4	14.5	9.0	14.3	13.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	17.8	19.5	14.8	18.2	11.8	17.8	16.8
3.3 ≤ E < 3.5	17.3	19.1	14.4	17.7	11.5	17.5	16.5
3.5 ≤ E < 3.7	17.0	18.7	14.0	17.4	11.2	17.1	16.1
3.7 ≤ E < 3.9	16.6	18.3	13.6	17.0	10.9	16.8	15.7
3.9 ≤ E < 4.1	16.3	17.9	13.3	16.7	10.6	16.4	15.4
4.1 ≤ E < 4.3	15.9	17.7	13.1	16.3	10.3	16.1	15.1
4.3 ≤ E < 4.5	15.7	17.4	12.8	16.1	10.1	15.8	14.8
4.5 ≤ E < 4.7	15.5	17.1	12.5	15.9	9.9	15.5	14.6
4.7 ≤ E < 4.9	15.2	16.9	12.3	15.6	9.8	15.3	14.4
E ≥ 4.9	15.0	16.7	12.1	15.4	9.6	15.1	14.2

Table 5.8.9-12 Loading Table for BWR Fuel – 360 W/Assembly (cont'd)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	18.7	20.4	15.7	19.2	12.6	18.9	17.8
3.3 ≤ E < 3.5	18.4	20.0	15.2	18.8	12.2	18.4	17.4
3.5 ≤ E < 3.7	18.0	19.7	14.9	18.4	11.9	18.1	17.1
3.7 ≤ E < 3.9	17.6	19.3	14.5	18.1	11.6	17.7	16.7
3.9 ≤ E < 4.1	17.2	18.9	14.1	17.7	11.2	17.3	16.3
4.1 ≤ E < 4.3	16.9	18.7	13.8	17.4	11.0	17.1	16.1
4.3 ≤ E < 4.5	16.6	18.4	13.6	17.1	10.8	16.8	15.7
4.5 ≤ E < 4.7	16.4	18.0	13.3	16.9	10.6	16.5	15.5
4.7 ≤ E < 4.9	16.1	17.8	13.1	16.6	10.3	16.2	15.3
E ≥ 4.9	15.9	17.6	12.9	16.3	10.2	15.9	15.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	19.3	21.0	16.0	19.7	12.9	19.5	18.4
3.5 ≤ E < 3.7	18.9	20.7	15.6	19.3	12.7	19.1	17.9
3.7 ≤ E < 3.9	18.6	20.3	15.2	19.0	12.3	18.7	17.7
3.9 ≤ E < 4.1	18.2	19.9	14.9	18.7	11.9	18.3	17.3
4.1 ≤ E < 4.3	17.9	19.7	14.5	18.3	11.6	17.9	17.0
4.3 ≤ E < 4.5	17.6	19.4	14.2	18.1	11.4	17.7	16.6
4.5 ≤ E < 4.7	17.3	19.1	14.0	17.7	11.2	17.5	16.4
4.7 ≤ E < 4.9	17.1	18.8	13.8	17.6	11.0	17.2	16.1
E ≥ 4.9	16.9	18.6	13.6	17.3	10.8	16.9	15.9

5.8.10 Axial Zoned Fuel/End Blanket Discussion

PWR and BWR fuel assemblies may contain axial zoned fuel (i.e., regions of lower or unenriched fuel at the top and bottom of the fuel pellet stack). These blankets have the potential of affecting overall source magnitudes, as sources are not constant as a function of initial enrichment at a fixed burnup and end blankets would tend to shift the burnup profile toward the fuel midplane. Minimum cool time tables are specified based on average assembly enrichment, including the axial end blankets. This section provides justification that the average enrichment represents a suitable value for zoned (end blanket) fuel to assure system safety and compliance with regulatory requirements.

Of primary interest in this evaluation is the fuel gamma source magnitude because the source magnitude, rather than profile, produces the cask overall surface radiation flux, which in turn is responsible for site boundary and site occupational exposure (i.e., dose peaking on the cask surface quickly diminishes as a function of distance from the cask surface; see dose profiles that demonstrate a disappearance of dose peaks within 4 meters of the cask surface). Additional focus is on the thermal heat load produced by the fuel assembly. Neutron source is not of a significant concern to system performance as concrete cask (site) exposures are dominated by gamma dose. Transfer cask operations are primarily accomplished while the system is flooded, producing low neutron dose rates.

The zoned (axial end blanket) configurations represent the majority of BWR fuel assemblies (e.g., typical BWR/4-6 class fuel assemblies contains 138 inches of enriched fuel pellets with nominal 6-inch top and bottom unenriched blankets) and are, therefore, explicitly accounted for in the axial burnup profile used in the analysis. Axially zoned fuel assemblies are also implemented in some PWRs. As the majority of the PWR profile data is based on nonzoned fuel, this section discusses PWR assemblies in detail. The conclusion drawn from the PWR study (i.e., that there is no significant effect on source due to blankets) is equally applicable to the BWR assemblies.

To demonstrate the overall effect of the end blankets on source magnitudes, SAS2H evaluations are completed for 18 node profiles with nominal 6-inch unenriched end blankets. The initial evaluation set employs the fixed 1.08 peak profile defined in Section 5.3 and compares the results of the 18 node analysis (one SAS2H run at each node-defined burnup) of assemblies with and without axial end blankets, where the source without blanket is based on the average assembly enrichment. To investigate the effect of profile changes, a zoned (axial end blanket) profile was extracted from YAEC-1937 for a Westinghouse fuel assembly at a single plant

(Millstone). The database for this plant contained information on both zoned and uniform enriched assembly profiles. The zoned profile case was then processed through SAS2H in 18 nodes. Results for the 1.08 peak profile and zoned Millstone profiles were compared to the baseline shielding source discussed in Sections 5.2 through 5.4.

The two evaluation sets are based on a 45 GWd/MTU burned assembly. The assembly is evaluated with a blanket-length-dependent uniform (average) enrichment and with a 4.3 wt % ^{235}U enriched center region and natural uranium blankets. This enrichment/burnup data set was chosen as it represents the Millstone assemblies within the profile database. Resulting source magnitudes for heat load, fuel gamma, and fuel neutron source are included in Table 5.8.10-1. None of the evaluations demonstrate a significant change in source magnitude from the baseline analysis applying a uniform enrichment.

Also evaluated was a source term comparison for Millstone assemblies with and without axial blankets, each with its appropriate burnup profile. The results of this comparison are included in Table 5.8.10-2. The change for the Millstone data from a uniform to a zoned profile, with its higher peak, had no significant effect on source magnitudes.

Note that the burnup profile provided in the reference documentation is in 18 nodes (8 inches per node), while a typical blanket is 6 inches. This approximation introduces a slight discrepancy in the results that is particularly noticeable on fuel neutron source (which is significantly more affected by profile and enrichment changes than heat load and gamma source) and accounts for some of the variation in trends seen in the neutron source differential.

Figure 5.8.10-1 Millstone Sample Axial Burnup Profiles

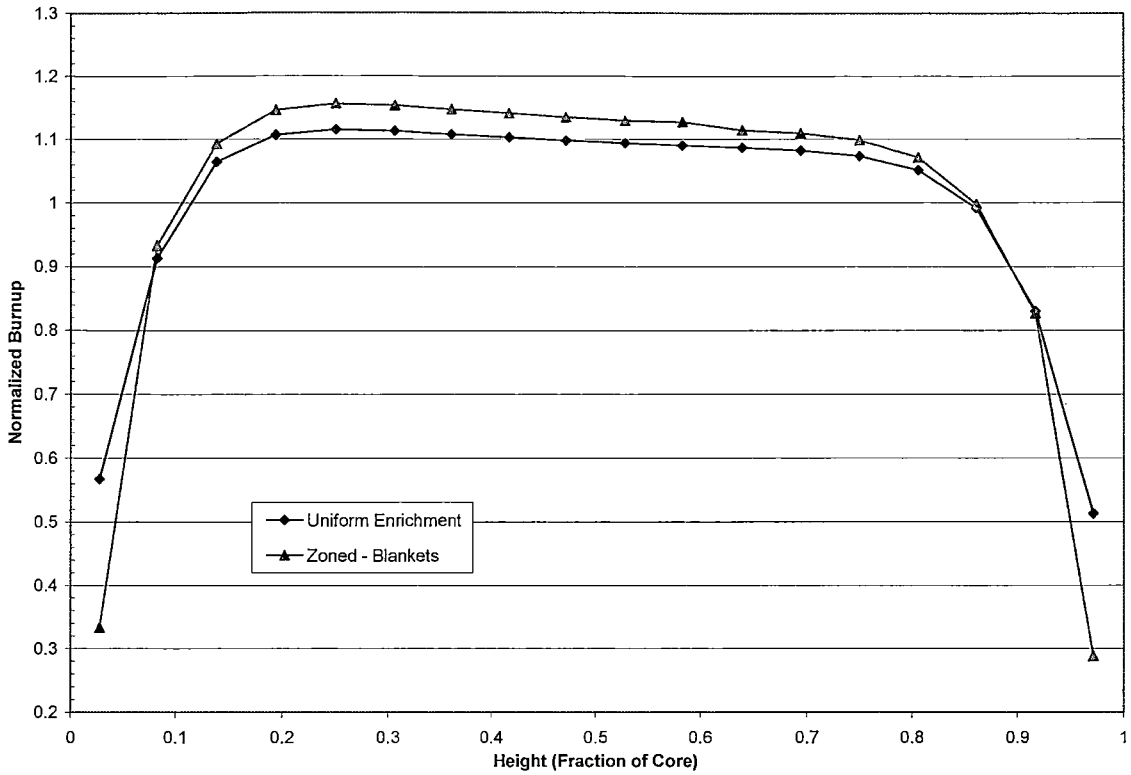


Table 5.8.10-1 Zoned Fuel and Profile Effects on Source Magnitudes

Source	Burnup Profile	Zone (Blanket) Length 6-inch
Heat	1.08 Peak	1.035E+03
(W)	1.08 Peak	1.032E+03
	% Diff	-0.2%
Neutron	1.08 Peak	3.619E+08
(n/s)	1.08 Peak	3.535E+08
	% Diff	-2.3%
Gamma	1.08 Peak	5.536E+15
(g/s)	1.08 Peak	5.533E+15
	% Diff	-0.1%
Heat	1.08 Peak	1.035E+03
(W)	Millstone - Zoned	1.038E+03
	% Diff	0.3%
Neutron	1.08 Peak	3.619E+08
(n/s)	Millstone - Zoned	3.705E+08
	% Diff	2.4%
Gamma	1.08 Peak	5.536E+15
(g/s)	Millstone - Zoned	5.528E+15
	% Diff	-0.1%

Notes:

1. Millstone burnup profile applied in the analysis is illustrated in Figure 5.8.10-1.
2. Uniform (average) enrichment is 4.0 wt % ^{235}U for 6-inch blankets.

Table 5.8.10-2 Millstone Zoned Fuel Effects on Source Magnitudes

Source	Burnup Profile	Zone (Blanket) Length
		6-inch
Heat	Millstone - Uniform	1.037E+03
(W)	Millstone - Zoned	1.038E+03
	% Diff	0.0%
Neutron	Millstone - Uniform	3.765E+08
(n/s)	Millstone - Zoned	3.705E+08
	% Diff	-1.6%
Gamma	Millstone - Uniform	5.531E+15
(g/s)	Millstone - Zoned	5.528E+15
	% Diff	-0.1%

Note: Millstone burnup profile applied in the analysis is illustrated in Figure 5.8.10-1.

5.8.11 Transfer Cask Moderator Condition Study

Primary shielding evaluations of the transfer cask applied a dry condition to the canister cavity. This condition was based on the results of similar canister/cask systems that have consistently produced higher dose rates for the dry condition (i.e., the shielding effect of the water within the canister cavity more than offsets any increase in neutron source due to subcritical multiplication). To confirm this condition as bounding, shielding evaluations are performed for PWR and BWR systems containing a canister flooded, a canister dry, and a canister filled 2/3 of the active fuel region. Increased subcritical multiplication is accounted for in the portion of the canister volume flooded. Both radial and axial dose rates are plotted for the configurations documented in Section 5.8.3 and Section 5.8.4 as producing bounding system dose rates. Bounding configurations are summarized as follows:

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)
PWR Radial	14a	11.5	59	3.1
PWR Top	14b	6.0	44	2.5
BWR Radial	09a	9.6	59	3.1
BWR Top	08b	4.3	32.5	2.1

The results in Figure 5.8.11-1 through Figure 5.8.11-4 demonstrate that the dry canister configuration produces bounding transfer cask dose rates.

Figure 5.8.11-1 PWR TSC Flood Study – Radial Surface Dose Rate Profile

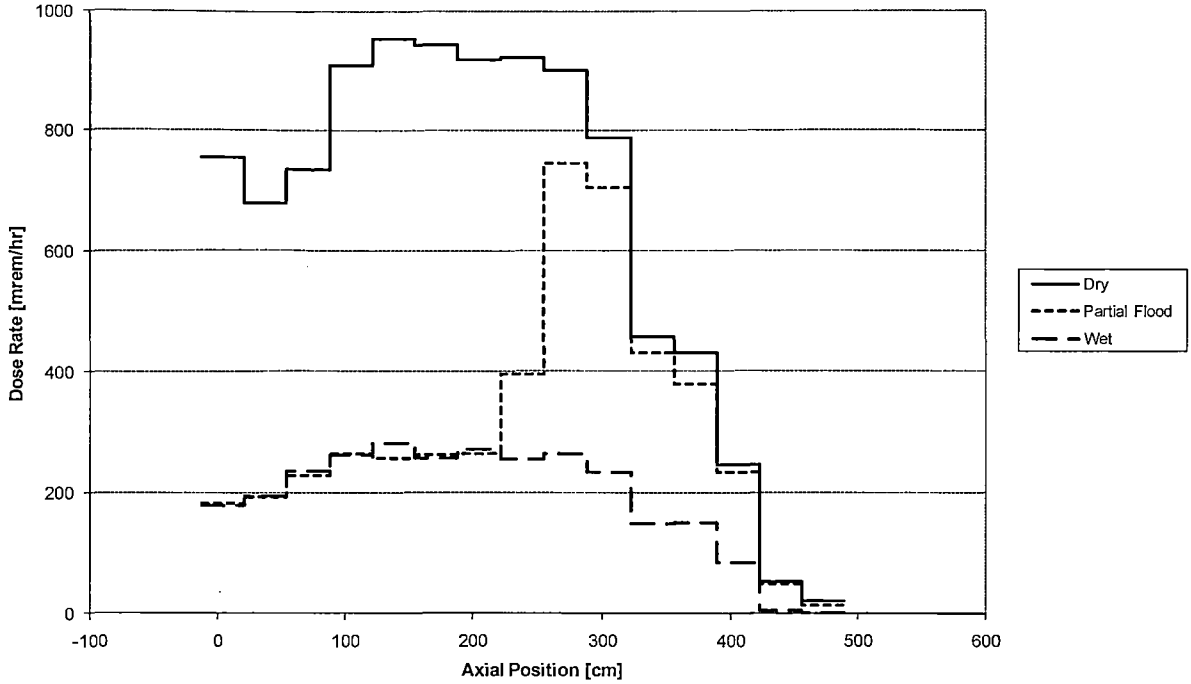


Figure 5.8.11-2 PWR TSC Flood Study – Top Axial Surface Dose Rate Profile

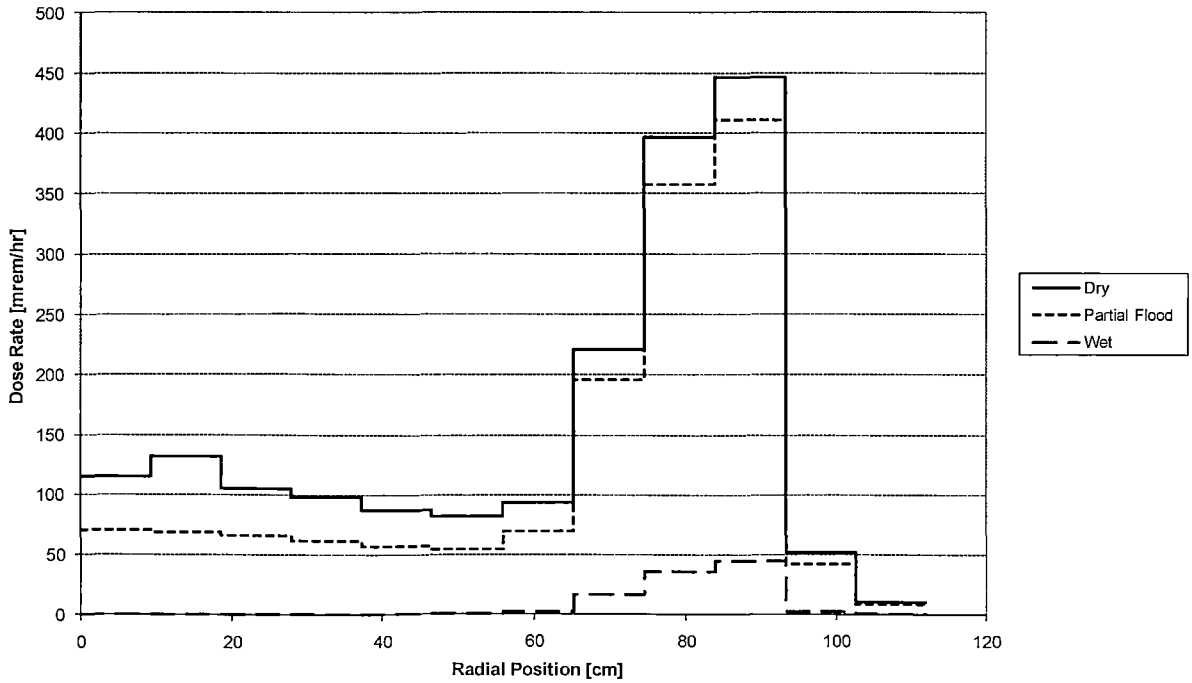


Figure 5.8.11-3 BWR TSC Flood Study – Radial Surface Dose Rate Profile

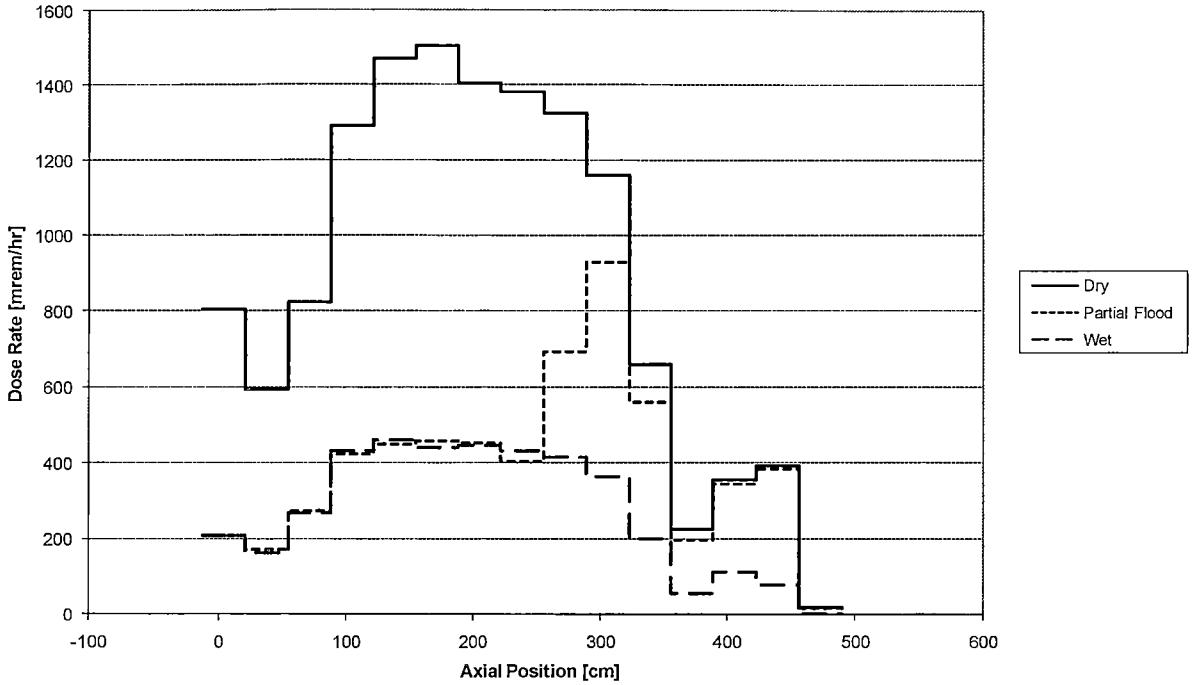
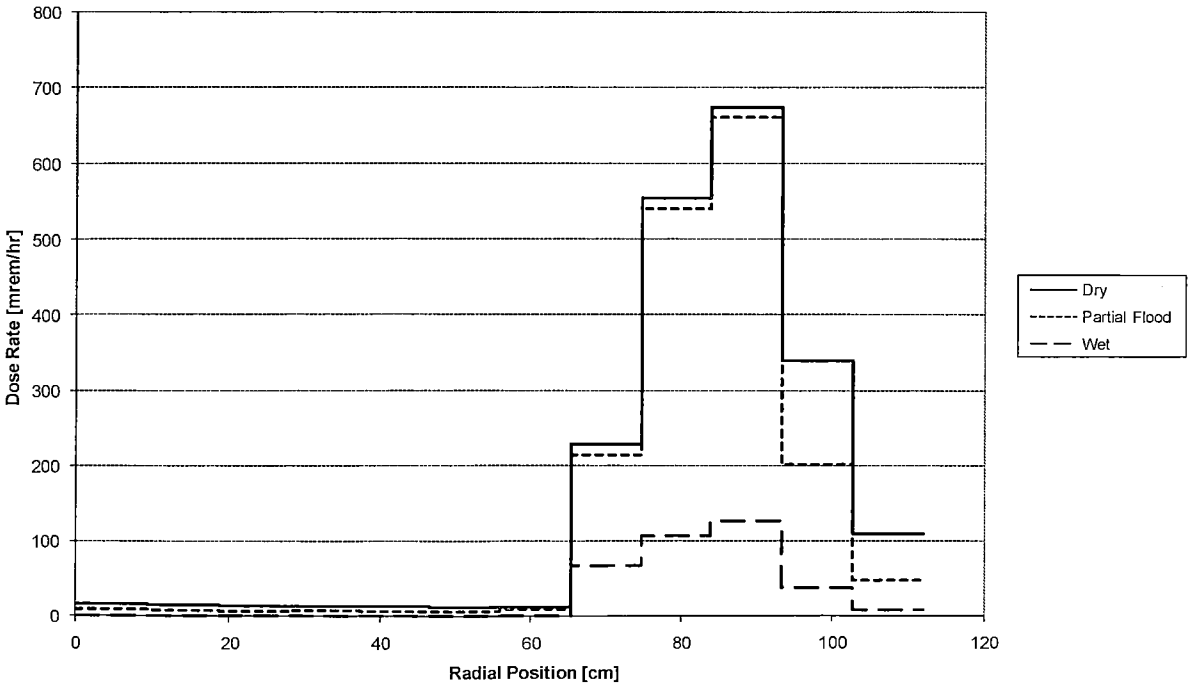


Figure 5.8.11-4 BWR TSC Flood Study – Top Axial Surface Dose Rate Profile



5.8.12 PWR Damaged Fuel

Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. DFC slots are locations 4, 8, 30 and 34 in Figure 5.8.12-10. To ensure that the worst case configuration is considered, two damaged fuel scenarios are evaluated. Damaged fuel includes fuel debris.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. This scenario is modeled by filling the fuel assembly interstitial volume with UO_2 and increasing the fuel neutron, gamma and n-gamma source consistent with this increase in mass.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. However, no credit is taken for the reduction in lower end fitting hardware dose rate due to the added UO_2 mass and self-shielding nor for the reduction in fuel mass migrated from the active fuel region.

The resulting material compositions are shown in Table 5.8.12-1 for WE 14×14 (14b) PWR fuel.

In the model, no credit is taken for the thicker plates in the corner locations of the damaged fuel basket or the thickness of the damaged fuel cans themselves.

For the transfer cask, damaged fuel dose rates are computed using the carbon steel transfer cask, as it produces higher dose rates than the stainless steel transfer cask due to the higher density of stainless versus carbon steel. For the concrete cask, damaged fuel dose rates are computed using the standard concrete cask (CC1/CC2) and the short, standard concrete cask (CC4), as they produce higher dose rates than the augmented shield concrete cask.

Cask array site boundary dose/exposure calculations performed for the undamaged fuel basket are bounding for the damaged fuel basket, as cask sources employed in the undamaged fuel basket cask array calculations are significantly higher than those used in the minimum cool time evaluation (40 kW for site boundary/cask array analysis versus 35.5 kW maximum in cool time/ cask dose analysis). Furthermore, the damaged fuel analysis results in Section 5.8.12.2 have demonstrated that the inclusion of damaged fuel has no significant effect on system surface dose rates. Therefore, there is not a significant effect on site exposure.

5.8.12.1 Transfer Cask Dose Rates

5.8.12.1.1 Active Fuel Scenario

Transfer cask dose rates are computed using the bounding fuel assembly source terms from Section 5.8.3.3.1 for the first scenario (fuel material filling void space at the active fuel region elevation). In addition to these source terms, the WE 14 ×14 (14b) bounding rail source term

from Section 5.8.5.2.3 was also included for comparison with the bounding combined maximum dose rates.

A comparison of transfer cask surface dose rates for undamaged and damaged fuel is shown in Figure 5.8.12-1 through Figure 5.8.12-3. At the top and bottom surfaces of the cask, the results for the damaged fuel model are less than those of the undamaged fuel model due to the additional self-shielding offsetting the increase in source in the four damaged fuel can basket locations. Results are based on a comparison of fuel neutron and fuel gamma sources only, as this scenario considers an increased density fuel source that would serve as additional shield material for any hardware gamma source in the region.

On the radial surface of the cask, the damaged PWR fuel results are greater than those in section 5.8.3.3.1. In order to compare the radial results to the lower nozzle scenario, the remaining source regions and BPRA results are added to the radial surface dose rate profiles for both CE 14×14 (14a) and WE 14×14 (14b) fuel assemblies resulting in maximum dose rates of 983 and 951 mrem/hr respectively. The radial surface dose rate profiles for all source regions and BPRA results are shown in Figure 5.8.12-11 and Figure 5.8.12-12. These values are less than the lower nozzle scenario maximum dose rate of 1,036 mrem/hr shown in Table 5.8.12-2.

5.8.12.1.2 Lower End Fitting Scenario

Transfer cask dose rates are computed using the bounding fuel assemblies from Section 5.8.5.2.3 for the second scenario.

The increase in radial and bottom axial dose rates from damaged fuel in the lower end fitting region of the four damaged fuel can basket locations is shown in Figure 5.8.12-4 and Figure 5.8.12-5. Damaged fuel maximum dose rates are greater than those in Section 5.8.5.2.3. Dose rates are summarized in Table 5.8.12-2.

5.8.12.2 Standard Concrete Cask Dose Rates

5.8.12.2.1 Active Fuel Scenario

Standard concrete cask dose rates are computed using the bounding fuel assembly source terms from Section 5.8.3.4.1 for the first scenario. In addition to these bounding source terms, the WE 14×14 (14b) bounding radial source term from Section 5.8.5.2.3 was also included for comparison with the bounding combined maximum dose rates.

Undamaged and damaged fuel radial and top axial dose surface rates are compared in Figure 5.8.12-6 and Figure 5.8.12-7. At the top surface of the cask, the results for the damaged fuel model are less than those of the undamaged fuel model due to the additional self-shielding

offsetting the increase in source in the four DFC basket locations. Comparisons are based on fuel neutron and fuel gamma sources only.

On the radial surface of the cask, the damaged PWR fuel results are greater than those in Section 5.8.3.4.1. In order to compare the radial results to the lower nozzle scenario, the remaining source regions and BPRA results are added to the radial surface dose rate profiles for both CE 14×14 (14a) and WE 14×14 (14b) fuel assemblies resulting in maximum dose rates of 81.7 and 80.8 mrem/hr respectively. The radial surface dose rate profiles for all source regions and BPRA results are shown in Figure 5.8.12-13 and Figure 5.8.12-14. These values are less than the lower nozzle scenario maximum dose rate of 82.3 mrem/hr shown in Table 5.8.12-3.

At the air inlets, the damaged fuel dose rate (fuel neutron and fuel gamma sources only) is greater by 24.2 mrem/hr. This value is less than the lower nozzle scenario maximum dose rate of 37.7 mrem/hr (33.0 mrem/hr damaged gamma and 4.7 mrem/hr damaged neutron) shown in Table 5.8.12-3. Therefore, the lower nozzle damaged fuel scenario is bounding.

At the air outlets, the damaged fuel dose rate (fuel neutron and fuel gamma sources only) is greater by 1.2 mrem/hr. However, this difference is within the statistical variation of the undamaged fuel results due to the difficulties in biasing the active fuel region source towards the air outlets. Therefore, no adjustment is made to the undamaged fuel air outlet dose rates for damaged fuel.

Note that the damaged fuel basket design does not physically accommodate CE 16×16 System 80 (16a) fuel that is bounding for top dose rates per Section 5.8.3.4.1. However, using CE 16×16 fuel is sufficient to demonstrate that the active fuel damaged fuel scenario does not produce bounding dose rates.

5.8.12.2.2 Lower End Fitting Scenario

Standard concrete cask dose rates are computed using the bounding fuel assemblies from Section 5.8.5.2.3 for the second scenario.

The increase in radial and inlet dose rates from damaged fuel in the lower end fitting region of the four damaged fuel can basket locations is shown in Figure 5.8.12-8 and Figure 5.8.12-9. Damaged fuel maximum dose rates are greater than those in Section 5.8.5.2.3. Dose rates are summarized in Table 5.8.12-3.

The average damaged fuel dose rate at the radial surface of the concrete cask is less than 1 mrem/hour. This increase is significantly less than the average lower end fitting hardware dose rate of 5.1 mrem/hr for undamaged fuel. Because much of the lower end fitting undamaged source is expected to be self-shielded by the UO_2 in the lower end fitting void space, no adjustment to the surface currents used in the site boundary evaluation is necessary.

5.8.12.3 CC4 Dose Rates

5.8.12.3.1 Active Fuel Scenario

CC4 dose rates are computed using the bounding fuel assembly source terms from Section 5.8.3.4.3 for the first scenario. Undamaged and damaged fuel radial and top axial dose surface rates are compared in Figure 5.8.12-15 and Figure 5.8.12-16. At the top and radial surfaces of the cask, maximum and average dose rates for the damaged PWR fuel model are statistically equivalent to those of the undamaged fuel model due to the additional self-shielding offsetting the increase in source in the four DFC basket locations. The same is true for inlet and outlet results. Comparisons are based on fuel neutron and fuel gamma sources only.

5.8.12.3.2 Lower End Fitting Scenario

CC4 dose rates are computed using the bounding fuel assemblies from Section 5.8.5.2.3 for the second scenario. The increase in radial and inlet dose rates from damaged fuel in the lower end fitting region of the four damaged fuel can basket locations is shown in Figure 5.8.12-17 and Figure 5.8.12-18. Damaged fuel maximum radial dose rates are statistically unchanged from those in Section 5.8.5.2.3. Inlet dose rates are increased for the damaged fuel but are still bounded by the standard concrete cask due to lack of additional inlet shielding. Dose rates are summarized in Table 5.8.12-4.

Figure 5.8.12-1 Dose Rate Profile Comparison at Radial Surface of Transfer Cask – Active Fuel Damaged PWR Fuel – CE 14×14

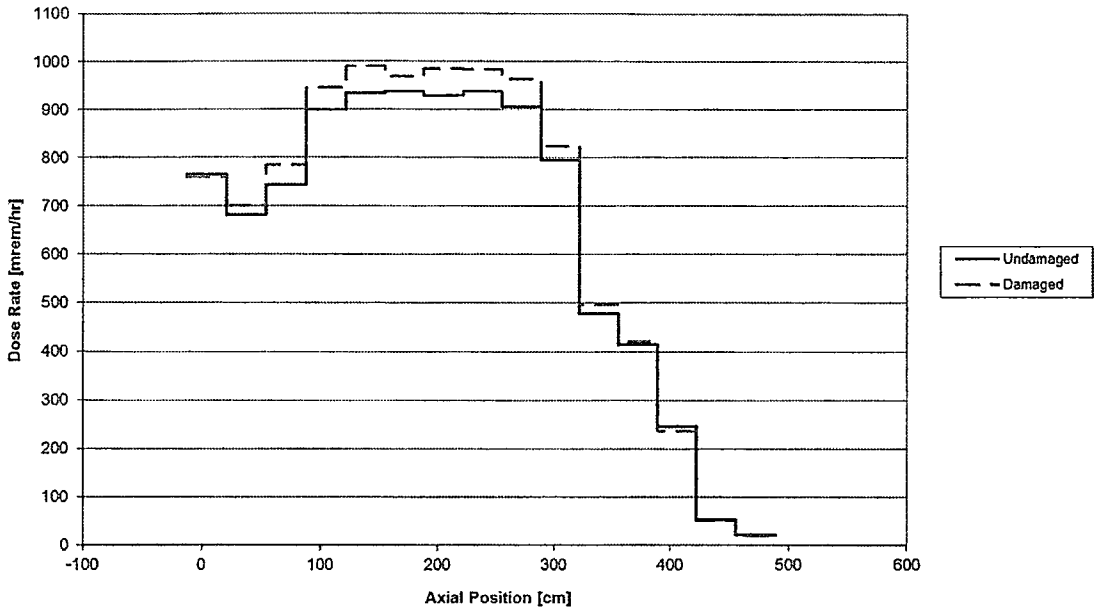


Figure 5.8.12-2 Dose Rate Profile Comparison at Top Surface of Transfer Cask – Active Fuel Damaged PWR Fuel – WE 14×14

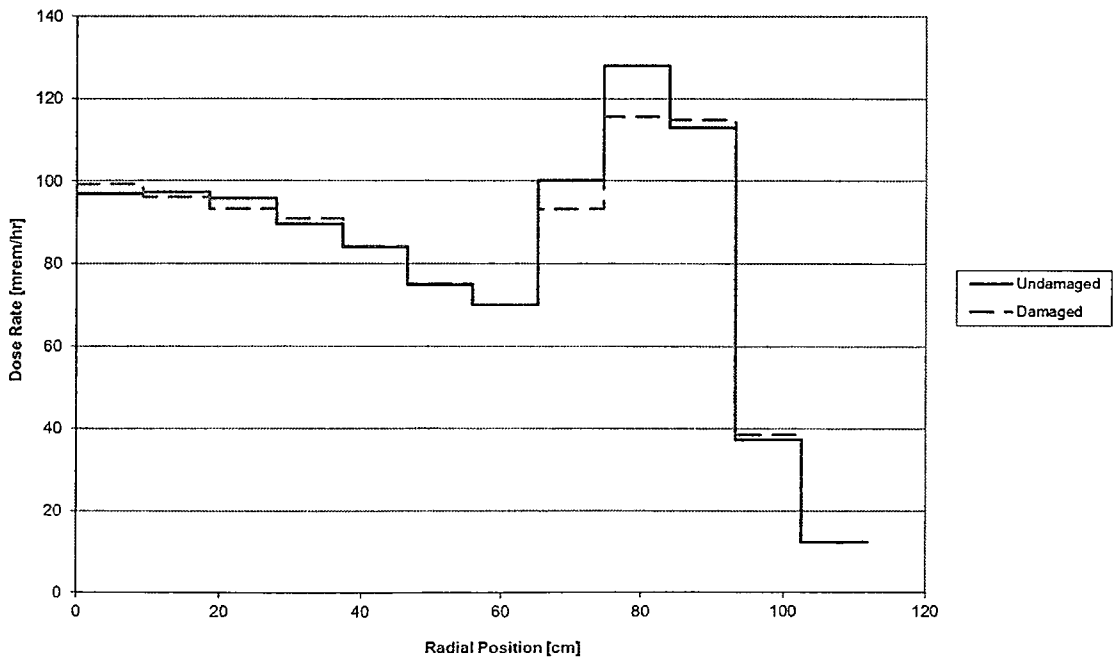


Figure 5.8.12-3 Dose Rate Profile Comparison at Bottom Surface of Transfer Cask – Active Fuel Damaged PWR Fuel – WE 14×14

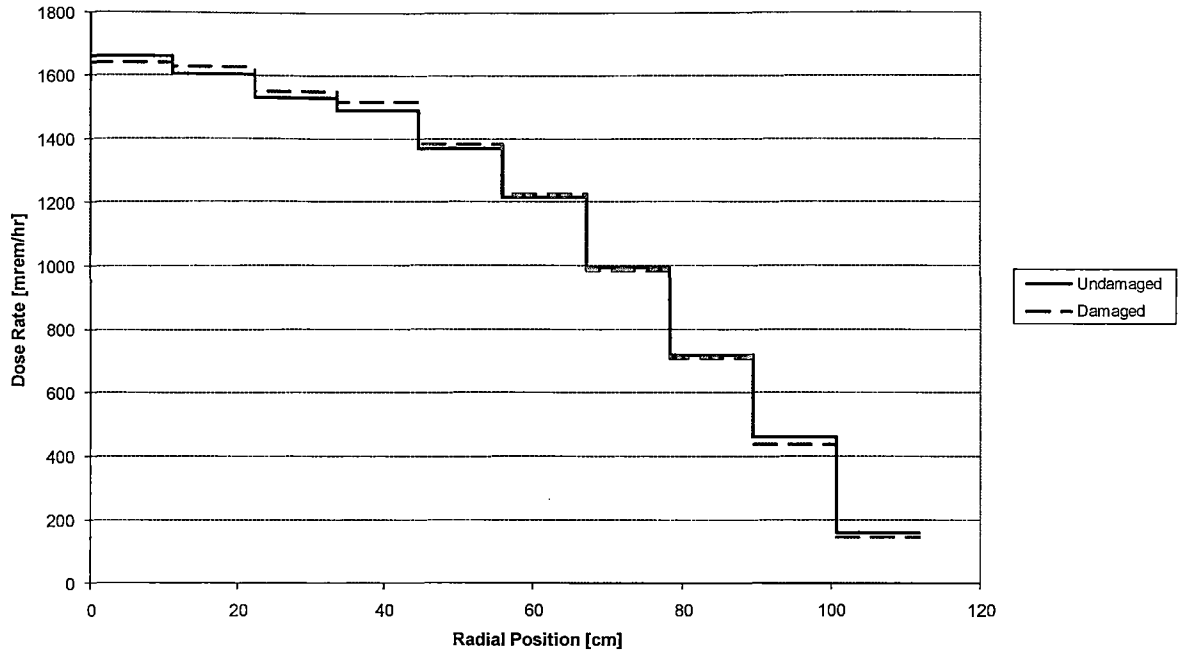


Figure 5.8.12-4 Dose Rate Profile at Radial Surface of Transfer Cask – Lower End Fitting Damaged PWR Fuel – WE 14×14

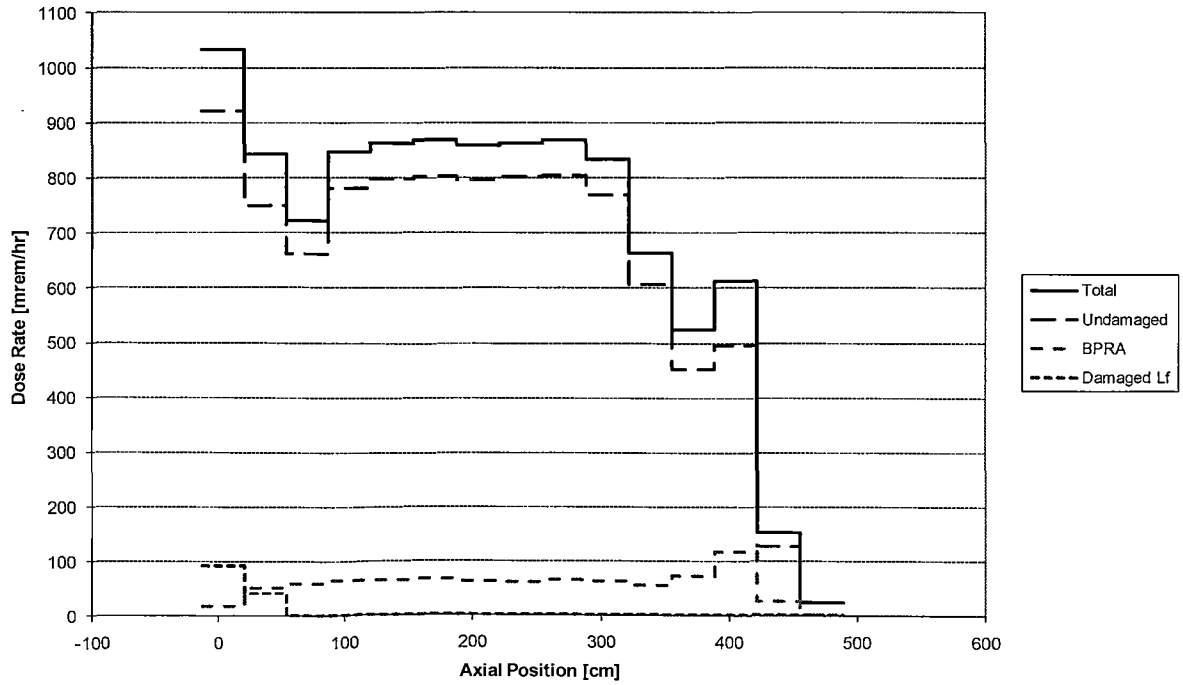


Figure 5.8.12-5 Dose Rate Profile at Bottom Surface of Transfer Cask – Lower End Fitting Damaged PWR Fuel – WE 14×14

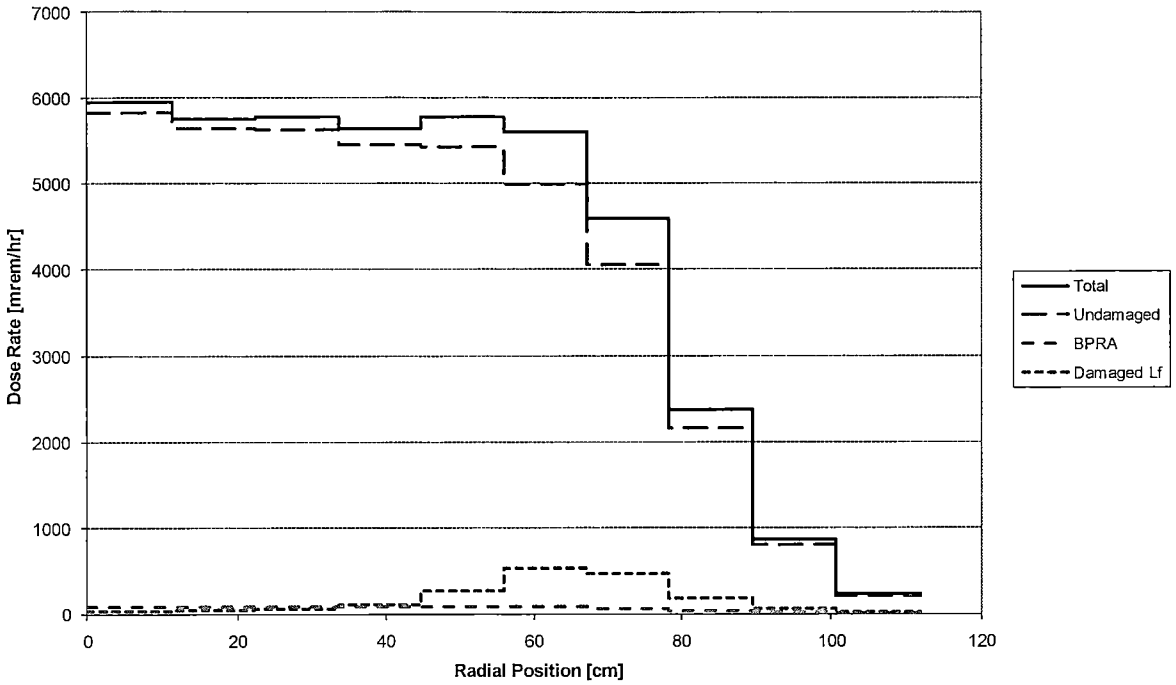


Figure 5.8.12-6 Dose Rate Profile Comparison at Radial Surface of Standard Concrete Cask – Active Fuel Damaged PWR Fuel – CE 14×14

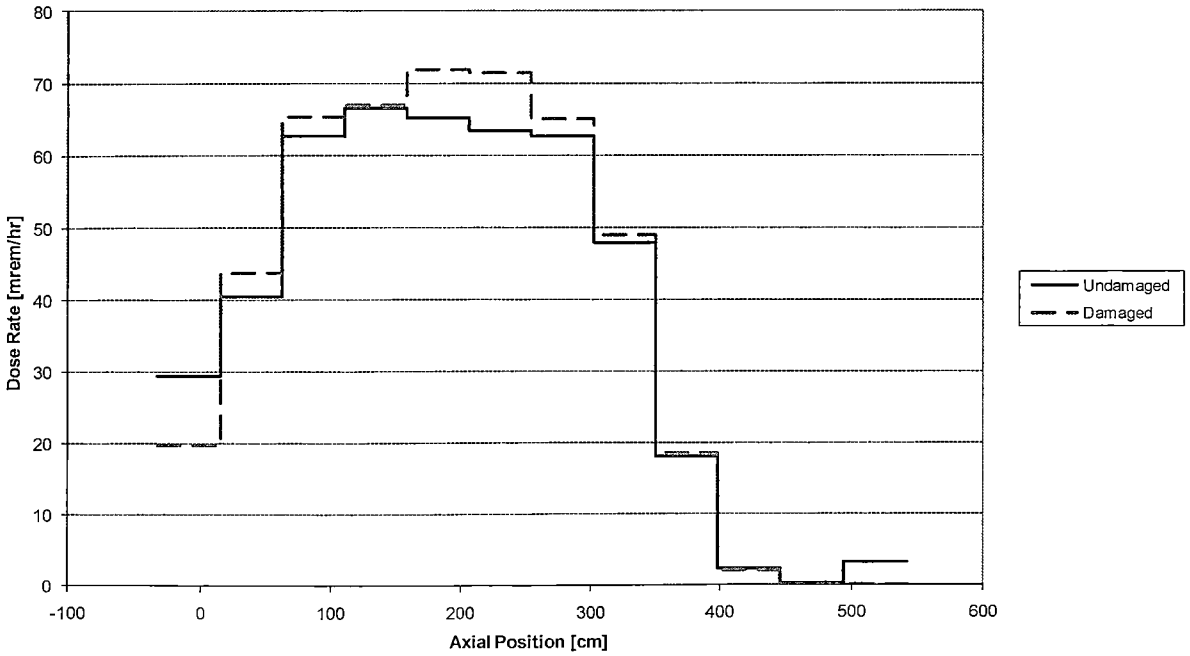


Figure 5.8.12-7 Dose Rate Profile Comparison at Top Surface of Standard Concrete Cask – Active Fuel Damaged PWR Fuel – CE 16×16

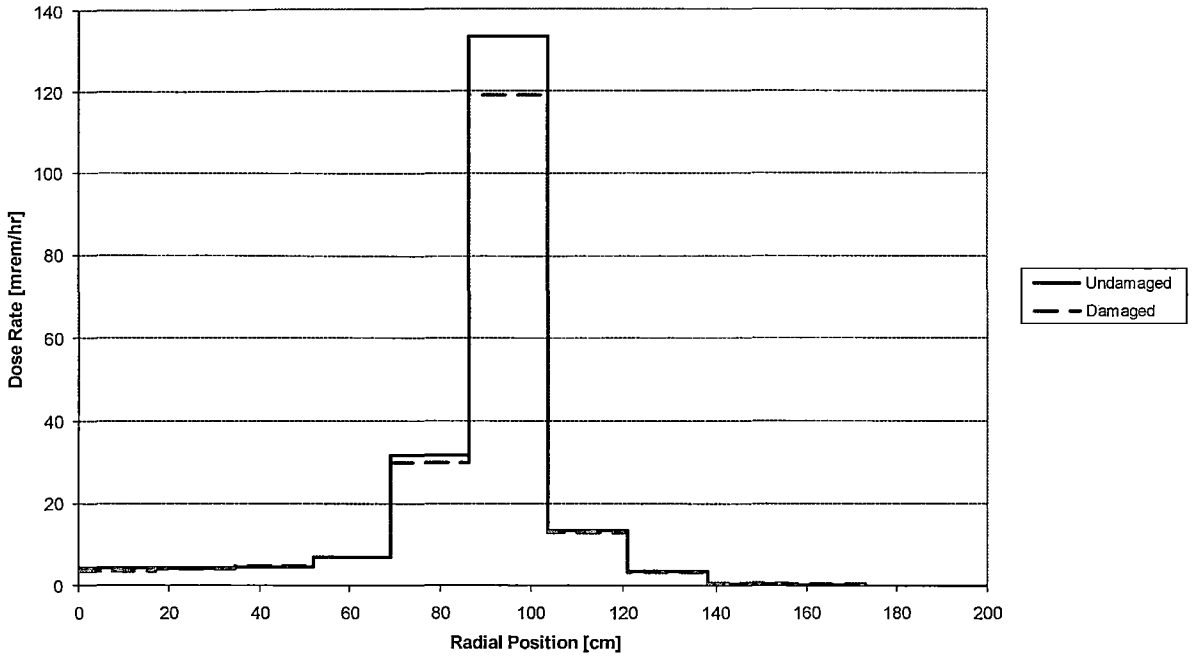


Figure 5.8.12-8 Dose Rate Profile at Radial Surface of Concrete Cask – Lower End Fitting Damaged PWR Fuel – WE 14×14

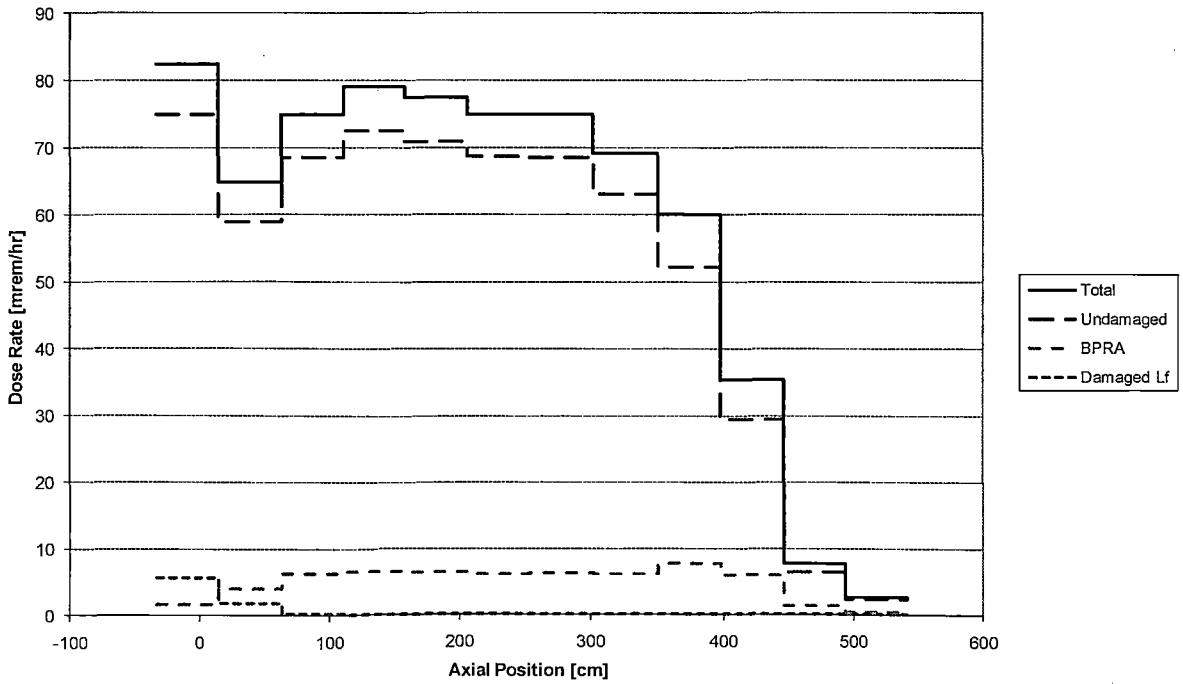


Figure 5.8.12-9 Concrete Cask Inlet Dose Rate Profile – Lower End Fitting Damaged PWR Fuel – WE 14×14

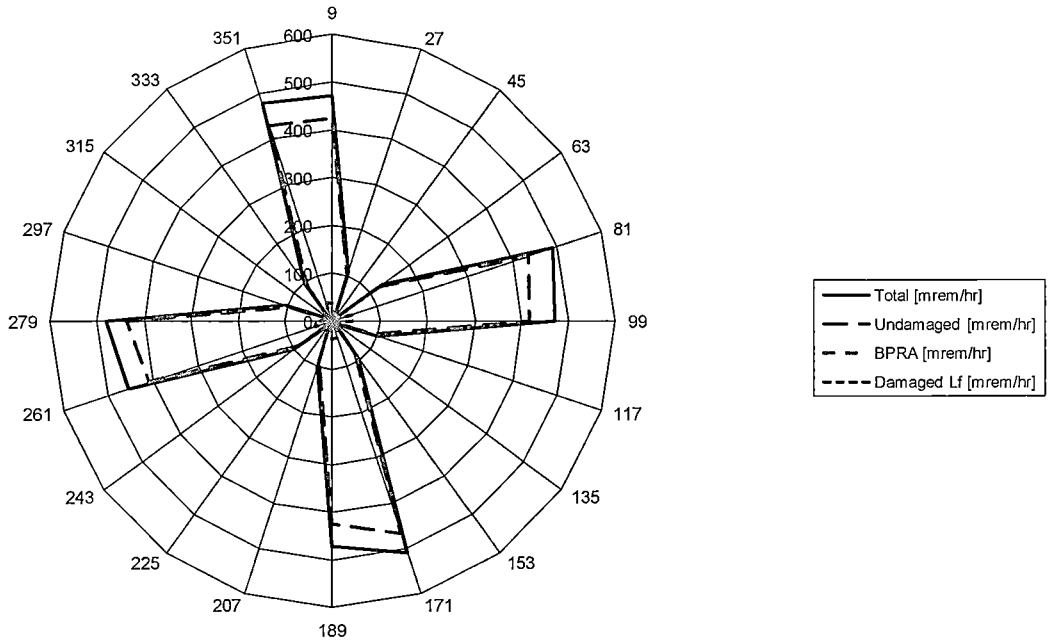
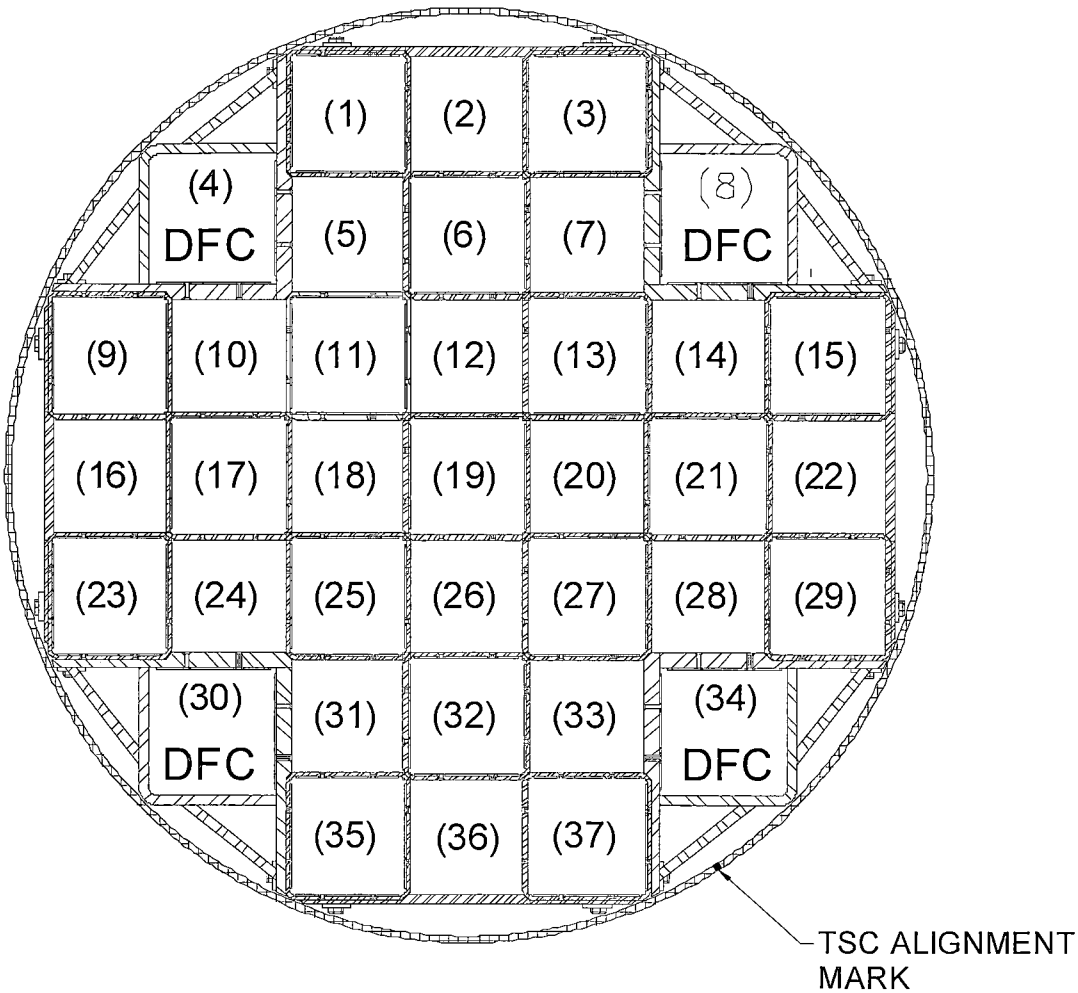


Figure 5.8.12-10 Schematic of DF Basket Assembly Configuration for PWR SNF with DFCs



DFC designated locations may contain a loaded DFC or a PWR UNDAMAGED SNF ASSEMBLY.

Figure 5.8.12-11 Dose Rate Profile Comparison at Radial Surface of Transfer Cask – Active Fuel Damaged PWR Fuel – CE 14×14 – All Source Regions

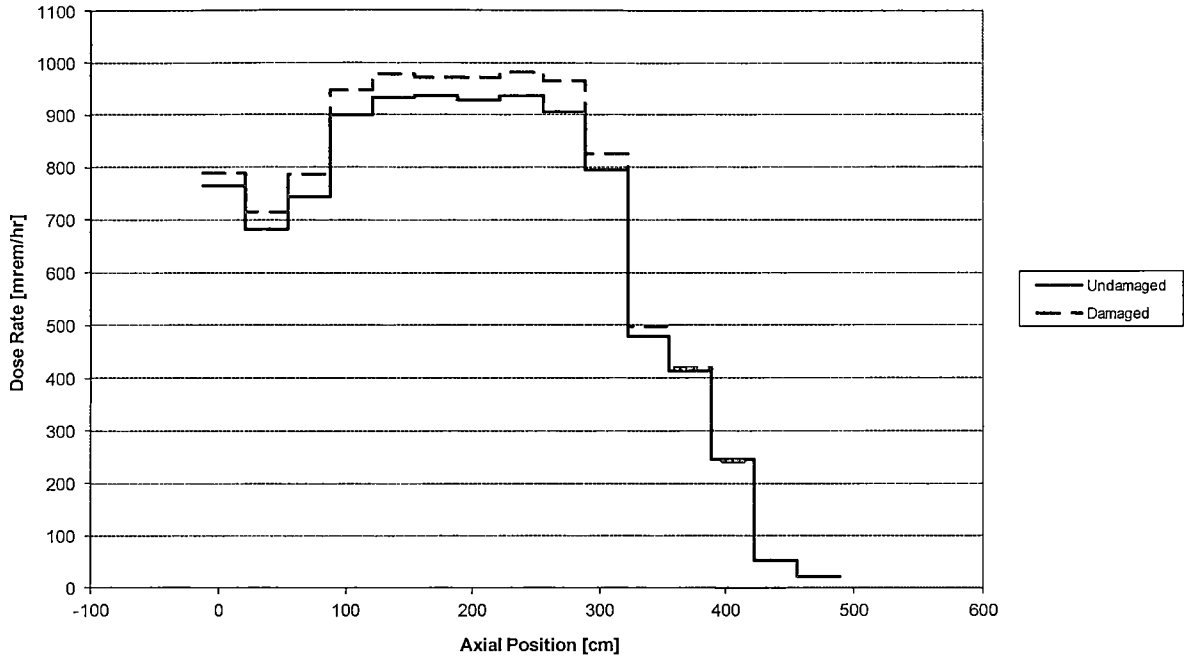


Figure 5.8.12-12 Dose Rate Profile Comparison at Radial Surface of Transfer Cask – Active Fuel Damaged PWR Fuel – WE 14×14 – All Source Regions and BPRAs

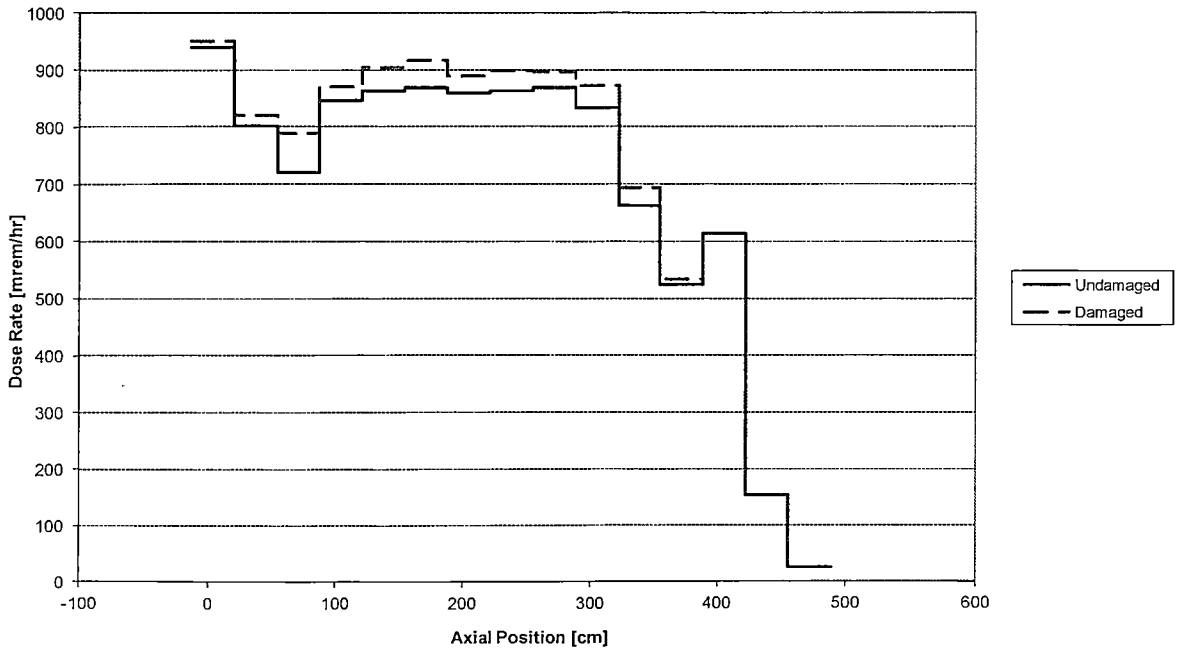


Figure 5.8.12-13 Dose Rate Profile Comparison at Radial Surface of Standard Storage Cask – Active Fuel Damaged PWR Fuel – CE 14×14 – All Source Regions

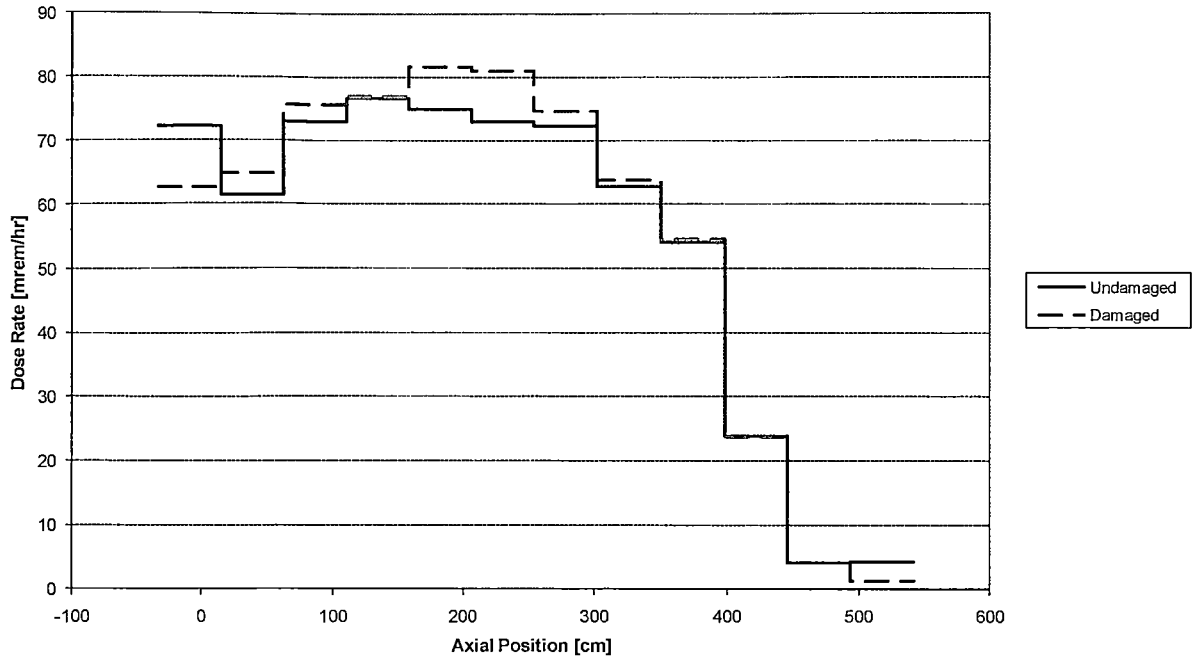


Figure 5.8.12-14 Dose Rate Profile Comparison at Radial Surface of Standard Storage Cask – Active Fuel Damaged PWR Fuel – WE 14×14 – All Source Regions and BPRAs

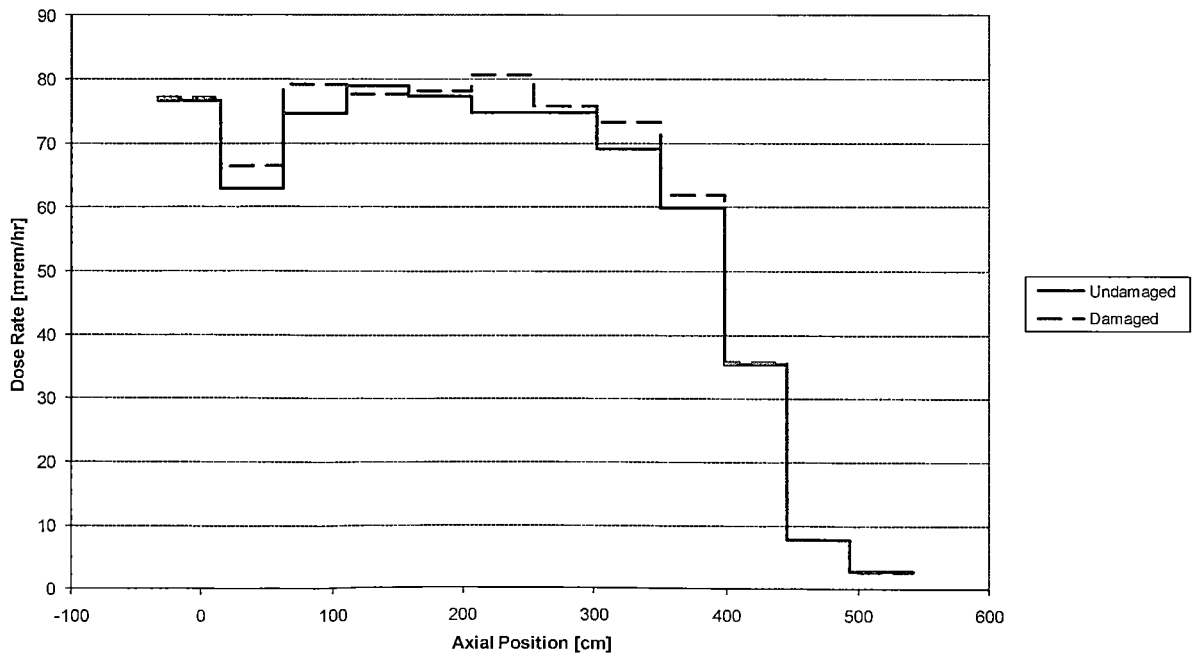


Figure 5.8.12-15 Dose Rate Profile Comparison at Radial Surface of CC4 Concrete Cask – Active Fuel Damaged PWR Fuel – CE 14x14

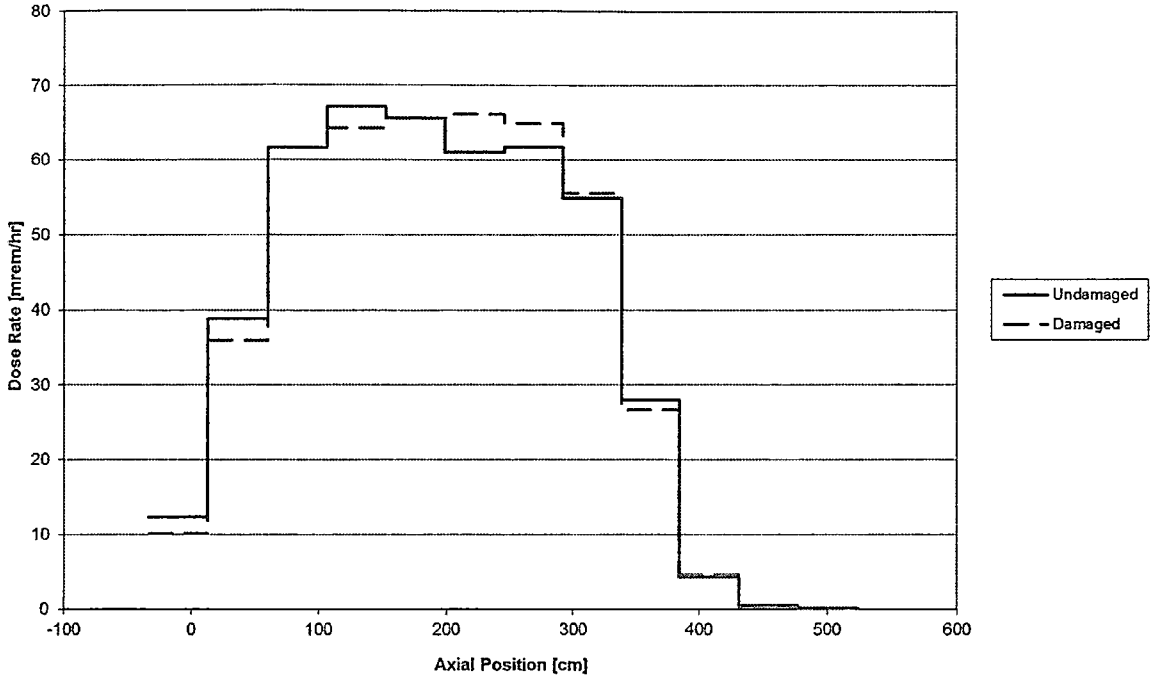


Figure 5.8.12-16 Dose Rate Profile Comparison at Top Surface of CC4 Concrete Cask – Active Fuel Damaged PWR Fuel – WE 14x14

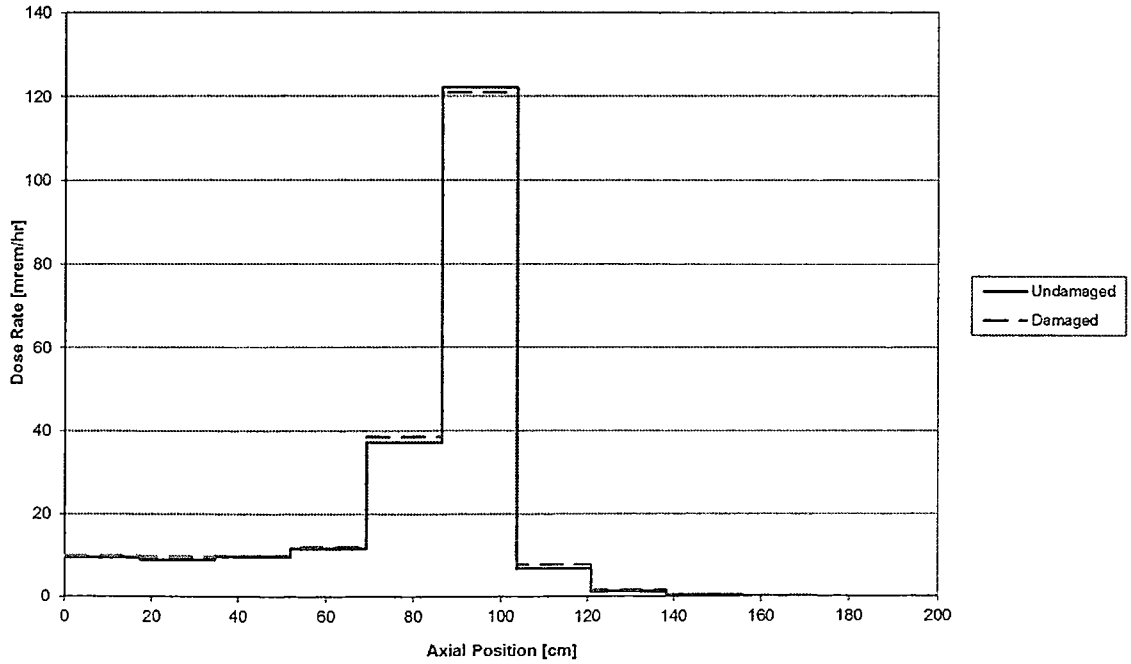


Figure 5.8.12-17 Dose Rate Profile at Radial Surface of CC4 – Lower End Fitting Damaged PWR Fuel

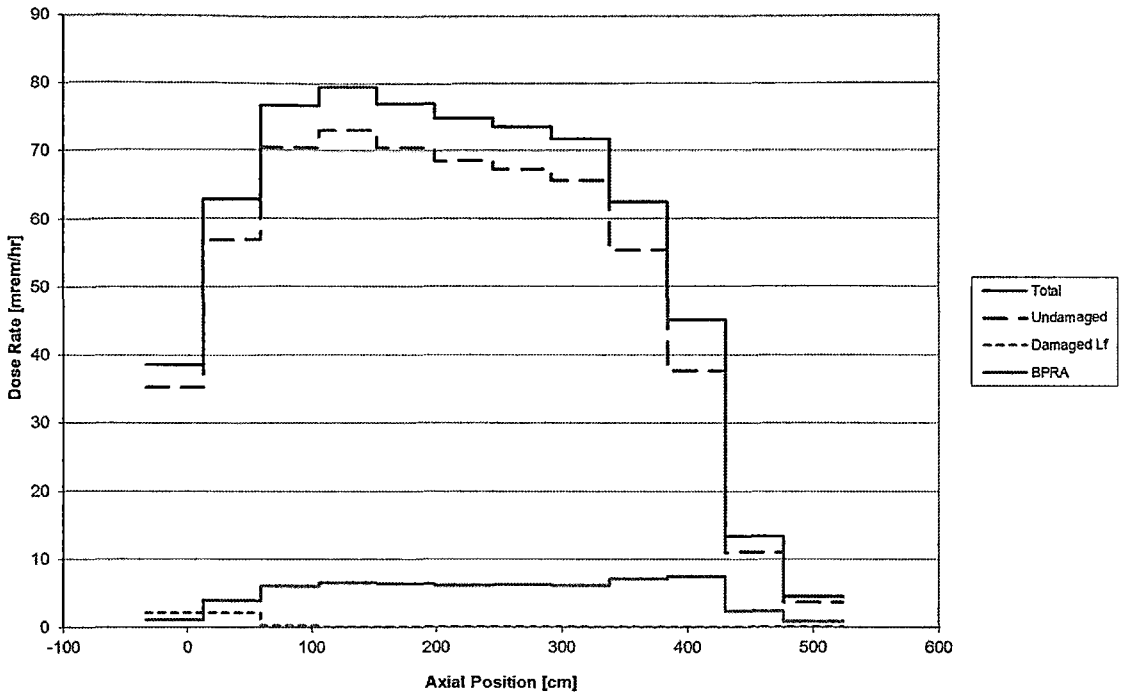


Figure 5.8.12-18 CC4 Inlet Dose Rate Profile – Lower End Fitting Damaged PWR Fuel

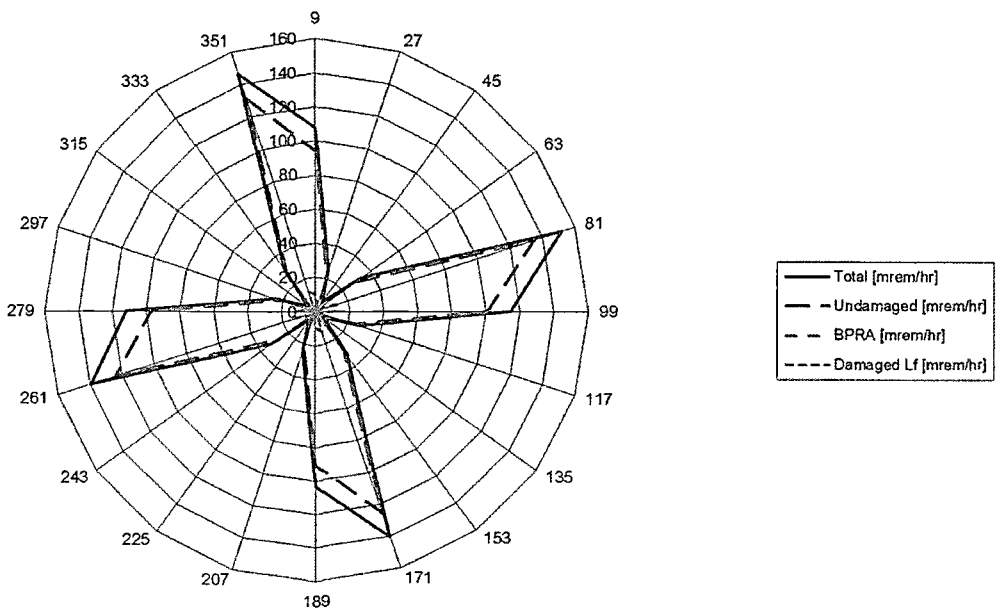


Table 5.8.12-1 Damaged Fuel Material Summary – 14b PWR Fuel

Material	Element/ Isotope	Density [atom/-b-cm]	Density [g/cm³]
Damaged Fuel (Lower Nozzle)	Chromium	5.5169E-03	9.6315
	Manganese	5.4963E-04	
	Iron	1.8789E-02	
	Nickel	2.4436E-03	
	Uranium 235	8.0452E-04	
	Uranium 238	1.5093E-02	
	Oxygen	3.1786E-02	
Damaged Fuel (Active Fuel)	Zirconium	3.6954E-03	9.8635
	Chromium	6.6005E-06	
	Tin	4.3366E-05	
	Nitrogen	1.2255E-05	
	Iron	7.6817E-06	
	Uranium 235	1.0495E-03	
	Uranium 238	1.9688E-02	
	Oxygen	4.1462E-02	

Table 5.8.12-2 Transfer Cask Maximum Damaged PWR Fuel Dose Rates

		Surface		1 meter	
Detector	Source	mrem/hr	FSD[a]	mrem/hr	FSD
Radial	Undamaged	923	0.5%	320	0.3%
	BPRA	19	4.3%	29	1.3%
	Damaged Neutron	46	1.2%	0.6	4.3%
	Damaged Gamma	48	2.0%	0.4	4.7%
	Total	1,036	0.5%	350	0.3%
Bottom	Undamaged	5,824	1.6%	2,638	0.7%
	BPRA	84	5.4%	45	1.8%
	Damaged Neutron	53	9.2%	61	3.6%
	Damaged Gamma	--	--	88	1.2%
	Total	5,961	1.5%	2,832	0.6%

[a] Fractional standard deviation.

Table 5.8.12-3 Standard Concrete Cask Maximum Damaged PWR Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD	mrem/hr	FSD
Radial	Undamaged	74.9	7.3%	37.1	0.3%
	BPRA	1.7	3.5%	3.3	0.5%
	Damaged Neutron	0.4	0.3%	0.0	1.4%
	Damaged Gamma	5.3	7.6%	0.1	4.3%
	Total	82.3	6.6%	40.5	0.2%
Inlet	Undamaged	425.4	1.4%	69.7	2.6%
	BPRA	8.7	3.5%	1.3	5.7%
	Damaged Neutron	4.7	0.6%	0.7	1.2%
	Damaged Gamma	33.0	2.7%	6.6	4.9%
	Total	471.8	1.3%	78.3	2.4%

Table 5.8.12-4 CC4 Maximum Damaged PWR Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD	mrem/hr	FSD
Radial	Undamaged	73.0	1.5%	37.3	1.0%
	BPRA	6.5	1.1%	3.3	0.7%
	Damaged Neutron	0.0	2.5%	0.0	0.8%
	Damaged Gamma	0.01	38%	0.1	8.9%
	Total	79.5	1.4%	40.7	0.9%
Inlet	Undamaged	112.4	1.4%	16.2	9.2%
	BPRA	2.6	21.8%	0.3	36.9%
	Damaged Neutron	4.1	0.6%	0.5	1.8%
	Damaged Gamma	7.5	2.7%	1.1	19.1%
	Total	126.6	4.4%	18.2	8.3%

5.8.13 Nonfuel Hardware Components – Neutron Sources, Reconstituted Assemblies, and Hafnium Flux Reduction Assemblies

This section discusses effects of neutron sources, reconstituted assemblies with stainless steel replacement rods, and hafnium flux reduction assemblies.

5.8.13.1 Primary and Secondary Neutron Sources and Source Assemblies

Primary neutron source strengths and source assembly strengths are on the order of 1×10^8 to 1×10^9 neutrons/second when they are initially put into the reactor [30]. These sources diminish as the source isotopes decay over time or are transmuted by neutron absorption during in-core use. Typical primary neutron sources are Pu-Be and ^{252}Cf sources, but other radionuclides may be used. A majority of the isotopes in neutron sources have half lives on the order of days or a few years (e.g., ^{252}Cf has a half life of 2.6 years), and the source strength will be significantly diminished before the neutron source is stored. The ^{238}Pu and ^{241}Am isotopes have half lives of 87 and 433 years, respectively. Therefore, their source strength does not diminish significantly as a result of radioactive decay alone.

Secondary neutron sources become active after activation by thermal neutrons in the reactor core. The most common secondary source, SbBe, relies on the gamma decay of ^{124}Sb to produce a γ,n reaction in Be. As ^{124}Sb has a half life of 2.7 years, the strength of the source significantly diminishes once removed from the reactor core as the production of ^{124}Sb ends. As maximum source strength occurs at core shutdown and is typically designed to produce a source no higher than the primary source due to source decay, the secondary sources are not bounding for system performance.

As the initial source strength of neutron sources has the same order of magnitude of a fuel assembly, the loading of a single neutron source in a system with 37 fuel assemblies would have less than a 3% effect on the neutron source in the system. The loading of neutron sources is restricted to one assembly, regardless of neutron source type, in one of the nine interior locations. Due to shielding provided by the outer assemblies, the dose rate effect of the already small source increase in the system is further mitigated. Therefore, there is no significant dose rate effect of loading a primary or secondary neutron source.

Neutron source assemblies may contain source rods attached to hardware similar in configuration to guide tube plug devices (thimble plugs) and burnable absorbers, in addition to containing burnable poison rodlets and/or thimble plug rodlets. For NSAs containing absorber rodlets, the BPRA cool time and burnup/exposure or hardware ^{60}Co curie limit listed in Section 5.8.5 are applied to the neutron sources. NSAs having only thimble plug rodlets require the thimble plug

restriction in Section 5.8.5.2.2 to be applied. Combination NSAs, containing both thimble plug and burnable absorber rodlets, must apply the more limiting of the two minimum cool time/curie limits.

5.8.13.2 Reconstituted Assemblies

Reconstituted assemblies have fuel rods that have been replaced with an inert material. When this inert material is stainless steel, the activation source of these rods must be considered.

If stainless steel rods are inserted into an assembly and further burned, the number of stainless steel replacement rods is limited to five per assembly (13.90 kg for the evaluated sample fuel type) and a maximum exposure of 32.5 GWd/MTU. Any number of unirradiated (i.e., no in-core use) stainless steel replacement rods are acceptable for storage. No credit is taken for the reduction in fuel (UO_2) source for the replaced fuel rods. The stainless steel replacement rod source was modeled in the basket periphery and at the periphery of the fuel assembly, minimizing the effect of intra- and inter-assembly self-shielding.

Azimuthal dose rate comparisons for the storage and transfer cask were made using the bounding radial source terms for Westinghouse 15×15 (15a) fuel. The azimuthal detectors for each cask are centered on the fuel midplane with a total height of 30.48 cm.

Storage cask dose rates are compared in Figure 5.8.13-1. The stainless steel rod contribution is approximately 20% that of the fuel assembly contribution in two azimuthal subdetectors (10% of the cask circumference). Over the entire circumference of the cask, the stainless steel rod contribution is approximately 2% that of the fuel assembly contribution.

Transfer cask dose rates are compared in Figure 5.8.13-2. The stainless steel rod contribution is approximately 30% that of the fuel assembly contribution in a single azimuthal subdetector (2% of the cask circumference). Over the entire circumference of the cask, the stainless steel rod contribution is approximately 2% that of the fuel assembly contribution.

With the narrow peak band, a bounding configuration of all activated steel facing the cask surface, and the overall minimal increase in total dose rate, the loading of a reconstituted fuel assembly in the MAGNASTOR system does not significantly affect dose rates. Therefore, a single reconstituted fuel assembly containing irradiated stainless steel rods may be loaded in any location in the basket. No limit exists on the number of reconstituted assemblies with unirradiated steel rods or zirconium alloy filler rods. Furthermore, no adjustment is required to site boundary dose rates or transfer cask occupational exposures due to the loading of a single reconstituted fuel assembly.

5.8.13.3 Hafnium Flux Reduction Assemblies

Hafnium flux reduction assemblies (HFRAs) are used to reduce neutron flux, typically at peripheral core locations where reactor vessel damage due to neutron fluence is a concern. Hafnium rods are inserted into guide tube locations and their maximum number is governed by the number of guide tubes.

Due to the effectiveness of the hafnium rods in reducing neutron flux, coupled with neutron leakage at the core periphery, the exposure of the hafnium rod containing assemblies is limited to 4,000 MWd/MTU. The assembly exposure is conservatively applied to hafnium flux rods with no credit for self-shielding or reduced flux in the guide tube locations. The SAS2H input for this exposure is shown in Figure 5.8.13-3. The input file models an initial enrichment of 1.1 wt % ^{235}U, consistent with the insertion of hafnium rods after two cycles of exposure.

The source from 20 hafnium rods (70.45 kg) is compared to the bounding active fuel region BPRA source for Westinghouse 15×15 (15a) fuel (55 GWd/MTU exposure, 3.1 wt % ^{235}U, and 8 years cool time) in Table 5.8.13-1. The only group where HFRAs have considerable gamma source at a considerable strength when compared to BPRAs is group 11. The HFRA has approximately 100 times the BPRA source in group 11, but the magnitude of the contribution from group 11 is insignificant when compared to surrounding groups. The HFRA source in group 11 is on the order of 10^4, which is nine orders of magnitude smaller than the BPRA source in group 12 (10^{13}) and four orders of magnitude smaller than the BPRA source in group 9.

Therefore, HFRAs are bounded by BPRAs and placement in any basket location is acceptable.

Figure 5.8.13-1 Reconstituted Assembly Radial Dose Rate Comparison – Storage Cask

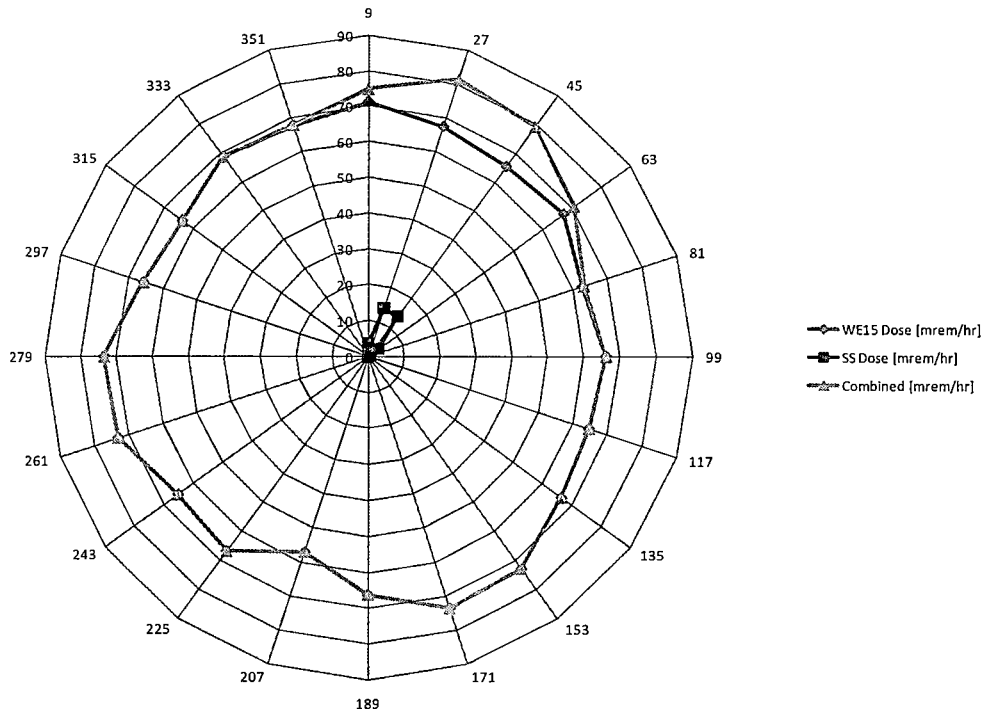


Figure 5.8.13-2 Reconstituted Assembly Radial Dose Rate Comparison – Transfer Cask

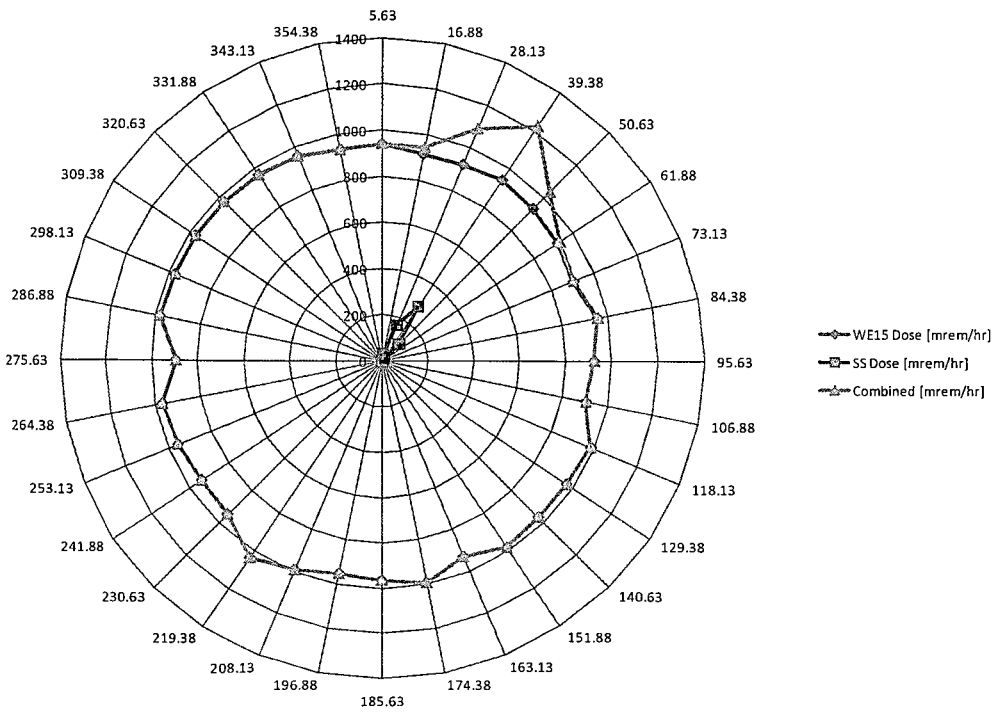


Figure 5.8.13-3 SAS2H Input for HFRA Source

```
=SAS2       PARM='HALT01,SKIPSHIPDATA'
Class 1 - ng15a - WE15 (Rev 0) - 1.1 w/o U235, 4000 MWD/MTU, 5-16 yrs cool
44GROUPNDF5  LATTICECELL
UO2         1 0.950 900 92235 1.1 92238 98.9 END
ZR 2 1.0 620. END
H2O         3 DEN=0.725 1.0 580 END
ARBM-BORMOD 0.725 1 1 0 0 5000 100 3 550.0E-6 580 END
ZR  4 1.0 580 END
H2O         5 DEN=0.725 0.9835 580 END
ZR  5 0.0165 580 END
END COMP
SQUAREPITCH 1.4300 0.9319 1 3 1.0719 2 0.9489 0 END
NPIN=204 FUEL=365.760 NCYC=1 NLIB=1 PRIN=6 LIGH=1
INPL=1 NUMH=20 NUMI=1 MXTUBE=4 ORTU=0.6147 SRTU=0.5766 END
POWER=7.3059 BURN=547.500 DOWN=1461 END
HF 1
END
```

Note: SAS2H run for four-year cool time is followed by ORIGENS decay run to 16 years.

Table 5.8.13-1 HFRA vs. BPRA Source Comparison

Energy Group	[MeV]			BPRA [gamma/sec]	HFRA [gamma/sec]	HFRA/BPRA
1	1.20E+01	to	1.40E+01	0.00E+00	0.00E+00	--
2	1.00E+01	to	1.20E+01	0.00E+00	0.00E+00	--
3	8.00E+00	to	1.00E+01	0.00E+00	0.00E+00	--
4	6.50E+00	to	8.00E+00	0.00E+00	0.00E+00	--
5	5.00E+00	to	6.50E+00	0.00E+00	0.00E+00	--
6	4.00E+00	to	5.00E+00	0.00E+00	0.00E+00	--
7	3.00E+00	to	4.00E+00	7.78E-14	0.00E+00	0
8	2.50E+00	to	3.00E+00	6.30E+05	0.00E+00	0
9	2.00E+00	to	2.50E+00	4.06E+08	3.98E-17	9.79E-26
10	1.66E+00	to	2.00E+00	1.02E-01	1.30E-04	1.28E-03
11	1.44E+00	to	1.66E+00	1.08E+02	1.25E+04	1.16E+02
12	1.22E+00	to	1.44E+00	3.85E+13	8.32E+06	2.16E-07
13	1.00E+00	to	1.22E+00	4.06E+13	2.15E+07	5.29E-07
14	8.00E-01	to	1.00E+00	5.68E+10	6.80E+05	1.20E-05
15	6.00E-01	to	8.00E-01	7.16E+07	8.82E+01	1.23E-06
16	4.00E-01	to	6.00E-01	2.06E+08	3.52E+02	1.71E-06
17	3.00E-01	to	4.00E-01	3.26E+09	7.16E+03	2.20E-06
18	2.00E-01	to	3.00E-01	2.49E+09	4.41E+06	1.77E-03
19	1.00E-01	to	2.00E-01	5.01E+10	7.90E+06	1.58E-04
20	5.00E-02	to	1.00E-01	2.08E+11	2.66E+07	1.28E-04
21	2.00E-02	to	5.00E-02	5.95E+11	1.12E+06	1.88E-06
22	1.00E-02	to	2.00E-02	7.08E+11	1.01E+06	1.42E-06
			TOTAL	8.07E+13	7.15E+07	8.86E-07

5.9 PWR Reduced Minimum Cool Time and Alternate Preferential Heat Load Pattern Shielding Evaluation Detail

This section contains evaluation detail for Westinghouse 14x14 fuel assemblies with a minimum cool time of 2.5 years loaded in the CC4 and stainless steel MTC. This section includes uniform loading and four zone preferential loading with a maximum assembly heat load of 1.8 kW. Evaluations are documented for undamaged and damaged fuel. The minimum cool time for the Westinghouse 14x14 CEAs was reduced to 2.5 years from the previous minimum cool time of 10 years.

Evaluation methods and models are based on those described in Section 5.8, with changes limited to those associated with reducing minimum permitted cool time to 2.5 years, modeling a four region preferential heat loading pattern, and allowing WE 14x14 CEAs to be cooled 2.5 years. Activated mass of the WE 14x14 CEA was calculated based on the known dimensions of the WE 15x15 CEA (see Section 5.9.5).

Uniform heat load evaluations at a minimum cool time of 2.5 years are included in Section 5.9.3. Preferential loading for heat load is discussed in Section 5.9.6. The effects of nonfuel hardware components to dose rates and heat load are discussed in Sections 5.9.4 and 5.9.5. Model differences, dose rates and minimum loading time impacts resulting from the damaged fuel basket configuration are discussed in Section 5.9.9.

5.9.1 Contents Description

Three-dimensional models of the loaded TSC within the stainless steel transfer or CC4 concrete cask require the relative elevations of the various source regions, hardware masses, and in-core condition to describe source and shielding models. The elevation of each of the assembly regions also defines the volume into which the fuel assembly is homogenized.

As described in Section 5.2, PWR fuel assemblies were surveyed to construct hybrids containing maximum fuel and hardware masses. Section 5.8.1 contains geometry data of the Westinghouse 14x14 hybrid used in this evaluation. Sample in-core characteristics are also contained in Section 5.8.1.

5.9.2 Response Function Method

The evaluation of reduced minimum cool time in the CC4 and MTC use the response function method described in Section 5.8.2.

Response functions for the transfer and storage cask (generated using MCNP) solve the particle transport equations at each relevant spectrum line using Monte Carlo techniques. The results of the individual spectrum lines are then statistically summed. As the basket is loaded uniformly (or in a four-region pattern for the 1.8 kW preferential loading pattern), the dose rate response can be calculated for a source located in multiple fuel assembly locations using Monte Carlo sampling within MCNP. For the uniform loading, the basket position variable is, therefore, not required within the summation. Note that the term is still accounted for directly within the MCNP run. For the four-region preferential loading scenario, the summation is limited to the dose rate response contribution of the four zones.

The response function method allows the MCNP weight window (acceleration) map to be optimized for a particular source energy, producing an increased number of particles scoring per source particle. The response function also allows for a significant reduction in the number of MCNP shielding runs, thereby increasing the number of particles per MCNP run (based on fixed computer resources). For example, a single PWR fuel type has approximately 20,000 source runs associated with it, requiring the same number of MCNP runs to determine a complete dose rate set. The same dose rate set for fuel gamma and neutron cases may be generated using approximately 20 MCNP runs (one per relevant neutron and gamma energy line) using the response function.

Section 5.8.2 demonstrates the applicability of the response method to determine the dose rates of the MAGNASTOR concrete cask and transfer cask systems.

5.9.3 Undamaged Fuel - Uniform Heat Load Pattern Evaluation

This section presents the detailed evaluations of the concrete and transfer casks loaded with PWR fuel assemblies at a minimum cool time of 2.5 years are based on models developed in Section 5.8 for a PWR undamaged fuel basket configuration with a payload of 37 fuel assemblies and no inserts. This section applies a uniform heat load pattern to determine system dose rates at a minimum cool time of 2.5 years. Preferential loading is discussed in Section 5.9.6. The effects of nonfuel hardware components to dose rates and heat load are discussed in Sections 5.9.4 and 5.9.5. Model differences, dose rates and minimum loading time impacts resulting from the damaged fuel basket configuration are discussed in Section 5.9.9.

5.9.3.1 PWR Fuel and Basket Models

The three-dimensional shielding evaluation includes a homogenized fuel assembly model and a detailed three-dimensional basket model. These models are discussed in length in Section 5.8.3.

5.9.3.2 Minimum Cool-time Specification

The 2.5-year evaluation method is identical to that employed in Section 5.8.3.2 other than the change allowing load tables to contain data down to 2.5 years rather than limiting content to 4 years minimum. The method is repeated in the following two paragraphs.

SAS2H generates heat loads based on the fuel data listed in Section 5.8.1.1. Based on the desired 35.5 kW system heat load, minimum allowed cool times for the matrix of initial enrichment and burnup are calculated. Calculated heat loads account for fuel material (actinide and fission product) and hardware (light element) generated sources. Minimum cool times are conservatively rounded up to the nearest one-tenth of a year. The resulting minimum cool times are listed in assembly specific loading tables.

The loading table removes combinations of high assembly average burnup and low enrichment (e.g., 60 GWd/MTU and 1.9 wt% ^{235}U) from the contents definition. Source term data covering these combinations produces unrealistic source terms due to the complete consumption of fissile uranium early in the burnup cycle and the SAS2H input of a fixed power density. To maintain power density, ORIGEN-S (SAS2H) will substantially increase flux levels, which would not occur during core operation of the assembly, to produce fissile material and to produce power by non-thermal fission. The increased flux level "breeds" higher actinides, which in turn increase source significantly. Since a high burnup and low enrichment combination would require repeated reinsertion of a burned assembly, the combination is excluded.

Minimum cool time tables, based on 2.5 years minimum cool time, are included in Section 5.9.8.

5.9.3.3 Stainless Steel Transfer Cask Dose Rates

Using the dose response method, transfer cask dose rates are tabulated for all allowed cool times, assembly average burnup, and initial enrichment combinations for the hybrid Westinghouse 14x14 fuel type (ng14b). Reducing the minimum cool time to 2.5 years has no impact on the bounding source terms for the stainless steel MTC. Bounding source term cool times remain above the previous minimum cool time of 4 years. No new dose rates are evaluated for the uniformly loaded stainless steel MTC.

5.9.3.4 CC4 Dose Rates

Using the dose response method, concrete cask dose rates are tabulated for all allowed cool times, assembly average burnup, and initial enrichment combinations for the hybrid Westinghouse 14x14 fuel type (ng14b). The reduction in minimum cool time results in a new bounding source term for the radial dose rates. The three other detector locations (Top, Inlet, and Outlet) remain bounded by previous evaluations.

Maximum dose rates as a function of distance from the CC4 radial surface are shown in Figure 5.9.3-1. A breakdown of the CC4 radial surface dose rates into the source components is shown in Figure 5.9.3-2. Refer to Table 5.9.3-1 for the maximum concrete cask surface dose rates and the contents that develop the dose rates. Reducing the minimum cool time to 2.5 years significantly increases radial dose rates on the CC4.

5.9.3.5 NAC-CASC Site Boundary Evaluation

The previous section demonstrated that the WE14x14 CC4 average radial dose rate is 68 mrem/hr. This evaluation was based on a bounding assessment at 2.5 year minimum cool time and 35.5 kW maximum system heat load. Design basis input to the site boundary analysis is an average radial dose rate of 57 mrem/hr, which was based on an assessment of 4.0 year minimum cool time and 40.0 kW maximum system heat load. For site boundary dose rates the increased radial dose component can be accounted for by conservatively increasing reported single cask and array yearly dose and exposure values by 20%. This will conservatively neglect the smaller height CC evaluated at the reduced cool time (with the associated lower surface area for emission) and reduced axial dose components versus the 40 kW design basis source.

Figure 5.9.3-1 Concrete Cask Side Dose Rate Profile at Various Distances – PWR (CC4)

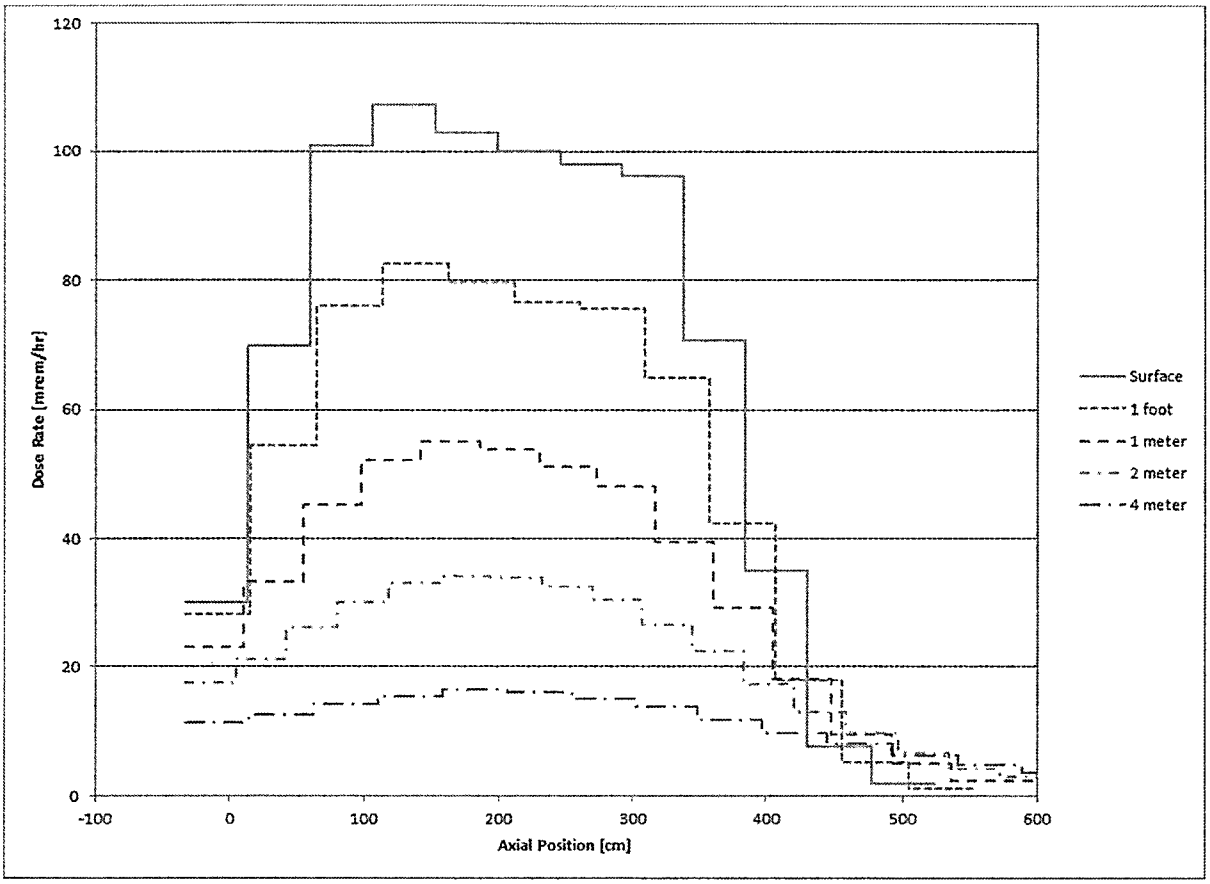


Figure 5.9.3-2 Concrete Cask Side Surface Dose Rate Profile by Source – PWR (CC4)

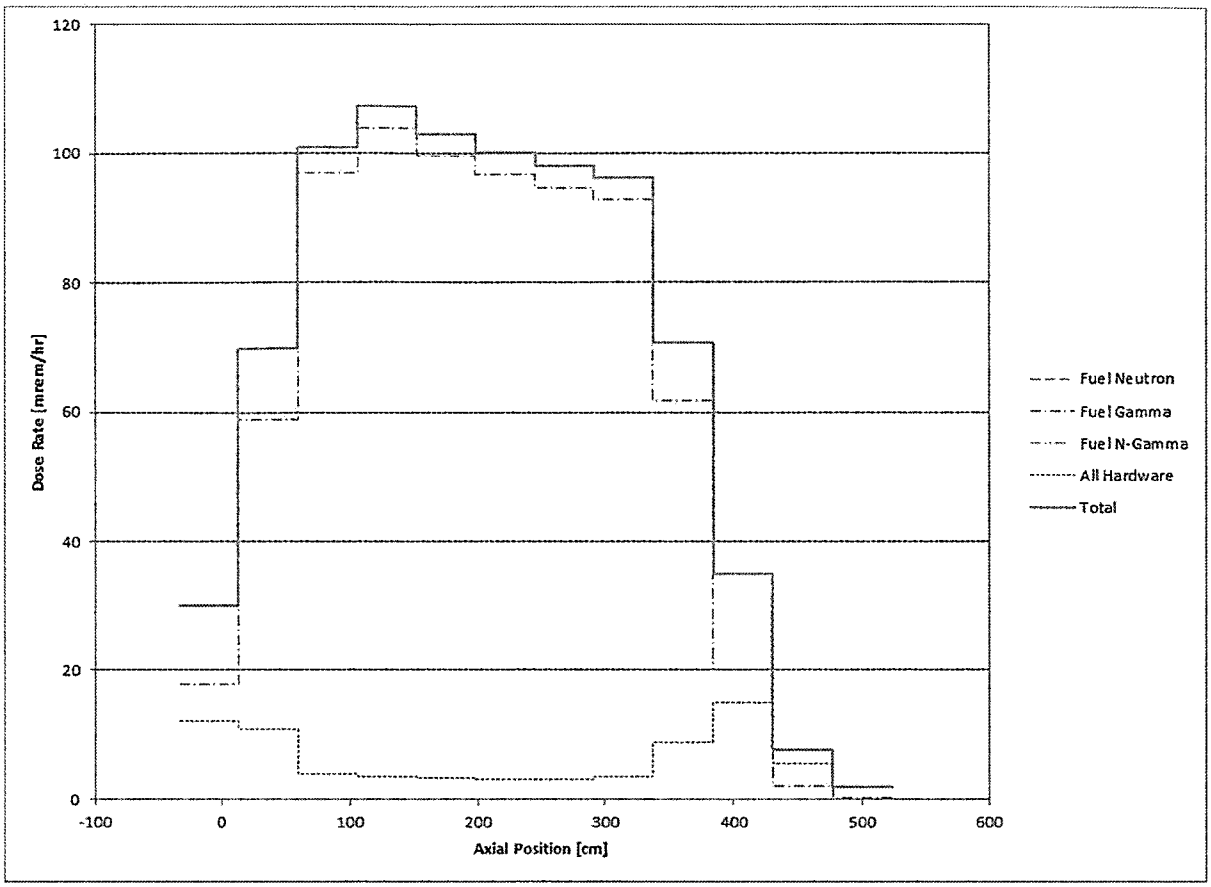


Table 5.9.3-1 Maximum CC4 Surface Dose Rates – Reduced Cool Time

Surface	Fuel Type	Cool Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt% ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14b	2.6	20	3.9	107.4	68.4

5.9.4 PWR Nonfuel Hardware Components - BPRA and Thimble Plug

The PWR fuel assembly basket is designed to store nonfuel components inside the fuel assembly. The BPRA and TP evaluations were not changed from Section 5.8.5; refer to that section for expanded explanation of the BPRA and TP nonfuel hardware components. Additional assembly cool time required to load the nonfuel hardware components is shown in Table 5.9.4-1. The table includes results for the preferential loading described in Section 5.9.6.

Table 5.9.4-1 Additional Assembly Cool Time (Years) Required to Load BPRA or TP

Zone:	A	B1	B2	C	Uniform
Additional Cool Time BPRA:	1.4	0.1	0.1	0.7	0.5
Additional Cool Time TP:	0.2	0.1	0.1	0.1	0.1

5.9.4.1 Combination of Fuel, BPRA, and Thimble Plug Dose Rates

Maximum combined dose rates at the cask radial surface are calculated for the reduced minimum cool time. The combined dose rate is listed in Table 5.9.4-2 for the uniform loading.

Table 5.9.4-2 Reduced Cool Time Combined Dose Rate Results

Cask / Dose Location	Fuel		Combined	
	Assembly	Max. Dose Rate (mrem/hr)	Assembly	Max. Dose Rate (mrem/hr)
CC4 Radial	WE 14×14	107.4	WE 14×14	113.9

5.9.5 Nonfuel Hardware Component – Reactor Control Elements

Reactor control element (e.g., CEAs and RCCAs) material quantities and the core region in which the material was exposed to the neutron activation flux were obtained from the DOE characteristics database [30] for previous sections. This database assumes the Westinghouse 14x14 CEA is fully inserted when calculating activated CEA masses which severely overestimates the activated CEA mass. During typical core operation only the tips of the CEA rods are located within a significant neutron flux field. Rod tips are above the active fuel region at full withdrawal limiting activated regions to the plenum and assembly top regions. Activation volumes and masses for the WE 14x14 assembly type CEA are calculated in this section to more accurately evaluate the heat and dose contribution from the CEAs.

As the WE 14x14 CEA rod dimensions are not known the rod dimensions of the WE 15x15 CEA are used to approximate volumes and masses for the 14x14 CEA. The WE 15x15 CEA rod to guide tube gap is applied to the WE 14x14 assembly to approximate the 14x14 CEA rod outer diameter. The cone on the bottom of the CEA rod is assumed the same length. The CEA is assumed inserted to the top of the active fuel region. Using the calculated CEA rod cross section and the length of the upper nozzle and upper plenum the activated mass of the WE 14x14 CEA is calculated.

Mass quantities activated in the assembly top and gas plenum regions are listed in Table 5.9.5-2. Similar to the fuel assembly hardware evaluation, the plenum material is activated at a 0.2 flux factor, with top material activation at a 0.1 flux factor. Material above the top is not considered to be activated to a significant extent and is, therefore, not modeled. In the shielding evaluation, the source material activated in the plenum region of the fuel assembly is located at the bottom of the active fuel region. This is the result of the full insertion of the CEA into the assembly under storage conditions. To minimize the increased dose due to loading of CEAs, only the center nine basket locations are allowed to contain the added source. The minimum cool time of the CEA is reduced to 2.5 years.

Results are shown in Table 5.9.5-3. On the sides of the concrete and transfer casks, the additive dose rate does not affect the maximum dose rates. At the concrete cask inlets and transfer cask bottom, loading of CEAs significantly increases the maximum dose rates.

The maximum decay heat produced by loading a single CEA is 18.5 W. An increase in assembly cool time required to allow loading of a CEA is shown in Table 5.9.5-4. As an increase in cool time will also decrease the fuel source term, the strict application of increased cool time without a recalculation of fuel dose rates is conservative.

Table 5.9.5-1 Westinghouse CEA Dimensions

	Dimension	14x14 [Calculated]	15x15 [Known]
RCCA Rod OD	inch	0.398	0.4395
RCCA Rod ID	inch	0.359	0.4005
Lower Plug OD	inch	0.398	0.4395
Lower Plug Length	inch	1.125	1.125
Conical Section Length	inch	0.625	0.625

Table 5.9.5-2 Calculated WE 14x14 CEA Activated Mass

Material	Neutron Zone	WE 14x14
Steel/Inconel	Top	0.169
Ag-In-Cd	Top	0.860
Steel/Inconel	Gas Plenum	0.593
Ag-In-Cd	Gas Plenum	1.820

Table 5.9.5-3 CEA Dose Rate Contributions – Westinghouse 14×14

Cask / Dose Location	Maximum Dose (mrem/hr)	Average Dose (mrem/hr)
Stainless Steel Transfer Cask Radial	1.41	0.2
Stainless Steel Transfer Cask Bottom	1654.1	546.2
CC4 Radial	0.53	< 0.1
CC4 Inlet	3.41	--

Table 5.9.5-4 Additional Assembly Cool Time (Years) Required to Load CEA

Zone:	A	B1	B2	C	Uniform
Additional Cool Time CEA:	2.2	0.2	0.1	1.0	0.7

5.9.6 Preferential Loading of PWR Fuel at a Minimum Cool time of 2.5 Years

In order to envelop fuel assemblies with heat loads higher than 959 W, a four-zone preferential loading pattern is proposed as follows.

Zone Description	Designator	Heat Load [W/assy]	# Assemblies
Inner Ring	A	513	9
Middle Ring	B1	1,300	8
	B2	1,800	4
Outer Ring	C	830	16

Preferential and uniform loading patterns limit total cask heat load to 35.5 kW. As will be seen in the results section, the maximum dose rate for the preferential loading pattern is less than that calculated for a uniform pattern.

A sketch of the PWR basket and loading pattern is shown in Figure 5.9.6-1.

Minimum cool time tables for the preferential heat load pattern are included in Section 5.9.8. The method and models for the preferential loading pattern shielding evaluations are identical to those of the uniform loading pattern with the exception of requiring three sets of response functions, one for each zone. Source spectrum varies as a result of changes in burnup, initial enrichment and minimum cool time and, therefore, requires cask dose responses (dose per unit source in each spectrum energy group) for each of the zones. The dose responses from each ring, accounting for the differences in the number of assemblies per zone, are added to arrive at the dose rate for a fully loaded cask.

5.9.6.1 MCNP Input File Setup

Based on a four-zone pattern, the source and tally descriptions are modified in the MCNP models to consider the sources in the appropriate basket locations with the proper scaling on the tally cards. For each cask/detector combination, four sets of runs (A, B1, B2 and C) are needed to characterize the dose rate response.

5.9.6.2 MTC and CC4 Dose Rates

Maximum and average surface dose rates for the preferential pattern are shown in Table 5.9.6-1, with the corresponding limiting results for the uniform pattern. The maximum dose rates for the analyzed preferential loading pattern are less than or statistically unchanged from those

calculated for a uniform pattern at each detector surface for both casks with the exception of MTC bottom dose rates. Maximum MTC bottom dose rates are increased minimally (< 7%).

The concrete cask radial and top axial average dose rates are less than or statistically unchanged in the preferential pattern. Therefore, using the uniform pattern to characterize the restricted area and controlled area boundaries is acceptable.

Figure 5.9.6-1 Schematic of PWR Fuel 1.8 kW Preferential Loading Pattern

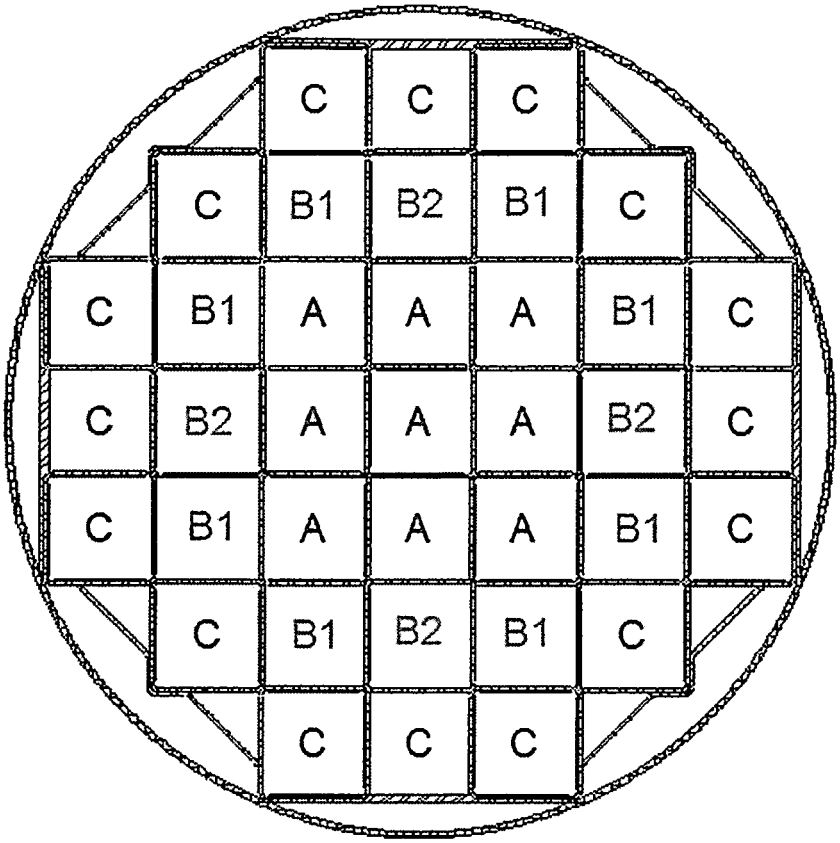


Table 5.9.6-1 Preferential Pattern Dose Rate Results

Cask / Dose Location	Uniform		Preferential	
	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)
Stainless Steel MTC Radial	628	883	689	888
Stainless Steel MTC Top	216	466	221	464
Stainless Steel MTC Bottom	2,713	5,239	2,687	5,630
CC4 Radial	68.4	107.4	67.1	103.2
CC4 Top	61.5	315	58.3	288.4
CC4 Inlet	--	112.4	--	103.3
CC4 Outlet	--	35.4	--	35.7

5.9.7 Sample Input Files

This section contains sample input files for the four zone preferential loading pattern. Figure 5.9.7-1 provides the preferential zone B1 loading pattern for the stainless steel transfer cask. Figure 5.9.7-2 provides the preferential zone B2 loading pattern for concrete cask. All other modeling configurations (i.e. damaged fuel) are unchanged from those presented in Section 5.8.8.

Figure 5.9.7-1 Transfer Cask Sample Input File – Preferential Zone B1

```
MAGNASTOR Duke Transfer Cask - trfShwDryRadFg_ng14b_B107g
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng14b - v1.0
1 1 -2.5071 -1      u=6 $ Lower Nozzle
2 2 -2.7253 -2 +1     u=6 $ Lower Plenum
3 3 -3.9171 -3 +2     u=6 $ Fuel
4 4 -1.0067 -4 +3     u=6 $ Upper Plenum
5 5 -2.8608 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube  v1.0
7 8 -7.8212 -8 +7     u=5 $ Tube
8 13 -2.6507 -9 -7     u=5 $ Poison
9 13 -2.6507 -10 -7     u=5 $ Poison
10 13 -2.6507 -11 -7     u=5 $ Poison
11 13 -2.6507 -12 -7     u=5 $ Poison
12 0          -7 #8 #9 #10 #11      u=5 $ Space Inside Tube
13 0          +7 +8     u=5 $ Space Below and Outside Tube
C Cells - PWR Basket v1.0
14 0          -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )     u=4 $ Assy loc 1
15 like 14 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )     u=4 $ Assy loc 3
16 like 14 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )     u=4 $ Assy loc 4
17 like 14 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )     u=4 $ Assy loc 6
18 like 14 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )     u=4 $ Assy loc 8
19 like 14 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )     u=4 $ Assy loc 9
20 like 14 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )     u=4 $ Assy loc 11
21 like 14 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )     u=4 $ Assy loc 13
22 like 14 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )     u=4 $ Assy loc 15
23 like 14 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )     u=4 $ Assy loc 17
24 like 14 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )     u=4 $ Assy loc 19
25 like 14 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )     u=4 $ Assy loc 21
26 like 14 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 23
27 like 14 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 25
28 like 14 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 27
29 like 14 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 29
30 like 14 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 30
31 like 14 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )     u=4 $ Assy loc 32
32 like 14 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 34
33 like 14 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 35
34 like 14 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 37
35 8 -7.8212 -15 #22 #29      u=4 $ Side support +x
36 8 -7.8212 -16 #19 #26      u=4 $ Side support -x
37 8 -7.8212 -17 #14 #15      u=4 $ Side support +y
38 8 -7.8212 -18 #33 #34      u=4 $ Side support -y
39 8 -7.8212 -19 +20 +21      u=4 $ Corner
40 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #14 #15 #19 #22 #26 #29 #33 #34       u=4 $ Corner diagonal
41 0          #14 #15 #16 #17 #18 #19 #20 #21 #22 #23 #24
              #25 #26 #27 #28 #29 #30 #31 #32 #33 #34
              #35 #36 #37 #38 #39 #40      u=4 $ Outside Basket Structure
C Cells - PWR Canister Cavity v1.0
42 0          -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )     u=3 $ Assy loc 1
43 like 42 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )     u=3 $ Assy loc 2
44 like 42 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )     u=3 $ Assy loc 3
45 like 42 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )     u=3 $ Assy loc 4
46 like 42 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )     u=3 $ Assy loc 5
47 like 42 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )     u=3 $ Assy loc 6
48 like 42 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )     u=3 $ Assy loc 7
49 like 42 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )     u=3 $ Assy loc 8
50 like 42 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )     u=3 $ Assy loc 9
51 like 42 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )     u=3 $ Assy loc 10
52 like 42 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )     u=3 $ Assy loc 11
53 like 42 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )     u=3 $ Assy loc 12
54 like 42 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )     u=3 $ Assy loc 13
55 like 42 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )     u=3 $ Assy loc 14
56 like 42 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )     u=3 $ Assy loc 15
57 like 42 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )     u=3 $ Assy loc 16
58 like 42 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )     u=3 $ Assy loc 17
```

```
59 like 42 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
60 like 42 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
61 like 42 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
62 like 42 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
63 like 42 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
64 like 42 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
65 like 42 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
66 like 42 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
67 like 42 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
68 like 42 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
69 like 42 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
70 like 42 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
71 like 42 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
72 like 42 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
73 like 42 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
74 like 42 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
75 like 42 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
76 like 42 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
77 like 42 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
78 like 42 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
79 0          #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52 #53 #54
              #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65 #66 #67
              #68 #69 #70 #71 #72 #73 #74 #75 #76 #77 #78      fill=4 u=3 $ Cavity
C Cells - Canister w/Weld Shield v1.0
80 0          -24 #92  #93  fill=3    u=2 $ Cavity
81 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
82 0          -25 +24.2 -28 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Bottom Drain Port
83 14 -3.9700 -26 +28 -30 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Middle Drain Port
84 0          -27 +30 -31.2 trcl = ( 62.7565 43.1314 0.0000 )    u=2 $ Top Drain Port
85 like 82 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Bottom Vent Port
86 like 83 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Middle Vent Port
87 like 84 but   trcl = ( -62.7565 -43.1314 0.0000 )    u=2 $ Top Vent Port
88 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
89 8 -7.8212 -31 -24.1 +24.2 -29 #82 #83  #85 #86   u=2 $ Lower lid
90 7 -7.9400 -31 -24.1 +29 #83 #84  #86 #87    u=2 $ Upper lid
91 7 -7.9400 (-32 +35 +36) : (-33 +35 +36) : (-34 +35 +36)       u=2 $ Weld Shield
92 8 -7.8212 -39 +38 +37 -24.2 trcl = ( 62.7565 43.1314 0.0000 )   u=2 $ Drain port
shield
93 8 -7.8212 -39 +38 +37 -24.2 trcl = ( -62.7565 -43.1314 0.0000 )   u=2 $ Vent port
shield
94 0          +31 #91       u=2 $ Outside void
C Transfer Cask Cells - v1.2_ng14b
95 0          -57  #108  fill=2 ( 0.0000 0.0000 7.0350 )   u=1 $ Canister and Weld Shield
96 0          -40 -41 +57 -48   u=1 $ Gap MTC to Canister below seal
97 6 -0.9982 -40 -41 +57 -49 +48  u=1 $ Gap between seals
98 0          -40 -41 +57 +49 #108   u=1 $ Gap MTC to Canister above seal
99 7 -7.9400 -40 +41 -46    u=1 $ Bottom forging
100 7 -7.9400 -42 +41 +46 -47   u=1 $ Inner shell
101 0          -43 +42 +46 -47   u=1 $ Gap
102 10 -11.344 -44 +43 +46 -47   u=1 $ Lead shell
103 11 -1.6316 -45 +44 +46 -47   u=1 $ NS4FR shell
104 7 -7.9400 -40 +45 +46 -47   u=1 $ Outer shell
105 7 -7.9400 -40 +41 +47    u=1 $ Top forging
106 7 -7.9400 (-50 +51 -56) : (-50 -52 -56)      u=1 $ Door rail
107 7 -7.9400 -55 -53 +54 -56 +57  u=1 $ Door steel
108 7 -7.9400 -59 +58 -40    u=1 $ Weld bar
109 0          +40 #106  #107  +57   u=1 $ Void
C Detector Cells - Radial Biasing
400  0  -400  fill=1  $ Surface
500  0  -500  +400  $ 1ft
600  0  -600  +400  +500  $ 1m
700  0  -700  +400  +500  +600  $ 2m
800  0  -800  +400  +500  +600  +700  $ 4m
900  0  +400  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.0
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
```

```
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094       $ Flood elevation
C Surfaces - Fuel Tube v1.0
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4200  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.0
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4200  $ Tube opening
14 8 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4200  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 8 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 8 RPP -77.8329 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.0
23 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister w/Weld Shield v1.0
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4200 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1200         $ Lower/upper lid
30 PZ 459.4860         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9950 0.0000 0.0000 469.2750 91.4500   $ Canister
32 RCC 0.0000 0.0000 462.2800 0.0000 0.0000 5.0800 78.1050   $ Weld shield bot
33 RCC 0.0000 0.0000 467.3600 0.0000 0.0000 5.0800 71.7550   $ Weld shield mid
34 RCC 0.0000 0.0000 472.4400 0.0000 0.0000 5.0900 66.6750   $ Weld shield top
35 RCC 62.7565 43.1314 462.2800 0.0000 0.0000 15.2500 8.8900   $ Weld shield cutout +x+y
36 RCC -62.7565 -43.1314 462.2800 0.0000 0.0000 15.2500 8.8900   $ Weld shield cutout -x-
y
37 PZ 433.0700         $ Port shield elevation
38 CZ 2.8575         $ Port shield ID
39 CZ 5.0800         $ Port shield OD
C Transfer Cask Surfaces - v1.2_ng14b
40 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 471.1700 111.7600  $ Cask (Without Rail /
Doors)
41 CZ 92.7100        $ Cavity
42 CZ 94.6150        $ Inner shell
43 CZ 94.7420        $ Gap
44 CZ 102.8700        $ Lead shell
45 CZ 108.5850        $ NS4FR shell
46 PZ 30.4800        $ Bottom forging
47 PZ 435.6100        $ Top forging
48 PZ 3.9116        $ Lower Elevation Water Jaccket
49 PZ 463.3214        $ Upper Elevation Water Jaccket
50 RPP -104.0765 104.0765 -111.7600 111.7600 -12.7000 0.0000   $ Door container
51 PY 97.0026        $ Inside rail +y
52 PY -97.0026        $ Inside rail -y
53 PY 96.5200        $ Door +y
54 PY -96.5200        $ Door -y
55 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000   $ Door prism
       108.4699 0.0000 0.0000 89.7374 -73.7172 0.0000
       -89.7374 -73.7172 0.0000
56 RCC 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000 111.7600  $ Door container
57 RCC 0.0000 0.0000 0.0500 0.0000 0.0000 484.5550 91.4400  $ Canister and Weld Shield
58 CZ 90.8049        $ Weld bar inner
59 RCC 0.0000 0.0000 469.3150 0.0000 0.0000 1.9050 92.7100  $ Weld bar outer
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -12.8000  0.0000  0.0000  497.4550  111.8600
401  PZ  20.3637
402  PZ  53.5273
```

```
403  PZ  86.6910
404  PZ  119.8547
405  PZ  153.0183
406  PZ  186.1820
407  PZ  219.3457
408  PZ  252.5093
409  PZ  285.6730
410  PZ  318.8367
411  PZ  352.0003
412  PZ  385.1640
413  PZ  418.3277
414  PZ  451.4913
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -43.2800  0.0000  0.0000  558.4150  142.3400
501  PZ  -6.0523
502  PZ  31.1753
503  PZ  68.4030
504  PZ  105.6307
505  PZ  142.8583
506  PZ  180.0860
507  PZ  217.3137
508  PZ  254.5413
509  PZ  291.7690
510  PZ  328.9967
511  PZ  366.2243
512  PZ  403.4520
513  PZ  440.6797
514  PZ  477.9073
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -112.8000  0.0000  0.0000  697.4550  211.8600
601  PZ  -77.9273
602  PZ  -43.0545
603  PZ  -8.1817
604  PZ  26.6910
605  PZ  61.5638
606  PZ  96.4365
607  PZ  131.3093
608  PZ  166.1820
609  PZ  201.0548
610  PZ  235.9275
611  PZ  270.8003
612  PZ  305.6730
613  PZ  340.5458
614  PZ  375.4185
615  PZ  410.2913
616  PZ  445.1640
617  PZ  480.0368
618  PZ  514.9095
619  PZ  549.7823
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -212.8000  0.0000  0.0000  897.4550  311.8600
701  PZ  -167.9273
702  PZ  -123.0545
703  PZ  -78.1818
704  PZ  -33.3090
705  PZ  11.5638
706  PZ  56.4365
707  PZ  101.3093
708  PZ  146.1820
709  PZ  191.0548
710  PZ  235.9275
711  PZ  280.8003
712  PZ  325.6730
713  PZ  370.5458
714  PZ  415.4185
715  PZ  460.2913
716  PZ  505.1640
717  PZ  550.0368
718  PZ  594.9095
```

```
719  PZ  639.7823
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -412.8000  0.0000  0.0000  1297.4550  511.8600
801  PZ  -347.9273
802  PZ  -283.0545
803  PZ  -218.1818
804  PZ  -153.3090
805  PZ  -88.4363
806  PZ  -23.5635
807  PZ  41.3093
808  PZ  106.1820
809  PZ  171.0548
810  PZ  235.9275
811  PZ  300.8003
812  PZ  365.6730
813  PZ  430.5458
814  PZ  495.4185
815  PZ  560.2913
816  PZ  625.1640
817  PZ  690.0368
818  PZ  754.9095
819  PZ  819.7823

C
C Materials List - Common Materials - v1.0
C
C Homogenized Lower Nozzle
m1    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Homogenized Lower Plenum
m2    24000 -1.0000E-03 50000 -1.5000E-02
      26000 -1.2500E-03  7014 -5.0000E-04
      40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3    92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
      92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
       8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4    24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
      26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
      40000 -2.1362E-01
C Homogenized Upper Nozzle
m5    24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
      28000 -9.5000E-02
C Water
m6    1001 2 8016 1
C Stainless Steel
m7    24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Carbon Steel
m8    26000 -0.99  6012 -0.01
C Aluminum
m9    13027 -1.0
C Lead
m10   82000 -1.0
C NS-4-FR
m11   5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
      5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
      8016 -4.2500E-01
C Concrete
m12   26000 -0.014 20000 -0.044 14000 -0.337
       1001 -0.010  8016 -0.532 11023 -0.029
      13027 -0.034
C Vent Port Middle Cylinder
m14   24000 -0.190 25055 -0.020 26000 -0.695
      28000 -0.095
C Neutron Absorber
m13   13027 -0.7470 5010 -0.0356 5011 -0.1624
      6012 -0.0549
```

```
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:p 1 113r 0
C
C PWR Source Definition - Fuel Gamma Response to Group 7
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=400:95:80:d5:3
si1   -9.85901 9.85901
sp1   0 1
si2   -9.85901 9.85901
sp2   0 1
si3 a 9.8374 19.0576 28.2778 37.4980 46.7182 55.9384 65.1586
      323.3242 332.5444 341.7646 350.9848 360.2050 369.4252 378.6454
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
si4   3.000E+00 4.000E+00
sp4   0 1
C Source Information
si5 l       42 43 44
         45 46 47 48 49
      50 51 52 53 54 55 56
      57 58 59 60 61 62 63
      64 65 66 67 68 69 70
         71 72 73 74 75
            76 77 78
C Source Probability
sp5           0.0 0.0 0.0
          0.0 1.0 0.0 1.0 0.0
      0.0 1.0 0.0 0.0 0.0 1.0 0.0
      0.0 0.0 0.0 0.0 0.0 0.0 0.0
      0.0 1.0 0.0 0.0 0.0 1.0 0.0
          0.0 1.0 0.0 1.0 0.0
              0.0 0.0 0.0
mode p
nps 400000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Rate Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
C
de0   0.01 0.03 0.05 0.07 0.1 0.15 0.2
      0.25 0.3 0.35 0.4 0.45 0.5 0.55
      0.6 0.65 0.7 0.8 1 1.4 1.8
      2.2 2.6 2.8 3.25 3.75 4.25 4.75
      5 5.25 5.75 6.25 6.75 7.5 9
      11 13 15
df0   3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
      6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
      1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
      3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
      5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
      1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=65 0 201 origin=0.1 0.1 -513
     imesh 90.2 91.4 92.7 94.6 102.9 108.6 111.8 611.8
     iints 5 1 1 1 3 1 1 1
     jmesh 500 513 520 528 530 898 920 929 959 997 1497
     jints 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
C wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +400.1
fm2 8.0000E+00
```

```
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  -412
     -413  -414  T
tf2
fc12 Radial 1ft Tally
f12:p +500.1
fm12 8.0000E+00
fs12  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  -512
     -513  -514  T
tf12
fc22 Radial 1m Tally
f22:p +600.1
fm22 8.0000E+00
fs22  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  -615  -616  -617  -618
     -619  T
tf22
fc32 Radial 2m Tally
f32:p +700.1
fm32 8.0000E+00
fs32  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf32
fc42 Radial 4m Tally
f42:p +800.1
fm42 8.0000E+00
fs42  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf42
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 5.625 degree rotation around z-axis
*TR1 0.0 0.0 0.0 5.625 95.625 90 -84.375 5.625 90 90 90 0
C 11.25 degree rotation around z-axis
*TR2 0.0 0.0 0.0 11.250 101.250 90 -78.750 11.250 90 90 90 0
C 16.875 degree rotation around z-axis
*TR3 0.0 0.0 0.0 16.875 106.875 90 -73.125 16.875 90 90 90 0
C 22.5 degree rotation around z-axis
*TR4 0.0 0.0 0.0 22.500 112.500 90 -67.500 22.500 90 90 90 0
C 28.125 degree rotation around z-axis
*TR5 0.0 0.0 0.0 28.125 118.125 90 -61.875 28.125 90 90 90 0
C 33.75 degree rotation around z-axis
*TR6 0.0 0.0 0.0 33.750 123.750 90 -56.250 33.750 90 90 90 0
C 39.375 degree rotation around z-axis
*TR7 0.0 0.0 0.0 39.375 129.375 90 -50.625 39.375 90 90 90 0
C 45 degree rotation around z-axis
*TR8 0.0 0.0 0.0 45.000 135.000 90 -45.000 45.000 90 90 90 0
C 50.625 degree rotation around z-axis
*TR9 0.0 0.0 0.0 50.625 140.625 90 -39.375 50.625 90 90 90 0
C 56.25 degree rotation around z-axis
*TR10 0.0 0.0 0.0 56.250 146.250 90 -33.750 56.250 90 90 90 0
C 61.875 degree rotation around z-axis
```

```
*TR11 0.0 0.0 0.0 61.875 151.875 90 -28.125 61.875 90 90 90 0
C 67.5 degree rotation around z-axis
*TR12 0.0 0.0 0.0 67.500 157.500 90 -22.500 67.500 90 90 90 0
C 73.125 degree rotation around z-axis
*TR13 0.0 0.0 0.0 73.125 163.125 90 -16.875 73.125 90 90 90 0
C 78.75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 78.750 168.750 90 -11.250 78.750 90 90 90 0
C 84.375 degree rotation around z-axis
*TR15 0.0 0.0 0.0 84.375 174.375 90 -5.625 84.375 90 90 90 0
C 95.625 degree rotation around z-axis
*TR16 0.0 0.0 0.0 95.625 185.625 90 5.625 95.625 90 90 90 0
C 101.25 degree rotation around z-axis
*TR17 0.0 0.0 0.0 101.250 191.250 90 11.250 101.250 90 90 90 0
C 106.875 degree rotation around z-axis
*TR18 0.0 0.0 0.0 106.875 196.875 90 16.875 106.875 90 90 90 0
C 112.5 degree rotation around z-axis
*TR19 0.0 0.0 0.0 112.500 202.500 90 22.500 112.500 90 90 90 0
C 118.125 degree rotation around z-axis
*TR20 0.0 0.0 0.0 118.125 208.125 90 28.125 118.125 90 90 90 0
C 123.75 degree rotation around z-axis
*TR21 0.0 0.0 0.0 123.750 213.750 90 33.750 123.750 90 90 90 0
C 129.375 degree rotation around z-axis
*TR22 0.0 0.0 0.0 129.375 219.375 90 39.375 129.375 90 90 90 0
C 135 degree rotation around z-axis
*TR23 0.0 0.0 0.0 135.000 225.000 90 45.000 135.000 90 90 90 0
C 140.625 degree rotation around z-axis
*TR24 0.0 0.0 0.0 140.625 230.625 90 50.625 140.625 90 90 90 0
C 146.25 degree rotation around z-axis
*TR25 0.0 0.0 0.0 146.250 236.250 90 56.250 146.250 90 90 90 0
C 151.875 degree rotation around z-axis
*TR26 0.0 0.0 0.0 151.875 241.875 90 61.875 151.875 90 90 90 0
C 157.5 degree rotation around z-axis
*TR27 0.0 0.0 0.0 157.500 247.500 90 67.500 157.500 90 90 90 0
C 163.125 degree rotation around z-axis
*TR28 0.0 0.0 0.0 163.125 253.125 90 73.125 163.125 90 90 90 0
C 168.75 degree rotation around z-axis
*TR29 0.0 0.0 0.0 168.750 258.750 90 78.750 168.750 90 90 90 0
C 174.375 degree rotation around z-axis
*TR30 0.0 0.0 0.0 174.375 264.375 90 84.375 174.375 90 90 90 0
```

Figure 5.9.7-2 Storage Cask Sample Input File – Preferential Zone B2

```
MAGNASTOR VCC - strShlDryRadFg_ng14b_B207g
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells - ng14b - v1.1
1 1 -2.5071 -1      u=6 $ Lower Nozzle
2 2 -2.7253 -2 +1     u=6 $ Lower Plenum
3 3 -3.9171 -3 +2     u=6 $ Fuel
4 4 -1.0067 -4 +3     u=6 $ Upper Plenum
5 5 -2.8608 -5 +4     u=6 $ Upper Nozzle
6 0          +5      u=6 $ Outside
C Cells - Fuel Tube  v1.3
7 8 -7.8212 -8 +7     u=5 $ Tube
8 9 -2.6336 -9 : -10 : -11 : -12      u=5 $ Poison
9 0          #7  #8  -6    u=5 $ Outside below PFE
10 0          #7  #8  +6    u=5 $ Outside above PFE
C Cells - PWR Basket v1.5
11 0          -13 -14 fill=5 trcl = ( -23.5331 70.5993 0.0000 )     u=4 $ Assy loc 1
12 like 11 but fill=5 trcl = ( 23.5331 70.5993 0.0000 )     u=4 $ Assy loc 3
13 like 11 but fill=5 trcl = ( -47.0662 47.0662 0.0000 )     u=4 $ Assy loc 4
14 like 11 but fill=5 trcl = ( 0.0000 47.0662 0.0000 )     u=4 $ Assy loc 6
15 like 11 but fill=5 trcl = ( 47.0662 47.0662 0.0000 )     u=4 $ Assy loc 8
16 like 11 but fill=5 trcl = ( -70.5993 23.5331 0.0000 )     u=4 $ Assy loc 9
17 like 11 but fill=5 trcl = ( -23.5331 23.5331 0.0000 )     u=4 $ Assy loc 11
18 like 11 but fill=5 trcl = ( 23.5331 23.5331 0.0000 )     u=4 $ Assy loc 13
19 like 11 but fill=5 trcl = ( 70.5993 23.5331 0.0000 )     u=4 $ Assy loc 15
20 like 11 but fill=5 trcl = ( -47.0662 0.0000 0.0000 )     u=4 $ Assy loc 17
21 like 11 but fill=5 trcl = ( 0.0000 0.0000 0.0000 )     u=4 $ Assy loc 19
22 like 11 but fill=5 trcl = ( 47.0662 0.0000 0.0000 )     u=4 $ Assy loc 21
23 like 11 but fill=5 trcl = ( -70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 23
24 like 11 but fill=5 trcl = ( -23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 25
25 like 11 but fill=5 trcl = ( 23.5331 -23.5331 0.0000 )     u=4 $ Assy loc 27
26 like 11 but fill=5 trcl = ( 70.5993 -23.5331 0.0000 )     u=4 $ Assy loc 29
27 like 11 but fill=5 trcl = ( -47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 30
28 like 11 but fill=5 trcl = ( 0.0000 -47.0662 0.0000 )     u=4 $ Assy loc 32
29 like 11 but fill=5 trcl = ( 47.0662 -47.0662 0.0000 )     u=4 $ Assy loc 34
30 like 11 but fill=5 trcl = ( -23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 35
31 like 11 but fill=5 trcl = ( 23.5331 -70.5993 0.0000 )     u=4 $ Assy loc 37
32 8 -7.8212 -15 #19 #26      u=4 $ Side support +x
33 8 -7.8212 -16 #16 #23      u=4 $ Side support -x
34 8 -7.8212 -17 #11 #12      u=4 $ Side support +y
35 8 -7.8212 -18 #30 #31      u=4 $ Side support -y
36 8 -7.8212 -19 +20 +21      u=4 $ Corner
37 8 -7.8212 -21 +22 +20  +15.2 +16.1 +17.4 +18.3
             #11 #12 #16 #19 #23 #26 #30 #31       u=4 $ Corner diagonal
38 0         -6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
                #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
                #32 #33 #34 #35 #36 #37      u=4 $ Basket below PFE
39 0         +6 #11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21
               #22 #23 #24 #25 #26 #27 #28 #29 #30 #31
               #32 #33 #34 #35 #36 #37      u=4 $ Basket above PFE
C Cells - PWR Canister Cavity v1.5
40 0          -23 fill=6 trcl = ( -23.5331 70.5993 0.0000 )     u=3 $ Assy loc 1
41 like 40 but fill=6 trcl = ( 0.0000 70.5993 0.0000 )     u=3 $ Assy loc 2
42 like 40 but fill=6 trcl = ( 23.5331 70.5993 0.0000 )     u=3 $ Assy loc 3
43 like 40 but fill=6 trcl = ( -47.0662 47.0662 0.0000 )     u=3 $ Assy loc 4
44 like 40 but fill=6 trcl = ( -23.5331 47.0662 0.0000 )     u=3 $ Assy loc 5
45 like 40 but fill=6 trcl = ( 0.0000 47.0662 0.0000 )     u=3 $ Assy loc 6
46 like 40 but fill=6 trcl = ( 23.5331 47.0662 0.0000 )     u=3 $ Assy loc 7
47 like 40 but fill=6 trcl = ( 47.0662 47.0662 0.0000 )     u=3 $ Assy loc 8
48 like 40 but fill=6 trcl = ( -70.5993 23.5331 0.0000 )     u=3 $ Assy loc 9
49 like 40 but fill=6 trcl = ( -47.0662 23.5331 0.0000 )     u=3 $ Assy loc 10
50 like 40 but fill=6 trcl = ( -23.5331 23.5331 0.0000 )     u=3 $ Assy loc 11
51 like 40 but fill=6 trcl = ( 0.0000 23.5331 0.0000 )     u=3 $ Assy loc 12
52 like 40 but fill=6 trcl = ( 23.5331 23.5331 0.0000 )     u=3 $ Assy loc 13
53 like 40 but fill=6 trcl = ( 47.0662 23.5331 0.0000 )     u=3 $ Assy loc 14
54 like 40 but fill=6 trcl = ( 70.5993 23.5331 0.0000 )     u=3 $ Assy loc 15
55 like 40 but fill=6 trcl = ( -70.5993 0.0000 0.0000 )     u=3 $ Assy loc 16
56 like 40 but fill=6 trcl = ( -47.0662 0.0000 0.0000 )     u=3 $ Assy loc 17
```

```
57 like 40 but fill=6 trcl = ( -23.5331 0.0000 0.0000 )    u=3 $ Assy loc 18
58 like 40 but fill=6 trcl = ( 0.0000 0.0000 0.0000 )    u=3 $ Assy loc 19
59 like 40 but fill=6 trcl = ( 23.5331 0.0000 0.0000 )    u=3 $ Assy loc 20
60 like 40 but fill=6 trcl = ( 47.0662 0.0000 0.0000 )    u=3 $ Assy loc 21
61 like 40 but fill=6 trcl = ( 70.5993 0.0000 0.0000 )    u=3 $ Assy loc 22
62 like 40 but fill=6 trcl = ( -70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 23
63 like 40 but fill=6 trcl = ( -47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 24
64 like 40 but fill=6 trcl = ( -23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 25
65 like 40 but fill=6 trcl = ( 0.0000 -23.5331 0.0000 )    u=3 $ Assy loc 26
66 like 40 but fill=6 trcl = ( 23.5331 -23.5331 0.0000 )    u=3 $ Assy loc 27
67 like 40 but fill=6 trcl = ( 47.0662 -23.5331 0.0000 )    u=3 $ Assy loc 28
68 like 40 but fill=6 trcl = ( 70.5993 -23.5331 0.0000 )    u=3 $ Assy loc 29
69 like 40 but fill=6 trcl = ( -47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 30
70 like 40 but fill=6 trcl = ( -23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 31
71 like 40 but fill=6 trcl = ( 0.0000 -47.0662 0.0000 )    u=3 $ Assy loc 32
72 like 40 but fill=6 trcl = ( 23.5331 -47.0662 0.0000 )    u=3 $ Assy loc 33
73 like 40 but fill=6 trcl = ( 47.0662 -47.0662 0.0000 )    u=3 $ Assy loc 34
74 like 40 but fill=6 trcl = ( -23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 35
75 like 40 but fill=6 trcl = ( 0.0000 -70.5993 0.0000 )    u=3 $ Assy loc 36
76 like 40 but fill=6 trcl = ( 23.5331 -70.5993 0.0000 )    u=3 $ Assy loc 37
77 0          #40 #41 #42 #43 #44 #45 #46 #47 #48 #49 #50 #51 #52
              #53 #54 #55 #56 #57 #58 #59 #60 #61 #62 #63 #64 #65
              #66 #67 #68 #69 #70 #71 #72 #73 #74 #75 #76      fill=4 u=3 $ Cavity
C Cells - Canister v1.3
78 0          -24 fill=3      u=2 $ Cavity
79 7 -7.9400 -31 +24.3      u=2 $ Canister Bottom
80 7 -7.9400 -25 +24.2 -28 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Bottom Drain Port
81 7 -7.9400 -26 +28 -30 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Middle Drain Port
82 7 -7.9400 -27 +30 -31.2 trcl = ( 61.7220 44.7040 0.0000 )    u=2 $ Top Drain Port
83 like 80 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Bottom Vent Port
84 like 81 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Middle Vent Port
85 like 82 but   trcl = ( -61.7220 -44.7040 0.0000 )    u=2 $ Top Vent Port
86 7 -7.9400 -31 -24.3 +24.1     u=2 $ Canister Shell
87 8 -7.8212 -31 -24.1 +24.2 -29 #80 #81  #83 #84   u=2 $ Lower lid
88 7 -7.9400 -31 -24.1 +29 #81 #82  #84 #85    u=2 $ Upper lid
89 0          +31       u=2 $ Outside
C VCC Cells - v1.3.1_ng14b
90 8 -7.8212 -32       u=1 $ Pedestal plate
91 8 -7.8212 -33 +34      u=1 $ Stand
92 8 -7.8212 -39 +40 +46 +47    u=1 $ Bottom plate outer
93 8 -7.8212 (-40 +41 -35) : (-40 +41 -36)       u=1 $ Bottom plate connector
94 8 -7.8212 -41       u=1 $ Bottom plate inner
95 8 -7.8212 (-34 -60 +61 -43) : (-34 -58 +59 +60 -43)       u=1 $ Support rail inside stand
96 8 -7.8212 (+33 -60 +61 -43) : (+33 -58 +59 +60 -43)       u=1 $ Support rail outside stand
97 8 -7.8212 (-51 +53 +35 +36 -44) :
             (-52 +53 +35 +36 -44 +51)       u=1 $ Air inlet top
98 8 -7.8212 (-48 +46 +50 -44 +35 +36 +39) :
             (-49 +47 +50 -44 +35 +36 +39)       u=1 $ Air inlet wall
99 8 -7.8212 (-35 +37 +33 -44 +39) : (-36 +38 +33 -44 +39)       u=1 $ Air inlet angular wall
100 8 -7.8212 (-50 -48 +46 +35 +36 +47 +39) :
              (-50 -49 +47 +35 +36 +46 +39)       u=1 $ Air inlet remaining wall
101 8 -7.8212 -54 +56 +43 -44    u=1 $ Air outlet steel X
102 8 -7.8212 -55 +57 +43 -44    u=1 $ Air outlet steel Y
103 13 -2.3234 -44 +42 +35 +36 +39 +51 +52 +48 +49 +45 +54 +55 +62
              fill=7 u=1 $ Concrete
104 13 -2.3234 -45       u=1 $ Concrete pad
105 8 -7.8212 -42 +43 +54 +55    u=1 $ Liner
106 8 -7.8212 -62 +42      u=1 $ Top flange
107 8 -7.8212 -63       u=1 $ Lid top
108 13 -2.2432 -64       u=1 $ Lid concrete
109 8 -7.8212 -65 +64      u=1 $ Lid shell
110 8 -7.8212 (-66 +78 -43) :
              (-67 +79 -43) :
              (-68 +80 -43) :
              (-69 +81 -43) :
              (-70 +82 -43) :
              (-71 +83 -43) :
              (-72 +84 -43) :
              (-73 +85 -43) :
```

```
                (-74 +86 -43) :
                (-75 +87 -43) :
                (-76 +88 -43) :
                (-77 +89 -43)        u=1 $ Standoffs
111 8 -7.8212 -90        u=1 $ -x inlet pipe 1
112 8 -7.8212 -91        u=1 $ -x inlet pipe 2
113 8 -7.8212 -92        u=1 $ -x inlet pipe 3
114 8 -7.8212 -93        u=1 $ -x inlet pipe 4
115 8 -7.8212 -94        u=1 $ -x inlet pipe 5
116 8 -7.8212 -95        u=1 $ -x inlet pipe 6
117 8 -7.8212 -96        u=1 $ -x inlet pipe 7
118 8 -7.8212 -97        u=1 $ -x inlet pipe 8
119 8 -7.8212 -98        u=1 $ -x inlet pipe 9
120 8 -7.8212 -99        u=1 $ -x inlet pipe 10
121 8 -7.8212 -100        u=1 $ -x inlet pipe 11
122 8 -7.8212 -101        u=1 $ -x inlet pipe 12
123 8 -7.8212 -102        u=1 $ -x inlet pipe 13
124 8 -7.8212 -103        u=1 $ -x inlet pipe 14
125 8 -7.8212 -104        u=1 $ -x inlet pipe 15
126 8 -7.8212 -105        u=1 $ -x inlet pipe 16
127 8 -7.8212 -106        u=1 $ -x inlet pipe 17
128 8 -7.8212 -107        u=1 $ +x inlet pipe 1
129 8 -7.8212 -108        u=1 $ +x inlet pipe 2
130 8 -7.8212 -109        u=1 $ +x inlet pipe 3
131 8 -7.8212 -110        u=1 $ +x inlet pipe 4
132 8 -7.8212 -111        u=1 $ +x inlet pipe 5
133 8 -7.8212 -112        u=1 $ +x inlet pipe 6
134 8 -7.8212 -113        u=1 $ +x inlet pipe 7
135 8 -7.8212 -114        u=1 $ +x inlet pipe 8
136 8 -7.8212 -115        u=1 $ +x inlet pipe 9
137 8 -7.8212 -116        u=1 $ +x inlet pipe 10
138 8 -7.8212 -117        u=1 $ +x inlet pipe 11
139 8 -7.8212 -118        u=1 $ +x inlet pipe 12
140 8 -7.8212 -119        u=1 $ +x inlet pipe 13
141 8 -7.8212 -120        u=1 $ +x inlet pipe 14
142 8 -7.8212 -121        u=1 $ +x inlet pipe 15
143 8 -7.8212 -122        u=1 $ +x inlet pipe 16
144 8 -7.8212 -123        u=1 $ +x inlet pipe 17
145 8 -7.8212 -124        u=1 $ -y inlet pipe 1
146 8 -7.8212 -125        u=1 $ -y inlet pipe 2
147 8 -7.8212 -126        u=1 $ -y inlet pipe 3
148 8 -7.8212 -127        u=1 $ -y inlet pipe 4
149 8 -7.8212 -128        u=1 $ -y inlet pipe 5
150 8 -7.8212 -129        u=1 $ -y inlet pipe 6
151 8 -7.8212 -130        u=1 $ -y inlet pipe 7
152 8 -7.8212 -131        u=1 $ -y inlet pipe 8
153 8 -7.8212 -132        u=1 $ -y inlet pipe 9
154 8 -7.8212 -133        u=1 $ -y inlet pipe 10
155 8 -7.8212 -134        u=1 $ -y inlet pipe 11
156 8 -7.8212 -135        u=1 $ -y inlet pipe 12
157 8 -7.8212 -136        u=1 $ -y inlet pipe 13
158 8 -7.8212 -137        u=1 $ -y inlet pipe 14
159 8 -7.8212 -138        u=1 $ -y inlet pipe 15
160 8 -7.8212 -139        u=1 $ -y inlet pipe 16
161 8 -7.8212 -140        u=1 $ -y inlet pipe 17
162 8 -7.8212 -141        u=1 $ +y inlet pipe 1
163 8 -7.8212 -142        u=1 $ +y inlet pipe 2
164 8 -7.8212 -143        u=1 $ +y inlet pipe 3
165 8 -7.8212 -144        u=1 $ +y inlet pipe 4
166 8 -7.8212 -145        u=1 $ +y inlet pipe 5
167 8 -7.8212 -146        u=1 $ +y inlet pipe 6
168 8 -7.8212 -147        u=1 $ +y inlet pipe 7
169 8 -7.8212 -148        u=1 $ +y inlet pipe 8
170 8 -7.8212 -149        u=1 $ +y inlet pipe 9
171 8 -7.8212 -150        u=1 $ +y inlet pipe 10
172 8 -7.8212 -151        u=1 $ +y inlet pipe 11
173 8 -7.8212 -152        u=1 $ +y inlet pipe 12
174 8 -7.8212 -153        u=1 $ +y inlet pipe 13
175 8 -7.8212 -154        u=1 $ +y inlet pipe 14
```

```
176 8 -7.8212 -155       u=1 $ +y inlet pipe 15
177 8 -7.8212 -156       u=1 $ +y inlet pipe 16
178 8 -7.8212 -157       u=1 $ +y inlet pipe 17
179 0         -39 +40 -46
              +90 +91 +92 +93 +94 +95 +96
              +97 +98 +99 +100 +101 +102 +103
              +104 +105 +106 +107 +108 +109 +110
              +111 +112 +113 +114 +115 +116 +117
              +118 +119 +120 +121 +122 +123       u=1 $ Bottom plate outer void x
180 0         -39 +40 -47
              +124 +125 +126 +127 +128 +129 +130
              +131 +132 +133 +134 +135 +136 +137
              +138 +139 +140 +141 +142 +143 +144
              +145 +146 +147 +148 +149 +150 +151
              +152 +153 +154 +155 +156 +157       u=1 $ Bottom plate outer void y
181 0         -40 +41 +35 +36    u=1 $ Bottom plate connector void
182 0         (-34 -61 -43) : (-34 -59 +60 -43)       u=1 $ Support rail inside stand void
183 0         (+33 -61 -43) : (+33 -59 +60 -43)       u=1 $ Support rail outside stand void
184 0         -46 +33 +35 +36 -44 +39
        +90 +91 +92 +93 +94 +95 +96
        +97 +98 +99 +100 +101 +102 +103
        +104 +105 +106 +107 +108 +109 +110
        +111 +112 +113 +114 +115 +116 +117
        +118 +119 +120 +121 +122 +123       u=1 $ Air inlet void x
185 0         -47 +33 +35 +36 -44 +39 +46
              +124 +125 +126 +127 +128 +129 +130
              +131 +132 +133 +134 +135 +136 +137
              +138 +139 +140 +141 +142 +143 +144
              +145 +146 +147 +148 +149 +150 +151
              +152 +153 +154 +155 +156 +157       u=1 $ Air inlet void y
186 0         -53 +33 +35 +36       u=1 $ Air inlet top void
187 0         (-37 +39 +33) : (-38 +39 +33)       u=1 $ Connector void
188 0         -34 +58 +60       u=1 $ Stand void
189 0         -56 +43 -44     u=1 $ Air outlet void X
190 0         -57 +43 -44     u=1 $ Air outlet void Y
191 0         -43 +32 +33 +58 +60 +65 #110
              fill=2 ( 0.0000 0.0000 6.9850 )       u=1 $ Cavity
192 0         +44 +42 +62 63    u=1 $ Outside
C VCC Rebar Cells - v1.3.1_ng14b
193 8 -7.8212 -158       u=7 $ Outer hoop 1
194 8 -7.8212 -159       u=7 $ Outer hoop 2
195 8 -7.8212 -160       u=7 $ Outer hoop 3
196 8 -7.8212 -161       u=7 $ Outer hoop 4
197 8 -7.8212 -162       u=7 $ Outer hoop 5
198 8 -7.8212 -163       u=7 $ Outer hoop 6
199 8 -7.8212 -164       u=7 $ Outer hoop 7
200 8 -7.8212 -165       u=7 $ Outer hoop 8
201 8 -7.8212 -166       u=7 $ Outer hoop 9
202 8 -7.8212 -167       u=7 $ Outer hoop 10
203 8 -7.8212 -168       u=7 $ Outer hoop 11
204 8 -7.8212 -169       u=7 $ Outer hoop 12
205 8 -7.8212 -170       u=7 $ Outer hoop 13
206 8 -7.8212 -171       u=7 $ Outer hoop 14
207 8 -7.8212 -172       u=7 $ Outer hoop 15
208 8 -7.8212 -173       u=7 $ Outer hoop 16
209 8 -7.8212 -174       u=7 $ Outer hoop 17
210 8 -7.8212 -175       u=7 $ Outer hoop 18
211 8 -7.8212 -176       u=7 $ Outer hoop 19
212 8 -7.8212 -177       u=7 $ Outer hoop 20
213 8 -7.8212 -178       u=7 $ Outer hoop 21
214 8 -7.8212 -179       u=7 $ Outer hoop 22
215 8 -7.8212 -180       u=7 $ Outer hoop 23
216 8 -7.8212 -181       u=7 $ Outer hoop 24
217 8 -7.8212 -182       u=7 $ Outer hoop 25
218 8 -7.8212 -183       u=7 $ Outer hoop 26
219 8 -7.8212 -184       u=7 $ Outer hoop 27
220 8 -7.8212 -185       u=7 $ Outer hoop 28
221 8 -7.8212 -186       u=7 $ Outer hoop 29
222 8 -7.8212 -187       u=7 $ Outer hoop 30
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223 8 -7.8212 -188        u=7 $ Outer hoop 31
224 8 -7.8212 -189        u=7 $ Outer hoop 32
225 8 -7.8212 -190        u=7 $ Outer hoop 33
226 8 -7.8212 -191        u=7 $ Outer hoop 34
227 8 -7.8212 -192        u=7 $ Outer hoop 35
228 8 -7.8212 -193        u=7 $ Outer hoop 36
229 8 -7.8212 -194        u=7 $ Outer hoop 37
230 8 -7.8212 -195        u=7 $ Outer hoop 38
231 8 -7.8212 -196        u=7 $ Outer hoop 39
232 8 -7.8212 -197        u=7 $ Outer hoop 40
233 8 -7.8212 -198        u=7 $ Outer hoop 41
234 8 -7.8212 -199        u=7 $ Outer hoop 42
235 8 -7.8212 -200        u=7 $ Outer hoop 43
236 8 -7.8212 -201        u=7 $ Outer hoop 44
237 8 -7.8212 -202        u=7 $ Outer hoop 45
238 8 -7.8212 -203        u=7 $ Outer hoop 46
239 8 -7.8212 -204        u=7 $ Outer hoop 47
240 8 -7.8212 -205        u=7 $ Outer hoop 48
241 8 -7.8212 -206        u=7 $ Outer hoop 49
242 8 -7.8212 -207        u=7 $ Outer hoop 50
243 13 -2.3234 #193 #194 #195 #196 #197 #198 #199
        #200 #201 #202 #203 #204 #205 #206 #207 #208 #209
        #210 #211 #212 #213 #214 #215 #216 #217 #218 #219
        #220 #221 #222 #223 #224 #225 #226 #227 #228 #229
        #230 #231 #232 #233 #234 #235 #236 #237 #238 #239
        #240 #241 #242        fill=8 u=7
244 8 -7.8212 -208   trcl = ( 160.3375 0.0000 0.0000 )    u=8 $ Outer bar 1
245 like 244 but   trcl = ( 159.3293 17.9521 0.0000 )    u=8 $ Outer bar 2
246 like 244 but   trcl = ( 156.3175 35.6785 0.0000 )    u=8 $ Outer bar 3
247 like 244 but   trcl = ( 151.3399 52.9561 0.0000 )    u=8 $ Outer bar 4
248 like 244 but   trcl = ( 144.4591 69.5678 0.0000 )    u=8 $ Outer bar 5
249 like 244 but   trcl = ( 135.7616 85.3047 0.0000 )    u=8 $ Outer bar 6
250 like 244 but   trcl = ( 125.3569 99.9688 0.0000 )    u=8 $ Outer bar 7
251 like 244 but   trcl = ( 113.3757 113.3757 0.0000 )    u=8 $ Outer bar 8
252 like 244 but   trcl = ( 99.9688 125.3569 0.0000 )    u=8 $ Outer bar 9
253 like 244 but   trcl = ( 85.3047 135.7616 0.0000 )    u=8 $ Outer bar 10
254 like 244 but   trcl = ( 69.5678 144.4591 0.0000 )    u=8 $ Outer bar 11
255 like 244 but   trcl = ( 52.9561 151.3399 0.0000 )    u=8 $ Outer bar 12
256 like 244 but   trcl = ( 35.6785 156.3175 0.0000 )    u=8 $ Outer bar 13
257 like 244 but   trcl = ( 17.9521 159.3293 0.0000 )    u=8 $ Outer bar 14
258 like 244 but   trcl = ( 0.0000 160.3375 0.0000 )    u=8 $ Outer bar 15
259 like 244 but   trcl = ( -17.9521 159.3293 0.0000 )    u=8 $ Outer bar 16
260 like 244 but   trcl = ( -35.6785 156.3175 0.0000 )    u=8 $ Outer bar 17
261 like 244 but   trcl = ( -52.9561 151.3399 0.0000 )    u=8 $ Outer bar 18
262 like 244 but   trcl = ( -69.5678 144.4591 0.0000 )    u=8 $ Outer bar 19
263 like 244 but   trcl = ( -85.3047 135.7616 0.0000 )    u=8 $ Outer bar 20
264 like 244 but   trcl = ( -99.9688 125.3569 0.0000 )    u=8 $ Outer bar 21
265 like 244 but   trcl = ( -113.3757 113.3757 0.0000 )    u=8 $ Outer bar 22
266 like 244 but   trcl = ( -125.3569 99.9688 0.0000 )    u=8 $ Outer bar 23
267 like 244 but   trcl = ( -135.7616 85.3047 0.0000 )    u=8 $ Outer bar 24
268 like 244 but   trcl = ( -144.4591 69.5678 0.0000 )    u=8 $ Outer bar 25
269 like 244 but   trcl = ( -151.3399 52.9561 0.0000 )    u=8 $ Outer bar 26
270 like 244 but   trcl = ( -156.3175 35.6785 0.0000 )    u=8 $ Outer bar 27
271 like 244 but   trcl = ( -159.3293 17.9521 0.0000 )    u=8 $ Outer bar 28
272 like 244 but   trcl = ( -160.3375 0.0000 0.0000 )    u=8 $ Outer bar 29
273 like 244 but   trcl = ( -159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 30
274 like 244 but   trcl = ( -156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 31
275 like 244 but   trcl = ( -151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 32
276 like 244 but   trcl = ( -144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 33
277 like 244 but   trcl = ( -135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 34
278 like 244 but   trcl = ( -125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 35
279 like 244 but   trcl = ( -113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 36
280 like 244 but   trcl = ( -99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 37
281 like 244 but   trcl = ( -85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 38
282 like 244 but   trcl = ( -69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 39
283 like 244 but   trcl = ( -52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 40
284 like 244 but   trcl = ( -35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 41
285 like 244 but   trcl = ( -17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 42
286 like 244 but   trcl = ( 0.0000 -160.3375 0.0000 )    u=8 $ Outer bar 43
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287 like 244 but   trcl = ( 17.9521 -159.3293 0.0000 )    u=8 $ Outer bar 44
288 like 244 but   trcl = ( 35.6785 -156.3175 0.0000 )    u=8 $ Outer bar 45
289 like 244 but   trcl = ( 52.9561 -151.3399 0.0000 )    u=8 $ Outer bar 46
290 like 244 but   trcl = ( 69.5678 -144.4591 0.0000 )    u=8 $ Outer bar 47
291 like 244 but   trcl = ( 85.3047 -135.7616 0.0000 )    u=8 $ Outer bar 48
292 like 244 but   trcl = ( 99.9688 -125.3569 0.0000 )    u=8 $ Outer bar 49
293 like 244 but   trcl = ( 113.3757 -113.3757 0.0000 )    u=8 $ Outer bar 50
294 like 244 but   trcl = ( 125.3569 -99.9688 0.0000 )    u=8 $ Outer bar 51
295 like 244 but   trcl = ( 135.7616 -85.3047 0.0000 )    u=8 $ Outer bar 52
296 like 244 but   trcl = ( 144.4591 -69.5678 0.0000 )    u=8 $ Outer bar 53
297 like 244 but   trcl = ( 151.3399 -52.9561 0.0000 )    u=8 $ Outer bar 54
298 like 244 but   trcl = ( 156.3175 -35.6785 0.0000 )    u=8 $ Outer bar 55
299 like 244 but   trcl = ( 159.3293 -17.9521 0.0000 )    u=8 $ Outer bar 56
300 13 -2.3234 #244 #245 #246
        #247 #248 #249 #250 #251 #252 #253 #254 #255 #256
        #257 #258 #259 #260 #261 #262 #263 #264 #265 #266
        #267 #268 #269 #270 #271 #272 #273 #274 #275 #276
        #277 #278 #279 #280 #281 #282 #283 #284 #285 #286
        #287 #288 #289 #290 #291 #292 #293 #294 #295 #296
        #297 #298 #299        u=8
C Detector Cells - Radial Biasing
399  0  -399  fill=1  $ Cask
400  0  -400  +399  $ Surface
450  0  -450  +399  +400  $ SurfAzi
500  0  -500  +399  +400  +450  $ 1ft
600  0  -600  +399  +400  +450  +500  $ 1m
700  0  -700  +399  +400  +450  +500  +600  $ 2m
800  0  -800  +399  +400  +450  +500  +600  +700  $ 4m
900  0  +399  +400  +450  +500  +600  +700  +800  $ Exterior

C Fuel Assembly Surfaces - ng14b - v1.1
1 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 8.0975  $ Lower Nozzle
2 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 9.8374  $ Lower Plenum
3 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 378.6454  $ Fuel
4 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 400.3040  $ Upper Plenum
5 RPP -9.8590 9.8590 -9.8590 9.8590 0.0000 409.1940  $ Upper Nozzle
6 PZ 255.7094       $ Flood elevation
C Surfaces - Fuel Tube v1.3
7 RPP -11.6015 11.6015 -11.6015 11.6015 7.6200 439.4962  $ Tube void
8 RPP -12.3952 12.3952 -12.3952 12.3952 7.6200 430.5300  $ Tube
9 RPP -11.6015 -11.2840 -10.2362 10.2362 9.2075 428.9425  $ Poison left
10 RPP 11.2840 11.6015 -10.2362 10.2362 9.2075 428.9425  $ Poison right
11 RPP -10.2362 10.2362 11.2840 11.6015 9.2075 428.9425  $ Poison top
12 RPP -10.2362 10.2362 -11.6015 -11.2840 9.2075 428.9425  $ Poison bottom
C Surfaces - PWR Basket v1.5
13  RPP -12.3952 12.3952 -12.3952 12.3952 0.0000 439.4962  $ Tube opening
14 9 RPP -16.6370 16.6370 -16.6370 16.6370 0.0000 439.4962  $ Tube radius
15  RPP 81.8833 83.7883 -33.1851 33.1851 7.6200 430.5300  $ Side support +x
16  RPP -83.7883 -81.8833 -33.1851 33.1851 7.6200 430.5300  $ Side support -x
17  RPP -33.1851 33.1851 81.8833 83.7883 7.6200 430.5300  $ Side support +y
18  RPP -33.1851 33.1851 -83.7883 -81.8833 7.6200 430.5300  $ Side support -y
19  RPP -60.2552 60.2552 -60.2552 60.2552 7.6200 430.5300  $ Corner outer
20  RPP -59.4614 59.4614 -59.4614 59.4614 7.6200 430.5300  $ Corner inner
21 9 RPP -78.6267 78.6267 -78.6267 78.6267 7.6200 430.5300  $ Corner dia. outer
22 9 RPP -77.83291 77.8329 -77.8329 77.8329 7.6200 430.5300  $ Corner dia. inner
C Surfaces - PWR Canister Cavity v1.5
23 RPP -9.8595 9.8595 -9.8595 9.8595 0.0000 409.1941   $ Assy opening
C Surfaces - Canister v1.3
24 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 439.4962 90.1700   $ Cavity
25 CZ 2.6924         $ Bot Cylinder Radius
26 CZ 6.7691         $ Mid Cyclinder Radius
27 CZ 7.4041         $ Top Cylinder Radius
28 PZ 450.8500         $ Port plane bot/mid
29 PZ 452.1962         $ Lower/upper lid
30 PZ 459.5114         $ Port plane mid/top
31 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.3412 91.4400   $ Canister
C VCC Surfaces - v1.3.1_ng14b
32  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
33  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 63.4999  $ Stand outer
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34  RCC 0.0000 0.0000 -30.4800 0.0000 0.0000 25.4000 62.3888  $ Stand inner
35 9 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate A
36 10 RPP -100.3300 100.3300 -10.4775 10.4775 -33.0200 -16.5100   $ Connector plate B
37 9 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall A
38 10 RPP -99.0600 99.0600 -9.2075 9.2075 -33.0200 -16.5100   $ Air inlet angled wall B
39  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
40  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 100.3300  $ Connector radius
41  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
42  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 538.0228 105.41  $ VCC liner outer
43  RCC 0.0000 0.0000 -16.5100 0.0000 0.0000 538.0228 100.965  $ VCC liner inner
44  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 654.5328 172.7200  $ Concrete
45  RCC 0.0000 0.0000 -133.0200 0.0000 0.0000 100.0000 172.7200  $ Concrete pad
46  RPP -172.7200 172.7200 -63.5000 63.5000 -33.0200 -21.5900   $ Air inlet void X
47  RPP -63.5000 63.5000 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet void Y
48  RPP -172.7200 172.7200 -64.7700 64.7700 -33.0200 -21.5900   $ Air inlet wall X
49  RPP -64.7700 64.7700 -172.7200 172.7200 -33.0200 -21.5900   $ Air inlet wall Y
50  RCC 0.0000 0.0000 -33.0200 0.0000 0.0000 11.4300 100.3300  $ Air inlet divider
51  RPP -172.7200 172.7200 -64.7700 64.7700 -21.5900 -16.5100   $ Air inlet top X
52  RPP -64.7700 64.7700 -172.7200 172.7200 -21.5900 -16.5100   $ Air inlet top Y
53  RCC 0.0000 0.0000 -21.5900 0.0000 0.0000 5.0800 93.9800  $ Air inlet top plate radius
54  RPP -172.7200 172.7200 -64.7700 64.7700 494.0808 505.0028   $ Air outlet steel X
55  RPP -64.7700 64.7700 -172.7200 172.7200 494.0808 505.0028   $ Air outlet steel Y
56  RPP -172.7200 172.7200 -64.1350 64.1350 494.7158 504.3678   $ Air outlet void X
57  RPP -64.1350 64.1350 -172.7200 172.7200 494.7158 504.3678   $ Air outlet void Y
58  RPP -106.6800 106.6800 -5.7150 5.7150 -16.5100 -5.0800   $ Support rail exterior X
59  RPP -106.6800 106.6800 -4.4450 4.4450 -16.5100 -5.0800   $ Support rail interior X
60  RPP -5.7150 5.7150 -106.6800 106.6800 -16.5100 -5.0800   $ Support rail exterior Y
61  RPP -4.4450 4.4450 -106.6800 106.6800 -16.5100 -5.0800   $ Support rail interior Y
62  RCC 0.0000 0.0000 518.9728 0.0000 0.0000 2.5400 118.7450  $ Top flange
63  RCC 0.0000 0.0000 521.5128 0.0000 0.0000 1.9050 116.2050  $ Lid top
64  RCC 0.0000 0.0000 506.7808 0.0000 0.0000 14.7320 99.6950  $ Lid concrete
65  RCC 0.0000 0.0000 506.1458 0.0000 0.0000 15.3670 100.3300  $ Lid shell
66  RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 1
67 11 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 2
68 12 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 3
69 9 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 4
70 13 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 5
71 14 RPP -100.9650 100.9650 -0.4432 0.4432 174.8028 479.6028   $ Standoff outer 6
72  RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 7
73 11 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 8
74 12 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 9
75 9 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 10
76 13 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 11
77 14 RPP -0.4432 0.4432 -100.9650 100.9650 174.8028 479.6028   $ Standoff outer 12
78  RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 1
79 11 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 2
80 12 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 3
81 9 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 4
82 13 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 5
83 14 RPP -93.3450 93.3450 -0.4432 0.4432 174.8028 479.6028   $ Standoff inner 6
84  RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 7
85 11 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 8
86 12 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 9
87 9 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 10
88 13 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 11
89 14 RPP -0.4432 0.4432 -93.3450 93.3450 174.8028 479.6028   $ Standoff inner 12
90  RCC -146.0500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 1
91  RCC -146.0500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 2
92  RCC -146.0500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 3
93  RCC -146.0500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 4
94  RCC -146.0500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 5
95  RCC -146.0500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 6
96  RCC -133.3500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 7
97  RCC -133.3500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 8
98  RCC -133.3500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 9
99  RCC -133.3500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 10
100  RCC -133.3500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 11
101  RCC -133.3500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 12
102  RCC -120.6500 43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 13
```

```
RCC -120.6500 21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 14
RCC -120.6500 -0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 15
RCC -120.6500 -22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 16
RCC -120.6500 -44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -x inlet pipe 17
RCC 146.0500 -58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 1
RCC 146.0500 -36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 2
RCC 146.0500 -14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 3
RCC 146.0500 7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 4
RCC 146.0500 28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 5
RCC 146.0500 50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 6
RCC 133.3500 -50.8000 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 7
RCC 133.3500 -28.9560 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 8
RCC 133.3500 -7.1120 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 9
RCC 133.3500 14.7320 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 10
RCC 133.3500 36.5760 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 11
RCC 133.3500 58.4200 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 12
RCC 120.6500 -43.1800 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 13
RCC 120.6500 -21.3360 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 14
RCC 120.6500 0.5080 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 15
RCC 120.6500 22.3520 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 16
RCC 120.6500 44.1960 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +x inlet pipe 17
RCC -58.4200 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 1
RCC -36.5760 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 2
RCC -14.7320 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 3
RCC 7.1120 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 4
RCC 28.9560 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 5
RCC 50.8000 -146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 6
RCC -50.8000 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 7
RCC -28.9560 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 8
RCC -7.1120 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 9
RCC 14.7320 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 10
RCC 36.5760 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 11
RCC 58.4200 -133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 12
RCC -43.1800 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 13
RCC -21.3360 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 14
RCC 0.5080 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 15
RCC 22.3520 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 16
RCC 44.1960 -120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ -y inlet pipe 17
RCC 58.4200 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 1
RCC 36.5760 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 2
RCC 14.7320 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 3
RCC -7.1120 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 4
RCC -28.9560 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 5
RCC -50.8000 146.0500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 6
RCC 50.8000 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 7
RCC 28.9560 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 8
RCC 7.1120 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 9
RCC -14.7320 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 10
RCC -36.5760 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 11
RCC -58.4200 133.3500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 12
RCC 43.1800 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 13
RCC 21.3360 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 14
RCC -0.5080 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 15
RCC -22.3520 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 16
RCC -44.1960 120.6500 -33.0200 0.0000 0.0000 11.4300 3.8100  $ +y inlet pipe 17
C VCC Rebar Surfaces - v1.3.1_ng14b
TZ 0.0000 0.0000 -1.7182 162.2425 0.9525 0.9525   $ Outer hoop 1
TZ 0.0000 0.0000 7.9935 162.2425 0.9525 0.9525   $ Outer hoop 2
TZ 0.0000 0.0000 17.7053 162.2425 0.9525 0.9525   $ Outer hoop 3
TZ 0.0000 0.0000 27.4171 162.2425 0.9525 0.9525   $ Outer hoop 4
TZ 0.0000 0.0000 37.1288 162.2425 0.9525 0.9525   $ Outer hoop 5
TZ 0.0000 0.0000 46.8406 162.2425 0.9525 0.9525   $ Outer hoop 6
TZ 0.0000 0.0000 56.5524 162.2425 0.9525 0.9525   $ Outer hoop 7
TZ 0.0000 0.0000 66.2641 162.2425 0.9525 0.9525   $ Outer hoop 8
TZ 0.0000 0.0000 75.9759 162.2425 0.9525 0.9525   $ Outer hoop 9
TZ 0.0000 0.0000 85.6876 162.2425 0.9525 0.9525   $ Outer hoop 10
TZ 0.0000 0.0000 95.3994 162.2425 0.9525 0.9525   $ Outer hoop 11
TZ 0.0000 0.0000 105.1112 162.2425 0.9525 0.9525   $ Outer hoop 12
TZ 0.0000 0.0000 114.8229 162.2425 0.9525 0.9525   $ Outer hoop 13
```

```
171  TZ 0.0000 0.0000 124.5347 162.2425 0.9525 0.9525   $ Outer hoop 14
172  TZ 0.0000 0.0000 134.2465 162.2425 0.9525 0.9525   $ Outer hoop 15
173  TZ 0.0000 0.0000 143.9582 162.2425 0.9525 0.9525   $ Outer hoop 16
174  TZ 0.0000 0.0000 153.6700 162.2425 0.9525 0.9525   $ Outer hoop 17
175  TZ 0.0000 0.0000 163.3818 162.2425 0.9525 0.9525   $ Outer hoop 18
176  TZ 0.0000 0.0000 173.0935 162.2425 0.9525 0.9525   $ Outer hoop 19
177  TZ 0.0000 0.0000 182.8053 162.2425 0.9525 0.9525   $ Outer hoop 20
178  TZ 0.0000 0.0000 192.5171 162.2425 0.9525 0.9525   $ Outer hoop 21
179  TZ 0.0000 0.0000 202.2288 162.2425 0.9525 0.9525   $ Outer hoop 22
180  TZ 0.0000 0.0000 211.9406 162.2425 0.9525 0.9525   $ Outer hoop 23
181  TZ 0.0000 0.0000 221.6524 162.2425 0.9525 0.9525   $ Outer hoop 24
182  TZ 0.0000 0.0000 231.3641 162.2425 0.9525 0.9525   $ Outer hoop 25
183  TZ 0.0000 0.0000 241.0759 162.2425 0.9525 0.9525   $ Outer hoop 26
184  TZ 0.0000 0.0000 250.7876 162.2425 0.9525 0.9525   $ Outer hoop 27
185  TZ 0.0000 0.0000 260.4994 162.2425 0.9525 0.9525   $ Outer hoop 28
186  TZ 0.0000 0.0000 270.2112 162.2425 0.9525 0.9525   $ Outer hoop 29
187  TZ 0.0000 0.0000 279.9229 162.2425 0.9525 0.9525   $ Outer hoop 30
188  TZ 0.0000 0.0000 289.6347 162.2425 0.9525 0.9525   $ Outer hoop 31
189  TZ 0.0000 0.0000 299.3465 162.2425 0.9525 0.9525   $ Outer hoop 32
190  TZ 0.0000 0.0000 309.0582 162.2425 0.9525 0.9525   $ Outer hoop 33
191  TZ 0.0000 0.0000 318.7700 162.2425 0.9525 0.9525   $ Outer hoop 34
192  TZ 0.0000 0.0000 328.4818 162.2425 0.9525 0.9525   $ Outer hoop 35
193  TZ 0.0000 0.0000 338.1935 162.2425 0.9525 0.9525   $ Outer hoop 36
194  TZ 0.0000 0.0000 347.9053 162.2425 0.9525 0.9525   $ Outer hoop 37
195  TZ 0.0000 0.0000 357.6171 162.2425 0.9525 0.9525   $ Outer hoop 38
196  TZ 0.0000 0.0000 367.3288 162.2425 0.9525 0.9525   $ Outer hoop 39
197  TZ 0.0000 0.0000 377.0406 162.2425 0.9525 0.9525   $ Outer hoop 40
198  TZ 0.0000 0.0000 386.7524 162.2425 0.9525 0.9525   $ Outer hoop 41
199  TZ 0.0000 0.0000 396.4641 162.2425 0.9525 0.9525   $ Outer hoop 42
200  TZ 0.0000 0.0000 406.1759 162.2425 0.9525 0.9525   $ Outer hoop 43
201  TZ 0.0000 0.0000 415.8876 162.2425 0.9525 0.9525   $ Outer hoop 44
202  TZ 0.0000 0.0000 425.5994 162.2425 0.9525 0.9525   $ Outer hoop 45
203  TZ 0.0000 0.0000 435.3112 162.2425 0.9525 0.9525   $ Outer hoop 46
204  TZ 0.0000 0.0000 445.0229 162.2425 0.9525 0.9525   $ Outer hoop 47
205  TZ 0.0000 0.0000 454.7347 162.2425 0.9525 0.9525   $ Outer hoop 48
206  TZ 0.0000 0.0000 464.4465 162.2425 0.9525 0.9525   $ Outer hoop 49
207  TZ 0.0000 0.0000 474.1582 162.2425 0.9525 0.9525   $ Outer hoop 50
208  RCC 0.0000 0.0000 -11.4300 0.0000 0.0000 495.3000 0.9525  $ Bar
C Storage Cask & Pad Container
399  RCC  0.0000  0.0000  -133.0200  0.0000  0.0000  656.4378  172.7201
C Radial Detector DRA (Surface)
400  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  556.5378  172.8201
401  PZ  13.3582
402  PZ  59.7363
403  PZ  106.1145
404  PZ  152.4926
405  PZ  198.8708
406  PZ  245.2489
407  PZ  291.6271
408  PZ  338.0052
409  PZ  384.3834
410  PZ  430.7615
411  PZ  477.1397
C Radial Detector DRAA (SurfAzi)
450  RCC  0.0000  0.0000  16.8224  0.0000  0.0000  368.8080  172.9201
451     PX  0.0000
452  1  PX  0.0000
453  2  PX  0.0000
454  3  PX  0.0000
455  4  PX  0.0000
456     PY  0.0000
457  5  PX  0.0000
458  6  PX  0.0000
459  7  PX  0.0000
460  8  PX  0.0000
C Radial Detector DRB (1ft)
500  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  587.0178  203.3001
501  PZ  15.8982
502  PZ  64.8163
```

```
503  PZ  113.7345
504  PZ  162.6526
505  PZ  211.5708
506  PZ  260.4889
507  PZ  309.4071
508  PZ  358.3252
509  PZ  407.2434
510  PZ  456.1615
511  PZ  505.0797
C Radial Detector DRC (1m)
600  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  656.5378  272.8201
601  PZ  10.7492
602  PZ  54.5184
603  PZ  98.2876
604  PZ  142.0567
605  PZ  185.8259
606  PZ  229.5951
607  PZ  273.3643
608  PZ  317.1335
609  PZ  360.9027
610  PZ  404.6719
611  PZ  448.4411
612  PZ  492.2102
613  PZ  535.9794
614  PZ  579.7486
C Radial Detector DRD (2m)
700  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  756.5378  372.8201
701  PZ  4.8069
702  PZ  42.6338
703  PZ  80.4607
704  PZ  118.2876
705  PZ  156.1145
706  PZ  193.9413
707  PZ  231.7682
708  PZ  269.5951
709  PZ  307.4220
710  PZ  345.2489
711  PZ  383.0758
712  PZ  420.9027
713  PZ  458.7296
714  PZ  496.5565
715  PZ  534.3834
716  PZ  572.2102
717  PZ  610.0371
718  PZ  647.8640
719  PZ  685.6909
C Radial Detector DRE (4m)
800  RCC  0.0000  0.0000  -33.0200  0.0000  0.0000  956.5378  572.8201
801  PZ  14.8069
802  PZ  62.6338
803  PZ  110.4607
804  PZ  158.2876
805  PZ  206.1145
806  PZ  253.9413
807  PZ  301.7682
808  PZ  349.5951
809  PZ  397.4220
810  PZ  445.2489
811  PZ  493.0758
812  PZ  540.9027
813  PZ  588.7296
814  PZ  636.5565
815  PZ  684.3834
816  PZ  732.2102
817  PZ  780.0371
818  PZ  827.8640
819  PZ  875.6909

C
```

```
C Materials List - Common Materials - v1.7
C
C Homogenized Lower Nozzle
m1     24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
       28000 -9.5000E-02
C Homogenized Lower Plenum
m2     24000 -1.0000E-03 50000 -1.5000E-02
       26000 -1.2500E-03  7014 -5.0000E-04
       40000 -9.8225E-01
C Homogenized UO2 Fuel - Dry
m3     92235 -3.6891E-02 40000 -1.6011E-01 24000 -1.6300E-04
       92238 -7.0092E-01 50000 -2.4450E-03  7014 -8.1499E-05
        8016 -9.9186E-02 26000 -2.0375E-04
C Homogenized Upper Plenum
m4     24000 -1.4890E-01 50000 -3.2622E-03 25055 -1.5650E-02
       26000 -5.4413E-01  7014 -1.0874E-04 28000 -7.4340E-02
       40000 -2.1362E-01
C Homogenized Upper Nozzle
m5     24000 -1.9000E-01 25055 -2.0000E-02 26000 -6.9500E-01
       28000 -9.5000E-02
C Water
m6     1001 2 8016 1
C Stainless Steel
m7     24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Carbon Steel
m8     26000 -0.99  6012 -0.01
C Neutron Poison
m9     13027 -0.6605 5010 -0.0478 5011 -0.2179
       6012 -0.0737
C Aluminum
m10    13027 -1.0
C Lead
m11    82000 -1.0
C NS-4-FR
m12    5010 -9.3127E-04 13027 -2.1420E-01 6000 -2.7627E-01
       5011 -3.7721E-03 1001 -6.0012E-02 7014 -1.9815E-02
       8016 -4.2500E-01
C Concrete
m13    26000 -0.014 20000 -0.044 14000 -0.337
        1001 -0.010  8016 -0.532 11023 -0.029
       13027 -0.034
C Vent Port Middle Cylinder
m14    24000 -0.190 25055 -0.020 26000 -0.695
       28000 -0.095
C Balsa
m15    6012 6 1001 10 8016 5
C NS-4-FR (Accident)
m16    5010 -1.7596E-03 13027 -4.3257E-01 6012 -5.5793E-01
       5011 -7.7389E-03
C Copper
m17    29063 -6.8499E-01 29065 -3.1501E-01
C Damaged Fuel
m18    92235 -4.1222E-02
       92238 -7.8321E-01
        8016 -1.1083E-01
       40000 -6.3583E-02
       50000 -9.7099E-04
       26000 -8.0916E-05
       24000 -6.4732E-05
        7014 -3.2366E-05
C Damaged Lower Nozzle
m19    92235 -3.2602E-02
       92238 -6.1944E-01
        8016 -8.7656E-02
       24000 -4.9457E-02
       25055 -5.2060E-03
       26000 -1.8091E-01
       28000 -2.4728E-02
```

```
C Damaged Lower Plenum
m20    92235 -3.0443E-02
       92238 -5.7843E-01
        8016 -8.1852E-02
       24000 -3.0928E-04
       26000 -3.8660E-04
       40000 -3.0379E-01
       50000 -4.6392E-03
        7014 -1.5464E-04
C Damaged Upper Plenum
m21    92235 -3.9655E-02
       92238 -7.5344E-01
        8016 -1.0662E-01
       24000 -1.4932E-02
       26000 -5.4568E-02
       40000 -2.1423E-02
       50000 -3.2715E-04
        7014 -1.0905E-05
       25055 -1.5695E-03
       28000 -7.4552E-03
C Damaged upper Nozzle
m22    92235 -3.0832E-02
       92238 -5.8581E-01
        8016 -8.2897E-02
       24000 -5.7087E-02
       25055 -6.0091E-03
       26000 -2.0882E-01
       28000 -2.8543E-02
phys:p 100 0 0 0 1    $ Disable Doppler energy broadening
C
C Cell Importances
C
imp:p 1 306r 0
C
C Source Definition - Fuel Gamma Response to Group 7 - Symmetric Position B2
C
sdef x=d1 y=d2 z=d3 erg=d4 cell=399:191:78:d5:3
si1    -9.85901 9.85901
sp1    0 1
si2    -9.85901 9.85901
sp2    0 1
si3 a 9.8374 19.0576 28.2778 37.4980 46.7182 55.9384 65.1586
      323.3242 332.5444 341.7646 350.9848 360.2050 369.4252 378.6454
sp3 d 0.5470 0.6358 0.7247 0.8135 0.9023 0.9912 1.0800
      1.0800 0.9912 0.9023 0.8135 0.7247 0.6358 0.5470
sb3 d 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
      1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00 1.00E+00
si4    3.000E+00 4.000E+00
sp4    0 1
C Source Information
si5 l        40 41 42
          43 44 45 46 47
      48 49 50 51 52 53 54
      55 56 57 58 59 60 61
      62 63 64 65 66 67 68
         69 70 71 72 73
            74 75 76
C Source Probability
sp5            0.0 0.0 0.0
           0.0000 0.0 1.0 0.0 0.0000
      0.0 0.0 0.0 0.0 0.0 0.0 0.0
      0.0 1.0 0.0 0.0 0.0 1.0 0.0
      0.0 0.0 0.0 0.0 0.0 0.0 0.0
           0.0000 0.0 1.0 0.0 0.0000
               0.0 0.0 0.0
mode p
nps 40000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
```

```
C (mrem/hr)/(photons/cm2-sec)
C
de0    0.01 0.03 0.05 0.07 0.1 0.15 0.2
       0.25 0.3 0.35 0.4 0.45 0.5 0.55
       0.6 0.65 0.7 0.8 1 1.4 1.8
       2.2 2.6 2.8 3.25 3.75 4.25 4.75
       5 5.25 5.75 6.25 6.75 7.5 9
       11 13 15
df0    3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
       6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
       1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
       3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
       5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
       1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
C
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=57 0 201 origin=0.1 0.1 -134
     imesh 90.2 91.4 101.0 105.4 172.7 672.7
     iints 5 1 1 1 5 1
     jmesh 101 104 112 118 129 141 151 520 550 581 603 640 656 1156
     jints 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
C wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +400.1
fm2 4.0000E+00
fs2  -401  -402  -403  -404  -405  -406
     -407  -408  -409  -410  -411  T
tf2
fc12 Radial SurfAzi Tally Q1 (+x+y)
f12:p +450.1
fm12 4.0000E+00
fs12 -451  -456
     +455  +454  +453  +452  T
sd12 2.0035E+05  1.0018E+05  2.0035E+04  4r  4.0071E+05
tf12
fc22 Radial SurfAzi Tally Q2 (-x+y)
f22:p +450.1
fm22 4.0000E+00
fs22 +451  -456
     -460  -459  -458  -457  T
sd22 2.0035E+05  1.0018E+05  2.0035E+04  4r  4.0071E+05
tf22
fc32 Radial SurfAzi Tally Q3 (-x-y)
f32:p +450.1
fm32 4.0000E+00
fs32 +451  +456
     -455  -454  -453  -452  T
sd32 2.0035E+05  1.0018E+05  2.0035E+04  4r  4.0071E+05
tf32
fc42 Radial SurfAzi Tally Q4 (+x-y)
f42:p +450.1
fm42 4.0000E+00
fs42 -451  +456
     +460  +459  +458  +457  T
sd42 2.0035E+05  1.0018E+05  2.0035E+04  4r  4.0071E+05
tf42
fc52 Radial 1ft Tally
f52:p +500.1
fm52 4.0000E+00
fs52  -501  -502  -503  -504  -505  -506
     -507  -508  -509  -510  -511  T
tf52
fc62 Radial 1m Tally
f62:p +600.1
```

```
fm62 4.0000E+00
fs62  -601  -602  -603  -604  -605  -606
     -607  -608  -609  -610  -611  -612
     -613  -614  T
tf62
fc72 Radial 2m Tally
f72:p +700.1
fm72 4.0000E+00
fs72  -701  -702  -703  -704  -705  -706
     -707  -708  -709  -710  -711  -712
     -713  -714  -715  -716  -717  -718
     -719  T
tf72
fc82 Radial 4m Tally
f82:p +800.1
fm82 4.0000E+00
fs82  -801  -802  -803  -804  -805  -806
     -807  -808  -809  -810  -811  -812
     -813  -814  -815  -816  -817  -818
     -819  T
tf82
C
C
C Print Control
C
prdmp -30 -60 1 2
print
C
C Random Number Generator
C
rand gen=2 seed=19073486328125 stride=152917 hist=1
C
C Rotation Matrix
C
C 18 degree rotation around z-axis
*TR1 0.0 0.0 0.0 18 108 90 -72 18 90 90 90 0
C 36 degree rotation around z-axis
*TR2 0.0 0.0 0.0 36 126 90 -54 36 90 90 90 0
C 54 degree rotation around z-axis
*TR3 0.0 0.0 0.0 54 144 90 -36 54 90 90 90 0
C 72 degree rotation around z-axis
*TR4 0.0 0.0 0.0 72 162 90 -18 72 90 90 90 0
C 108 degree rotation around z-axis
*TR5 0.0 0.0 0.0 108 198 90 18 108 90 90 90 0
C 126 degree rotation around z-axis
*TR6 0.0 0.0 0.0 126 216 90 36 126 90 90 90 0
C 144 degree rotation around z-axis
*TR7 0.0 0.0 0.0 144 234 90 54 144 90 90 90 0
C 162 degree rotation around z-axis
*TR8 0.0 0.0 0.0 162 252 90 72 162 90 90 90 0
C 45 degree rotation around z-axis
*TR9 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0
C 135 degree rotation around z-axis
*TR10 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0
C 15 degree rotation around z-axis
*TR11 0.0 0.0 0.0 15 105 90 -75 15 90 90 90 0
C 30 degree rotation around z-axis
*TR12 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
C 60 degree rotation around z-axis
*TR13 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
C 75 degree rotation around z-axis
*TR14 0.0 0.0 0.0 75 165 90 -15 75 90 90 90 0
```

5.9.8 Cool-Time Tables

PWR system performance is evaluated for a cask heat load of 35.5 kW with preferential (1.8 kW max) and uniform (959 W/assy) heat load patterns. Minimum cool times are summarized for the uniform and preferential heat load patterns.

Allowed low burnup (up to 30,000 MWd/MTU) fuel loadings are shown in Table 5.8.9-1. Note that the listed minimum cool times at each burnup step are bounding for all fuel types and initial enrichments above the minimum enrichment specified. Collapsing the fuel type and initial enrichment-dependent minimum cool time matrix to a single value may result in a minimum cool time longer than individual values presented for higher burnups in the detailed tables that follow.

The minimum cool time tables account for potential uncertainties in the source generation abilities of SAS2H at burnups greater than 45 GWd/MTU by reducing allowed heat loads by 5 percent. Fuel assembly loading tables at greater than 45 GWd/MTU are, therefore, generated for a cask heat load of 33.725 kW with preferential (1.71 kW max) and uniform (911 W/assy) heat load patterns.

The 5% penalty adjusted four-zone preferential loading pattern is as follows.

Zone Description	Designator	Heat Load [W/assy]	Adjusted Heat Load [W/assy]	# Assemblies
Inner Ring	A	513	487	9
Middle Ring	B1	1300	1235	8
	B2	1800	1710	4
Outer Ring	C	830	788	16

Table 5.9.8-1 contains the minimum cool times for a uniform heat load of 959 W/assy (≤ 45 GWd/MTU) PWR fuel. Greater than 45 GWd/MTU uniform heat load minimum cool times are listed in Section 5.8.9. Table 5.9.8-2 through Table 5.9.8-5 contain the minimum cool times for the preferential loading of ≤ 45 GWd/MTU with higher burnup fuel cool times listed in Table 5.9.8-6 through Table 5.9.8-9.

Decay heat associated with loading nonfuel components requires an increase in the minimum fuel assembly cool time. The incremental cool time increase is documented in Table 5.9.4-1 for the BPRAs and TPs. The incremental cool time increase to allow loading of the Westinghouse 14x14 CEAs with a minimum cool time of 2.5 years is shown in Table 5.9.5-4.

Table 5.9.8-1 Loading Table for PWR Fuel – 959 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	2.5	-	-	-	-	-
1.5 ≤ E < 1.7	2.5	2.5	-	-	-	-
1.7 ≤ E < 1.9	2.5	2.5	2.9	-	-	-
1.9 ≤ E < 2.1	2.5	2.5	2.9	3.4	-	-
2.1 ≤ E < 2.3	2.5	2.5	2.8	3.3	3.9	4.1
2.3 ≤ E < 2.5	2.5	2.5	2.8	3.3	3.8	4.1
2.5 ≤ E < 2.7	2.5	2.5	2.8	3.3	3.8	4.0
2.7 ≤ E < 2.9	2.5	2.5	2.8	3.2	3.7	4.0
2.9 ≤ E < 3.1	2.5	2.5	2.7	3.2	3.7	3.9
3.1 ≤ E < 3.3	2.5	2.5	2.7	3.2	3.7	3.9
3.3 ≤ E < 3.5	2.5	2.5	2.7	3.2	3.6	3.9
3.5 ≤ E < 3.7	2.5	2.5	2.7	3.1	3.6	3.8
3.7 ≤ E < 3.9	2.5	2.5	2.7	3.1	3.6	3.8
3.9 ≤ E < 4.1	2.5	2.5	2.6	3.1	3.6	3.8
4.1 ≤ E < 4.3	2.5	2.5	2.6	3.1	3.5	3.8
4.3 ≤ E < 4.5	2.5	2.5	2.6	3.0	3.5	3.7
4.5 ≤ E < 4.7	2.5	2.5	2.6	3.0	3.5	3.7
4.7 ≤ E < 4.9	2.5	2.5	2.6	3.0	3.5	3.7
E ≥ 4.9	2.5	2.5	2.6	3.0	3.5	3.7

Table 5.9.8-1 Loading Table for PWR Fuel – 959 W/Assembly (Continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.4	4.8	-	-	-	-
2.5 ≤ E < 2.7	4.4	4.7	5.2	5.4	5.6	5.8
2.7 ≤ E < 2.9	4.3	4.7	5.1	5.3	5.5	5.7
2.9 ≤ E < 3.1	4.3	4.6	5.0	5.2	5.4	5.6
3.1 ≤ E < 3.3	4.2	4.5	4.9	5.1	5.3	5.6
3.3 ≤ E < 3.5	4.2	4.5	4.9	5.1	5.3	5.5
3.5 ≤ E < 3.7	4.1	4.5	4.8	5.0	5.2	5.4
3.7 ≤ E < 3.9	4.1	4.4	4.8	4.9	5.1	5.3
3.9 ≤ E < 4.1	4.1	4.4	4.8	4.9	5.1	5.3
4.1 ≤ E < 4.3	4.0	4.4	4.7	4.9	5.0	5.2
4.3 ≤ E < 4.5	4.0	4.3	4.7	4.8	5.0	5.2
4.5 ≤ E < 4.7	4.0	4.3	4.6	4.8	4.9	5.1
4.7 ≤ E < 4.9	4.0	4.3	4.6	4.7	4.9	5.0
E ≥ 4.9	3.9	4.2	4.5	4.7	4.9	5.0

Table 5.9.8-1 Loading Table for PWR Fuel – 959 W/Assembly (Continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	6.0	-
2.7 ≤ E < 2.9	5.9	6.2
2.9 ≤ E < 3.1	5.8	6.0
3.1 ≤ E < 3.3	5.8	6.0
3.3 ≤ E < 3.5	5.7	5.9
3.5 ≤ E < 3.7	5.6	5.8
3.7 ≤ E < 3.9	5.6	5.8
3.9 ≤ E < 4.1	5.5	5.7
4.1 ≤ E < 4.3	5.4	5.6
4.3 ≤ E < 4.5	5.4	5.6
4.5 ≤ E < 4.7	5.3	5.5
4.7 ≤ E < 4.9	5.3	5.5
E ≥ 4.9	5.2	5.4

Table 5.9.8-2 Loading Table for PWR Fuel – 513 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	2.9	-	-	-	-	-
1.5 ≤ E < 1.7	2.9	3.8	-	-	-	-
1.7 ≤ E < 1.9	2.9	3.7	4.5	-	-	-
1.9 ≤ E < 2.1	2.9	3.7	4.5	5.7	-	-
2.1 ≤ E < 2.3	2.8	3.7	4.5	5.7	7.5	8.9
2.3 ≤ E < 2.5	2.8	3.6	4.4	5.6	7.4	8.8
2.5 ≤ E < 2.7	2.8	3.6	4.4	5.6	7.3	8.6
2.7 ≤ E < 2.9	2.8	3.6	4.4	5.5	7.2	8.5
2.9 ≤ E < 3.1	2.8	3.5	4.4	5.5	7.1	8.5
3.1 ≤ E < 3.3	2.8	3.5	4.3	5.5	7.1	8.4
3.3 ≤ E < 3.5	2.8	3.5	4.3	5.4	7.0	8.3
3.5 ≤ E < 3.7	2.7	3.5	4.3	5.4	7.0	8.2
3.7 ≤ E < 3.9	2.7	3.5	4.3	5.4	7.0	8.1
3.9 ≤ E < 4.1	2.7	3.5	4.3	5.3	6.9	8.1
4.1 ≤ E < 4.3	2.7	3.5	4.2	5.3	6.9	8.0
4.3 ≤ E < 4.5	2.7	3.5	4.2	5.3	6.8	8.0
4.5 ≤ E < 4.7	2.7	3.5	4.2	5.2	6.8	7.9
4.7 ≤ E < 4.9	2.7	3.4	4.2	5.2	6.8	7.9
E ≥ 4.9	2.7	3.4	4.2	5.2	6.8	7.9

Table 5.9.8-2 Loading Table for PWR Fuel – 513 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	10.9	13.7	-	-	-	-
2.5 ≤ E < 2.7	10.7	13.5	16.9	18.2	19.7	21.2
2.7 ≤ E < 2.9	10.5	13.3	16.5	18.0	19.4	20.8
2.9 ≤ E < 3.1	10.4	13.1	16.3	17.7	19.2	20.6
3.1 ≤ E < 3.3	10.2	12.8	16.0	17.5	18.9	20.4
3.3 ≤ E < 3.5	10.1	12.7	15.9	17.2	18.7	20.1
3.5 ≤ E < 3.7	10.0	12.5	15.6	17.0	18.4	19.9
3.7 ≤ E < 3.9	9.9	12.4	15.5	16.8	18.2	19.6
3.9 ≤ E < 4.1	9.8	12.3	15.3	16.7	18.0	19.5
4.1 ≤ E < 4.3	9.8	12.1	15.2	16.5	17.9	19.3
4.3 ≤ E < 4.5	9.7	12.0	15.1	16.3	17.7	19.2
4.5 ≤ E < 4.7	9.7	11.9	15.0	16.2	17.6	19.0
4.7 ≤ E < 4.9	9.6	11.9	14.9	16.1	17.5	18.8
E ≥ 4.9	9.5	11.8	14.8	16.0	17.3	18.7

Table 5.9.8-2 Loading Table for PWR Fuel – 513 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	22.7	-
2.7 ≤ E < 2.9	22.3	23.8
2.9 ≤ E < 3.1	22.1	23.5
3.1 ≤ E < 3.3	21.8	23.2
3.3 ≤ E < 3.5	21.6	22.9
3.5 ≤ E < 3.7	21.3	22.7
3.7 ≤ E < 3.9	21.1	22.5
3.9 ≤ E < 4.1	20.9	22.3
4.1 ≤ E < 4.3	20.8	22.1
4.3 ≤ E < 4.5	20.6	21.9
4.5 ≤ E < 4.7	20.4	21.8
4.7 ≤ E < 4.9	20.3	21.6
E ≥ 4.9	20.1	21.5

Table 5.9.8-3 Loading Table for PWR Fuel – 1,300 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	2.5	-	-	-	-	-
1.5 ≤ E < 1.7	2.5	2.5	-	-	-	-
1.7 ≤ E < 1.9	2.5	2.5	2.5	-	-	-
1.9 ≤ E < 2.1	2.5	2.5	2.5	2.7	-	-
2.1 ≤ E < 2.3	2.5	2.5	2.5	2.6	3.0	3.2
2.3 ≤ E < 2.5	2.5	2.5	2.5	2.6	3.0	3.2
2.5 ≤ E < 2.7	2.5	2.5	2.5	2.6	3.0	3.1
2.7 ≤ E < 2.9	2.5	2.5	2.5	2.6	2.9	3.1
2.9 ≤ E < 3.1	2.5	2.5	2.5	2.5	2.9	3.0
3.1 ≤ E < 3.3	2.5	2.5	2.5	2.5	2.9	3.0
3.3 ≤ E < 3.5	2.5	2.5	2.5	2.5	2.9	3.0
3.5 ≤ E < 3.7	2.5	2.5	2.5	2.5	2.8	3.0
3.7 ≤ E < 3.9	2.5	2.5	2.5	2.5	2.8	3.0
3.9 ≤ E < 4.1	2.5	2.5	2.5	2.5	2.8	2.9
4.1 ≤ E < 4.3	2.5	2.5	2.5	2.5	2.8	2.9
4.3 ≤ E < 4.5	2.5	2.5	2.5	2.5	2.8	2.9
4.5 ≤ E < 4.7	2.5	2.5	2.5	2.5	2.7	2.9
4.7 ≤ E < 4.9	2.5	2.5	2.5	2.5	2.7	2.9
E ≥ 4.9	2.5	2.5	2.5	2.5	2.7	2.8

Table 5.9.8-3 Loading Table for PWR Fuel – 1,300 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	3.4	3.6	-	-	-	-
2.5 ≤ E < 2.7	3.3	3.6	3.8	3.9	4.0	4.1
2.7 ≤ E < 2.9	3.3	3.5	3.8	3.9	4.0	4.1
2.9 ≤ E < 3.1	3.3	3.5	3.7	3.8	3.9	4.0
3.1 ≤ E < 3.3	3.2	3.4	3.7	3.8	3.9	4.0
3.3 ≤ E < 3.5	3.2	3.4	3.6	3.7	3.8	3.9
3.5 ≤ E < 3.7	3.2	3.4	3.6	3.7	3.8	3.9
3.7 ≤ E < 3.9	3.1	3.4	3.6	3.6	3.8	3.9
3.9 ≤ E < 4.1	3.1	3.3	3.5	3.6	3.7	3.8
4.1 ≤ E < 4.3	3.1	3.3	3.5	3.6	3.7	3.8
4.3 ≤ E < 4.5	3.0	3.3	3.5	3.6	3.6	3.8
4.5 ≤ E < 4.7	3.0	3.2	3.4	3.5	3.6	3.7
4.7 ≤ E < 4.9	3.0	3.2	3.4	3.5	3.6	3.7
E ≥ 4.9	3.0	3.2	3.4	3.5	3.5	3.7

Table 5.9.8-3 Loading Table for PWR Fuel – 1,300 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	4.3	-
2.7 ≤ E < 2.9	4.2	4.3
2.9 ≤ E < 3.1	4.2	4.3
3.1 ≤ E < 3.3	4.1	4.2
3.3 ≤ E < 3.5	4.0	4.2
3.5 ≤ E < 3.7	4.0	4.1
3.7 ≤ E < 3.9	4.0	4.0
3.9 ≤ E < 4.1	3.9	4.0
4.1 ≤ E < 4.3	3.9	4.0
4.3 ≤ E < 4.5	3.8	3.9
4.5 ≤ E < 4.7	3.9	3.9
4.7 ≤ E < 4.9	3.8	3.9
E ≥ 4.9	3.8	3.8

Table 5.9.8-4 Loading Table for PWR Fuel – 1,800 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	2.5	-	-	-	-	-
1.5 ≤ E < 1.7	2.5	2.5	-	-	-	-
1.7 ≤ E < 1.9	2.5	2.5	2.5	-	-	-
1.9 ≤ E < 2.1	2.5	2.5	2.5	2.5	-	-
2.1 ≤ E < 2.3	2.5	2.5	2.5	2.5	2.5	2.5
2.3 ≤ E < 2.5	2.5	2.5	2.5	2.5	2.5	2.5
2.5 ≤ E < 2.7	2.5	2.5	2.5	2.5	2.5	2.5
2.7 ≤ E < 2.9	2.5	2.5	2.5	2.5	2.5	2.5
2.9 ≤ E < 3.1	2.5	2.5	2.5	2.5	2.5	2.5
3.1 ≤ E < 3.3	2.5	2.5	2.5	2.5	2.5	2.5
3.3 ≤ E < 3.5	2.5	2.5	2.5	2.5	2.5	2.5
3.5 ≤ E < 3.7	2.5	2.5	2.5	2.5	2.5	2.5
3.7 ≤ E < 3.9	2.5	2.5	2.5	2.5	2.5	2.5
3.9 ≤ E < 4.1	2.5	2.5	2.5	2.5	2.5	2.5
4.1 ≤ E < 4.3	2.5	2.5	2.5	2.5	2.5	2.5
4.3 ≤ E < 4.5	2.5	2.5	2.5	2.5	2.5	2.5
4.5 ≤ E < 4.7	2.5	2.5	2.5	2.5	2.5	2.5
4.7 ≤ E < 4.9	2.5	2.5	2.5	2.5	2.5	2.5
E ≥ 4.9	2.5	2.5	2.5	2.5	2.5	2.5

Table 5.9.8-4 Loading Table for PWR Fuel – 1,800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	2.6	2.7	-	-	-	-
2.5 ≤ E < 2.7	2.5	2.7	2.9	2.9	3.0	3.1
2.7 ≤ E < 2.9	2.5	2.7	2.8	2.9	3.0	3.0
2.9 ≤ E < 3.1	2.5	2.6	2.8	2.9	2.9	3.0
3.1 ≤ E < 3.3	2.5	2.6	2.8	2.8	2.9	3.0
3.3 ≤ E < 3.5	2.5	2.6	2.7	2.8	2.9	2.9
3.5 ≤ E < 3.7	2.5	2.5	2.7	2.8	2.8	2.9
3.7 ≤ E < 3.9	2.5	2.5	2.7	2.7	2.8	2.9
3.9 ≤ E < 4.1	2.5	2.5	2.6	2.7	2.8	2.8
4.1 ≤ E < 4.3	2.5	2.5	2.6	2.7	2.8	2.8
4.3 ≤ E < 4.5	2.5	2.5	2.6	2.7	2.7	2.8
4.5 ≤ E < 4.7	2.5	2.5	2.6	2.6	2.7	2.8
4.7 ≤ E < 4.9	2.5	2.5	2.5	2.6	2.7	2.7
E ≥ 4.9	2.5	2.5	2.5	2.6	2.6	2.7

Table 5.9.8-4 Loading Table for PWR Fuel – 1,800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	3.1	-
2.7 ≤ E < 2.9	3.1	3.2
2.9 ≤ E < 3.1	3.1	3.1
3.1 ≤ E < 3.3	3.0	3.1
3.3 ≤ E < 3.5	3.0	3.1
3.5 ≤ E < 3.7	3.0	3.0
3.7 ≤ E < 3.9	2.9	3.0
3.9 ≤ E < 4.1	2.9	3.0
4.1 ≤ E < 4.3	2.9	2.9
4.3 ≤ E < 4.5	2.8	2.9
4.5 ≤ E < 4.7	2.9	2.9
4.7 ≤ E < 4.9	2.8	2.9
E ≥ 4.9	2.8	2.8

Table 5.9.8-5 Loading Table for PWR Fuel – 830 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	2.5	-	-	-	-	-
1.5 ≤ E < 1.7	2.5	2.7	-	-	-	-
1.7 ≤ E < 1.9	2.5	2.7	3.2	-	-	-
1.9 ≤ E < 2.1	2.5	2.7	3.2	3.8	-	-
2.1 ≤ E < 2.3	2.5	2.6	3.1	3.7	4.4	4.7
2.3 ≤ E < 2.5	2.5	2.6	3.1	3.7	4.3	4.6
2.5 ≤ E < 2.7	2.5	2.6	3.1	3.6	4.3	4.6
2.7 ≤ E < 2.9	2.5	2.6	3.0	3.6	4.2	4.5
2.9 ≤ E < 3.1	2.5	2.5	3.0	3.6	4.2	4.5
3.1 ≤ E < 3.3	2.5	2.5	3.0	3.5	4.2	4.5
3.3 ≤ E < 3.5	2.5	2.5	3.0	3.5	4.1	4.4
3.5 ≤ E < 3.7	2.5	2.5	3.0	3.5	4.1	4.4
3.7 ≤ E < 3.9	2.5	2.5	3.0	3.5	4.0	4.4
3.9 ≤ E < 4.1	2.5	2.5	2.9	3.5	4.0	4.3
4.1 ≤ E < 4.3	2.5	2.5	2.9	3.4	4.0	4.3
4.3 ≤ E < 4.5	2.5	2.5	2.9	3.4	4.0	4.3
4.5 ≤ E < 4.7	2.5	2.5	2.9	3.4	4.0	4.2
4.7 ≤ E < 4.9	2.5	2.5	2.9	3.4	3.9	4.2
E ≥ 4.9	2.5	2.5	2.9	3.4	3.9	4.2

Table 5.9.8-5 Loading Table for PWR Fuel – 830 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.1	5.6	-	-	-	-
2.5 ≤ E < 2.7	5.0	5.6	6.1	6.4	6.8	7.1
2.7 ≤ E < 2.9	5.0	5.5	6.0	6.3	6.6	6.9
2.9 ≤ E < 3.1	4.9	5.4	6.0	6.2	6.5	6.8
3.1 ≤ E < 3.3	4.9	5.4	5.9	6.1	6.4	6.7
3.3 ≤ E < 3.5	4.8	5.3	5.8	6.0	6.3	6.6
3.5 ≤ E < 3.7	4.8	5.2	5.8	6.0	6.3	6.6
3.7 ≤ E < 3.9	4.7	5.2	5.7	5.9	6.2	6.5
3.9 ≤ E < 4.1	4.7	5.1	5.7	5.9	6.1	6.4
4.1 ≤ E < 4.3	4.6	5.1	5.6	5.8	6.0	6.3
4.3 ≤ E < 4.5	4.6	5.0	5.6	5.8	6.0	6.2
4.5 ≤ E < 4.7	4.6	5.0	5.5	5.7	5.9	6.2
4.7 ≤ E < 4.9	4.5	5.0	5.5	5.7	5.9	6.1
E ≥ 4.9	4.5	4.9	5.4	5.6	5.9	6.0

Table 5.9.8-5 Loading Table for PWR Fuel – 830 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	7.5	-
2.7 ≤ E < 2.9	7.3	7.7
2.9 ≤ E < 3.1	7.2	7.6
3.1 ≤ E < 3.3	7.0	7.5
3.3 ≤ E < 3.5	6.9	7.3
3.5 ≤ E < 3.7	6.8	7.2
3.7 ≤ E < 3.9	6.8	7.1
3.9 ≤ E < 4.1	6.7	7.0
4.1 ≤ E < 4.3	6.6	6.9
4.3 ≤ E < 4.5	6.6	6.8
4.5 ≤ E < 4.7	6.5	6.8
4.7 ≤ E < 4.9	6.4	6.7
E ≥ 4.9	6.4	6.7

Table 5.9.8-6 Loading Table for PWR Fuel – 487 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	27.9	29.3	30.7	32.0	-	-
2.9 ≤ E < 3.1	27.6	29.0	30.4	31.8	32.7	33.9
3.1 ≤ E < 3.3	27.4	28.8	30.2	31.6	32.4	33.7
3.3 ≤ E < 3.5	27.1	28.5	30.0	31.4	32.2	33.6
3.5 ≤ E < 3.7	26.9	28.3	29.7	31.1	32.0	33.3
3.7 ≤ E < 3.9	26.7	28.1	29.5	30.9	31.8	33.1
3.9 ≤ E < 4.1	26.6	27.9	29.4	30.8	31.6	32.9
4.1 ≤ E < 4.3	26.3	27.8	29.2	30.6	31.4	33.5
4.3 ≤ E < 4.5	26.1	27.5	29.0	30.3	31.2	32.6
4.5 ≤ E < 4.7	26.0	27.4	28.8	30.2	31.1	32.4
4.7 ≤ E < 4.9	25.9	27.3	28.6	30.1	30.9	32.3
E ≥ 4.9	25.8	27.1	28.5	30.0	30.8	32.1

Table 5.9.8-6 Loading Table for PWR Fuel – 487 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	35.2	36.4	37.7	-	-	-
3.1 ≤ E < 3.3	35.0	36.2	37.4	38.8	39.8	41.0
3.3 ≤ E < 3.5	34.8	36.0	37.2	38.5	39.6	40.9
3.5 ≤ E < 3.7	34.5	35.9	37.1	38.4	39.5	40.7
3.7 ≤ E < 3.9	34.3	35.6	36.9	38.2	39.4	40.5
3.9 ≤ E < 4.1	34.2	35.4	36.7	38.1	39.2	40.4
4.1 ≤ E < 4.3	34.1	35.2	36.6	37.9	39.2	40.2
4.3 ≤ E < 4.5	33.9	35.2	36.4	37.7	39.0	40.2
4.5 ≤ E < 4.7	33.7	35.0	36.3	37.6	38.8	40.0
4.7 ≤ E < 4.9	33.5	34.8	36.1	37.4	38.7	39.8
E ≥ 4.9	33.4	34.7	35.9	37.3	38.6	39.7

Table 5.9.8-6 Loading Table for PWR Fuel – 487 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	42.1	43.3	-
3.3 ≤ E < 3.5	42.0	43.1	44.1
3.5 ≤ E < 3.7	41.9	43.0	44.1
3.7 ≤ E < 3.9	41.7	42.9	43.9
3.9 ≤ E < 4.1	41.6	42.7	43.8
4.1 ≤ E < 4.3	41.5	42.6	43.7
4.3 ≤ E < 4.5	41.3	42.5	43.6
4.5 ≤ E < 4.7	41.2	42.4	43.5
4.7 ≤ E < 4.9	41.0	42.3	43.4
E ≥ 4.9	40.9	42.1	43.3

Table 5.9.8-7 Loading Table for PWR Fuel – 1235 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	4.7	4.9	5.0	5.2	-	-
2.9 ≤ E < 3.1	4.6	4.8	4.9	5.1	5.2	5.4
3.1 ≤ E < 3.3	4.6	4.7	4.9	5.0	5.1	5.3
3.3 ≤ E < 3.5	4.5	4.6	4.8	4.9	5.0	5.2
3.5 ≤ E < 3.7	4.5	4.6	4.7	4.9	5.0	5.2
3.7 ≤ E < 3.9	4.4	4.5	4.7	4.8	4.9	5.1
3.9 ≤ E < 4.1	4.4	4.5	4.6	4.8	4.9	5.0
4.1 ≤ E < 4.3	4.3	4.4	4.5	4.7	4.8	4.9
4.3 ≤ E < 4.5	4.3	4.4	4.5	4.6	4.8	4.9
4.5 ≤ E < 4.7	4.2	4.3	4.5	4.6	4.7	4.8
4.7 ≤ E < 4.9	4.2	4.3	4.4	4.6	4.7	4.8
E ≥ 4.9	4.1	4.3	4.4	4.5	4.6	4.7

Table 5.9.8-7 Loading Table for PWR Fuel – 1235 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	5.6	5.8	6.0	-	-	-
3.1 ≤ E < 3.3	5.5	5.7	5.9	6.1	6.4	6.7
3.3 ≤ E < 3.5	5.4	5.6	5.8	6.0	6.3	6.5
3.5 ≤ E < 3.7	5.4	5.5	5.7	5.9	6.1	6.4
3.7 ≤ E < 3.9	5.3	5.5	5.6	5.8	6.0	6.3
3.9 ≤ E < 4.1	5.2	5.4	5.6	5.8	5.9	6.1
4.1 ≤ E < 4.3	5.1	5.3	5.5	5.7	5.9	6.0
4.3 ≤ E < 4.5	5.0	5.2	5.4	5.6	5.8	6.0
4.5 ≤ E < 4.7	5.0	5.1	5.3	5.5	5.7	5.9
4.7 ≤ E < 4.9	4.9	5.1	5.3	5.5	5.6	5.8
E ≥ 4.9	4.9	5.0	5.3	5.4	5.6	5.7

Table 5.9.8-7 Loading Table for PWR Fuel – 1235 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	6.9	7.2	-
3.3 ≤ E < 3.5	6.8	7.0	7.4
3.5 ≤ E < 3.7	6.7	6.9	7.2
3.7 ≤ E < 3.9	6.5	6.8	7.0
3.9 ≤ E < 4.1	6.4	6.7	6.9
4.1 ≤ E < 4.3	6.3	6.5	6.8
4.3 ≤ E < 4.5	6.2	6.4	6.7
4.5 ≤ E < 4.7	6.1	6.3	6.6
4.7 ≤ E < 4.9	6.0	6.2	6.5
E ≥ 4.9	5.9	6.1	6.4

Table 5.9.8-8 Loading Table for PWR Fuel – 1710 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	3.4	3.5	3.6	3.7	-	-
2.9 ≤ E < 3.1	3.4	3.5	3.5	3.6	3.7	3.8
3.1 ≤ E < 3.3	3.3	3.4	3.5	3.6	3.6	3.7
3.3 ≤ E < 3.5	3.3	3.4	3.4	3.5	3.6	3.7
3.5 ≤ E < 3.7	3.3	3.3	3.4	3.5	3.5	3.6
3.7 ≤ E < 3.9	3.2	3.3	3.4	3.4	3.5	3.6
3.9 ≤ E < 4.1	3.2	3.3	3.3	3.4	3.5	3.5
4.1 ≤ E < 4.3	3.1	3.2	3.3	3.4	3.4	3.5
4.3 ≤ E < 4.5	3.1	3.2	3.3	3.3	3.4	3.5
4.5 ≤ E < 4.7	3.1	3.2	3.2	3.3	3.4	3.4
4.7 ≤ E < 4.9	3.0	3.1	3.2	3.3	3.4	3.4
E ≥ 4.9	3.0	3.1	3.2	3.2	3.3	3.4

Table 5.9.8-8 Loading Table for PWR Fuel – 1710 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	3.9	4.0	4.0	-	-	-
3.1 ≤ E < 3.3	3.8	3.9	4.0	4.1	4.2	4.3
3.3 ≤ E < 3.5	3.8	3.9	4.0	4.0	4.2	4.3
3.5 ≤ E < 3.7	3.7	3.8	3.9	4.0	4.1	4.2
3.7 ≤ E < 3.9	3.7	3.8	3.8	3.9	4.0	4.2
3.9 ≤ E < 4.1	3.6	3.7	3.8	3.9	4.0	4.1
4.1 ≤ E < 4.3	3.6	3.7	3.8	3.8	3.9	4.0
4.3 ≤ E < 4.5	3.5	3.6	3.7	3.8	3.9	4.0
4.5 ≤ E < 4.7	3.5	3.6	3.7	3.8	3.9	3.9
4.7 ≤ E < 4.9	3.5	3.5	3.6	3.7	3.8	3.9
E ≥ 4.9	3.4	3.5	3.6	3.7	3.8	3.9

Table 5.9.8-8 Loading Table for PWR Fuel – 1710 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	4.4	4.6	-
3.3 ≤ E < 3.5	4.4	4.5	4.6
3.5 ≤ E < 3.7	4.3	4.4	4.5
3.7 ≤ E < 3.9	4.3	4.4	4.5
3.9 ≤ E < 4.1	4.2	4.3	4.4
4.1 ≤ E < 4.3	4.1	4.2	4.3
4.3 ≤ E < 4.5	4.1	4.2	4.3
4.5 ≤ E < 4.7	4.0	4.1	4.2
4.7 ≤ E < 4.9	4.0	4.1	4.2
E ≥ 4.9	3.9	4.0	4.1

Table 5.9.8-9 Loading Table for PWR Fuel – 788 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.0	9.7	10.4	11.2	-	-
2.9 ≤ E < 3.1	8.9	9.5	10.1	10.9	11.4	12.2
3.1 ≤ E < 3.3	8.7	9.2	9.9	10.6	11.1	11.9
3.3 ≤ E < 3.5	8.5	9.0	9.7	10.3	10.9	11.6
3.5 ≤ E < 3.7	8.4	8.9	9.5	10.1	10.6	11.4
3.7 ≤ E < 3.9	8.2	8.7	9.3	9.9	10.4	11.1
3.9 ≤ E < 4.1	8.1	8.6	9.1	9.7	10.2	10.9
4.1 ≤ E < 4.3	8.0	8.5	9.0	9.5	10.0	10.7
4.3 ≤ E < 4.5	7.9	8.4	8.8	9.4	9.8	10.5
4.5 ≤ E < 4.7	7.8	8.2	8.7	9.3	9.7	10.3
4.7 ≤ E < 4.9	7.7	8.1	8.6	9.1	9.5	10.2
E ≥ 4.9	7.6	8.0	8.5	9.0	9.4	10.0

Table 5.9.8-9 Loading Table for PWR Fuel – 788 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	13.1	14.0	15.0	-	-	-
3.1 ≤ E < 3.3	12.8	13.6	14.6	15.6	16.6	17.7
3.3 ≤ E < 3.5	12.4	13.3	14.2	15.3	16.2	17.3
3.5 ≤ E < 3.7	12.1	13.0	13.9	14.9	15.9	16.9
3.7 ≤ E < 3.9	11.9	13.0	13.6	14.6	15.5	16.5
3.9 ≤ E < 4.1	11.6	12.5	13.3	14.2	15.2	16.2
4.1 ≤ E < 4.3	11.4	12.2	13.1	13.9	14.9	15.9
4.3 ≤ E < 4.5	11.3	11.9	12.8	13.7	14.7	15.6
4.5 ≤ E < 4.7	11.1	11.8	12.6	13.5	14.4	15.3
4.7 ≤ E < 4.9	10.9	11.6	12.4	13.3	14.1	15.1
E ≥ 4.9	10.7	11.5	12.6	13.1	13.9	14.8

Table 5.9.8-9 Loading Table for PWR Fuel – 788 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	18.7	19.7	-
3.3 ≤ E < 3.5	18.2	19.3	20.4
3.5 ≤ E < 3.7	17.9	18.9	19.9
3.7 ≤ E < 3.9	17.5	18.6	19.6
3.9 ≤ E < 4.1	17.2	18.2	19.2
4.1 ≤ E < 4.3	16.9	17.9	18.9
4.3 ≤ E < 4.5	16.6	17.6	18.6
4.5 ≤ E < 4.7	16.3	17.3	18.3
4.7 ≤ E < 4.9	16.0	17.0	18.0
E ≥ 4.9	15.8	16.8	17.8

5.9.9 Damaged Fuel

Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. DFC slots are locations 4, 8, 30 and 34 in Figure 5.9.9-1. To ensure that the worst case configuration is considered, two damaged fuel scenarios are evaluated. Damaged fuel includes fuel debris.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. This scenario is modeled by filling the fuel assembly interstitial volume with UO_2 and increasing the fuel neutron, gamma and n-gamma source consistent with this increase in mass.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. However, no credit is taken for the reduction in lower end fitting hardware dose rate due to the added UO_2 mass and self-shielding nor for the reduction in fuel mass migrated from the active fuel region.

The resulting material compositions are shown in Table 5.9.9-1 for WE 14×14 (14b) PWR fuel.

In the model, no credit is taken for the thicker plates in the corner locations of the damaged fuel basket or the thickness of the damaged fuel cans themselves.

The 1.8 kW preferential loading is also evaluated under both damaged fuel scenarios. Only zone C, where the damaged fuel is located, needs to be evaluated under the damaged fuel scenarios.

The four-zone preferential loading damaged fuel dose rates are statistically unchanged or less than the uniform loading damaged fuel dose rates.

5.9.9.1 Transfer Cask Dose Rates

As the reduction in minimum cool time has no impact on the bounding source terms of the stainless steel MTC, no additional uniform loading damaged fuel evaluations are run for the MTC. See Section 5.8.12 for the uniformly loaded MTC damaged fuel evaluation.

5.9.9.1.1 Preferential Loading Active Fuel Scenario - MTC

Transfer cask dose rates are computed using the bounding fuel assembly source terms from Section 5.9.6 for the first scenario (fuel material filling void space at the active fuel region elevation).

On the radial and bottom surfaces of the cask, the damaged PWR fuel results are greater than those in Section 5.9.6. In order to compare the radial and bottom results to the lower nozzle scenario, the remaining source regions and BPRA results are added to the surface dose rates resulting in maximum dose rates of 1,029 mrem/hr and 5,740 mrem/hr, respectively. The radial

surface dose rate is greater than the lower nozzle scenario maximum dose rate of 952 mrem/hr. The bottom surface dose rate is less than the lower nozzle scenario maximum dose rate of 5,969 mrem/hr.

5.9.9.1.2 Preferential Loading Lower End Fitting Scenario - MTC

Transfer cask dose rates are computed using the bounding fuel assemblies from Section 5.9.6 for the second scenario.

Damaged fuel maximum dose rates are greater than those in Section 5.9.6. Dose rates are summarized in Table 5.9.9-2.

5.9.9.2 CC4 Dose Rates

As only the CC4 radial bounding source term was affected by the decrease in minimum cool time, only the uniformly loaded CC4 radial detector is evaluated with damaged fuel in this section. Section 5.8.12 contains the damaged fuel results for the remaining detectors. The 1.8 kW four zone preferential pattern is evaluated under both damaged fuel scenarios.

5.9.9.2.1 Uniform Loading Active Fuel Scenario – CC4

Uniformly loaded CC4 dose rates are computed using the bounding fuel assembly source terms from Section 5.9.3 for the first scenario. At the radial surface of the cask, maximum and average dose rates for the damaged PWR fuel model are statistically equivalent to those of the undamaged fuel model.

5.9.9.2.2 Uniform Loading Lower End Fitting Scenario – CC4

Uniformly loaded CC4 dose rates are computed using the bounding fuel assemblies from Section 5.9.3 for the second scenario. Damaged fuel maximum radial dose rates are statistically unchanged from those in Section 5.9.4.1. Dose rates are summarized in Table 5.9.9-3.

5.9.9.2.3 Preferential Loading Active Fuel Scenario – CC4

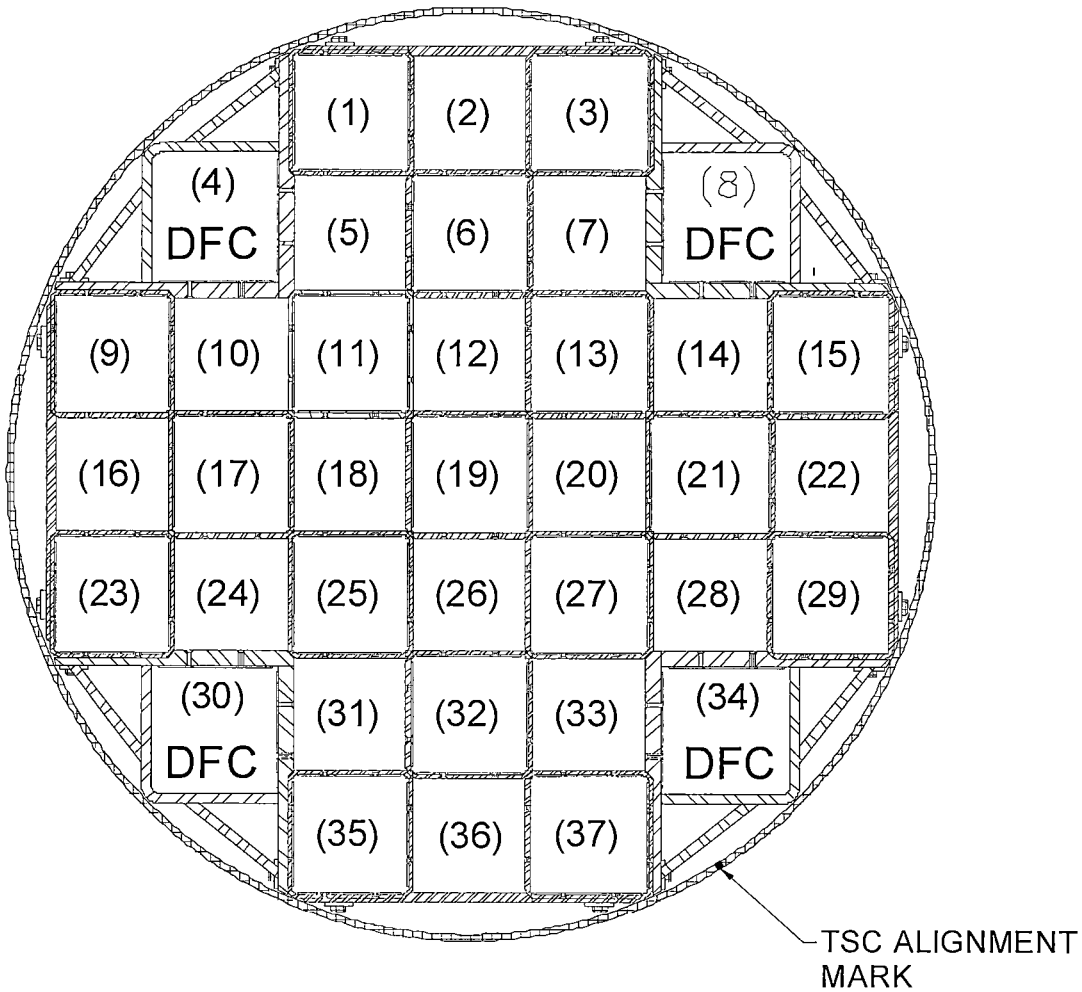
Preferentially loaded CC4 dose rates are computed using the bounding fuel assembly source terms from Section 5.9.6 for the first scenario. At the radial and inlet surfaces of the cask, maximum and average dose rates for the damaged PWR fuel model are slightly higher than those of the undamaged fuel model. All preferentially loaded CC4 damaged fuel dose rates remain below the dose rates of the uniformly loaded CC4 damaged fuel dose rates.

5.9.9.2.4 Preferential Loading Lower End Fitting Scenario – CC4

CC4 dose rates are computed using the bounding fuel assemblies from Section 5.9.6 for the second scenario. There is no change in radial dose rates from the damaged fuel in the lower end fitting region. There is an 8.5 mrem/hr increase in inlet dose rate from damaged fuel in the lower end fitting region of the four damaged fuel can basket. Inlet dose rates are increased for the

preferentially loaded CC4 damaged fuel but are bounded by the uniformly loaded CC4 damaged fuel dose rates. Dose rates are summarized in Table 5.9.9-4.

Figure 5.9.9-1 Schematic of DF Basket Assembly Configuration for PWR SNF with DFCs



DFC designated locations may contain a loaded DFC or a PWR UNDAMAGED SNF ASSEMBLY.

Table 5.9.9-1 Damaged Fuel Material Summary – 14b PWR Fuel

Material	Element/ Isotope	Density [atom/-b-cm]	Density [g/cm³]
Damaged Fuel (Lower Nozzle)	Chromium	5.5169E-03	9.6315
	Manganese	5.4963E-04	
	Iron	1.8789E-02	
	Nickel	2.4436E-03	
	Uranium 235	8.0452E-04	
	Uranium 238	1.5093E-02	
	Oxygen	3.1786E-02	
Damaged Fuel (Active Fuel)	Zirconium	3.6954E-03	9.8635
	Chromium	6.6005E-06	
	Tin	4.3366E-05	
	Nitrogen	1.2255E-05	
	Iron	7.6817E-06	
	Uranium 235	1.0495E-03	
	Uranium 238	1.9688E-02	
	Oxygen	4.1462E-02	

Table 5.9.9-2 Preferentially Loaded Stainless Steel MTC Maximum Damaged Fuel Dose Rates

		Surface		1 meter	
Detector	Source	mrem/hr	FSD[a]	mrem/hr	FSD
Radial	Neutron	231	0.2%	82	0.2%
	Gamma	734	2.2%	318	1.2%
	BPRA	64	2.2%	29	1.2%
	Total	1029	1.6%	429	0.9%
Bottom	Undamaged	5630	0.6%	2402	0.9%
	BPRA	79	1.8%	43	1.9%
	Damaged Neutron	85	0.2%	25	0.3%
	Damaged Gamma	175	9.7%	95	8.3%
	Total	5969	0.6%	2565	0.9%

[a] Fractional standard deviation.

Table 5.9.9-3 Uniformly Loaded CC4 Maximum Damaged PWR Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD	mrem/hr	FSD
Radial	Undamaged	107.2	1.9%	55.2	1.4%
	BPRA	6.6	0.8%	3.30	0.53%
	Damaged Neutron	< 0.1	3.0%	< 0.1	0.9%
	Damaged Gamma	< 0.1	14.8%	0.1	3.9%
	Total	113.9	1.8%	58.6	1.3%

Table 5.9.9-4 Preferentially Loaded CC4 Maximum Damaged PWR Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD	mrem/hr	FSD
Radial	Neutron	0.4	2.0%	0.2	1.3%
	Gamma	105.8	2.2%	55.0	1.5%
	BPRA	6.5	1.1%	3.3	0.7%
	Total	112.7	2.1%	58.5	1.4%
Inlet	Undamaged	103.7	1.0%	14.1	2.1%
	BPRA	8.7	3.5%	1.3	5.7%
	Damaged Neutron	2.5	0.5%	0.3	1.2%
	Damaged Gamma	6.0	5.3%	0.5	12.7%
	Total	120.9	0.9%	16.2	1.9%

5.10 CE16 Four-Zone Preferential Heat Load Pattern Shielding Evaluation Detail

This section contains evaluation detail for Combustion Engineering 16x16 fuel assemblies with a minimum cool time of 4 years loaded in the CC and carbon steel MTC. The carbon steel MTC evaluation bounds the stainless steel MTC configuration as stainless steel has a higher density and therefore has more shielding. The CC model is that of the standard shielded concrete cask detailed in Section 5.5. This section includes four-zone preferential heat load pattern with a maximum assembly heat load of 1.8 kW. Evaluations are documented for undamaged and damaged fuel. The minimum cool time for the CE 16x16 CEAs was reduced to 5 years from the previous minimum cool time of 10 years.

Evaluation methods and models are based on those described in Section 5.9

Uniform heat load evaluations at a minimum cool time of 4 years are included in Section 5.8.3. Preferential loading for heat load is discussed in Section 5.10.3. The effects of nonfuel hardware components to dose rates and heat load are discussed in Section 5.10.4. Model differences, dose rates, and minimum loading time impacts resulting from the damaged fuel basket configuration are discussed in Section 5.10.5.

5.10.1 Contents Description

As described in Section 5.2, PWR fuel assemblies were surveyed to construct hybrids containing maximum fuel and hardware masses. Section 5.8.1 contains geometry data of the CE 16x16 hybrid used in this evaluation. Sample in-core characteristics are also contained in Section 5.8.1.

5.10.2 Response Function Method

The evaluation of CE 16x16 fuel in the four-zone preferential loading in the CC and MTC use the response function method described in Section 5.8.2.

Section 5.8.2 demonstrates the applicability of the response method to determine the dose rates of the MAGNASTOR concrete cask and transfer cask systems.

5.10.3 Preferential Loading of CE 16x16 Fuel at a Minimum Cool time of 4 Years

The four-zone preferential loading pattern and method from Section 5.9 is used here to evaluate CE 16x16 fuel with a minimum cool time of 4 years. The four-zone preferential loading pattern is as follows.

Zone Description	Designator	Heat Load [W/assy]	# Assemblies
Inner Ring	A	513	9
Middle Ring	B1	1,300	8
	B2	1,800	4
Outer Ring	C	830	16

A sketch of the PWR basket and loading pattern is shown in Figure 5.10.3-1.

Preferential and uniform loading patterns limit total cask heat load to 35.5 kW. With the exception of the CC outlet, the maximum dose rates for the preferential loading pattern are less than those calculated for a uniform pattern.

Minimum cool time tables for CE 16x16 in the preferential heat load pattern are included in Section 5.10.6. The method used for the preferential loading pattern shielding evaluations is identical to those in Section 5.9 with the exception of the reduction in minimum cool time.

5.10.3.1 MTC and CC Dose Rates

Maximum and average surface dose rates for the preferential pattern are shown in Table 5.10.3-1, with the corresponding limiting results for the uniform pattern. The maximum dose rates for the analyzed preferential loading pattern are less than or statistically unchanged from those calculated for a uniform pattern at each detector surface for both casks with the exception of CC outlet dose rates. Maximum CC outlet dose rates are increased minimally (7%).

The concrete cask radial and top axial average dose rates are less than or statistically unchanged in the preferential pattern. Therefore, using the uniform pattern to characterize the restricted area and controlled area boundaries is acceptable.

Figure 5.10.3-1 Schematic of PWR Fuel 1.8 kW Preferential Loading Pattern

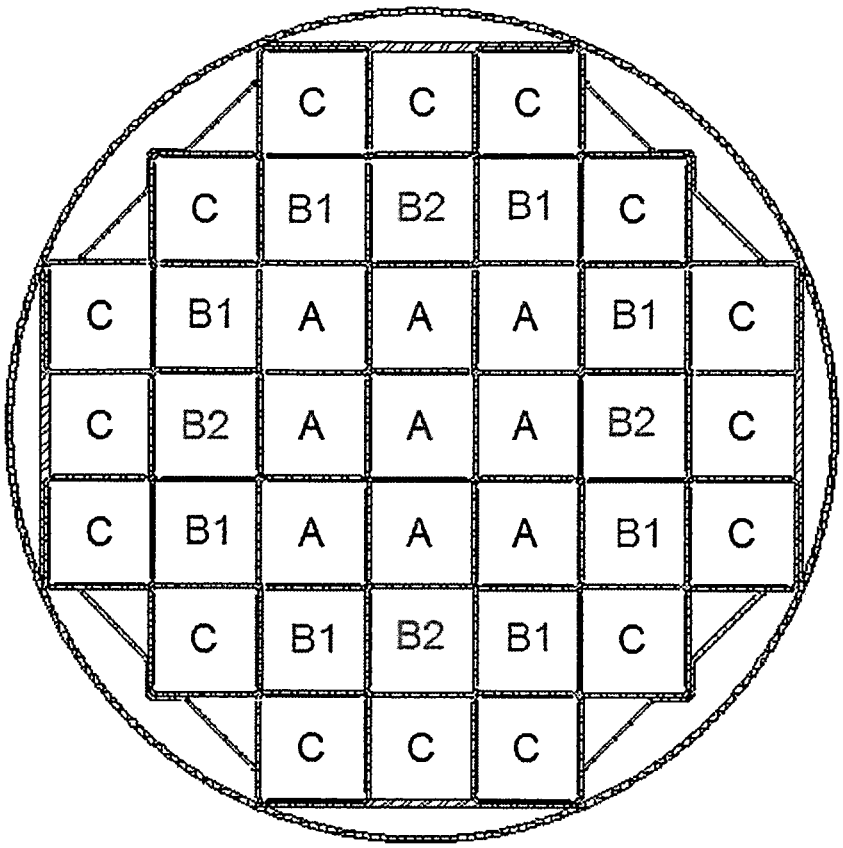


Table 5.10.3-1 Preferential Pattern Dose Rate Results

Cask / Dose Location	Uniform[a]		Preferential	
	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)	Avg. Dose Rate (mrem/hr)	Max. Dose Rate (mrem/hr)
Carbon Steel MTC Radial	650	939	574.5	899.1
Carbon Steel MTC Top	172	451	190	430.0
Carbon Steel MTC Bottom	2,953	5,824	2,717	5,747
Standard Shield CC Radial	54.4	76.7	49.1	65.1
Standard Shield CC Top	82.3	378	75.7	366.3
Standard Shield CC Inlet	--	425	--	377.1
Standard Shield CC Outlet	--	38.3	--	41.1

[a] Bounding uniform dose rates from Section 5.8.3.3.1 and Section 5.8.3.4.1

5.10.4 Nonfuel Hardware Component – Reactor Control Elements

Reactor control elements (e.g., CEAs and RCCAs) are evaluated using methods from Section 5.8.6 with the minimum cool time of the CEA reduced to 5 years.

Results are shown in Table 5.10.4-1. On the sides of the concrete and transfer casks, the additive dose rate does not affect the maximum dose rates. At the concrete cask inlets and transfer cask bottom, loading of CEAs statistically significantly increases the maximum dose rates. Dose rate increases are significantly below those listed in Section 5.8.6.

The maximum decay heat produced by loading a single CEA is 6.8 W. An increase in assembly cool time to accommodate loading a CEA is shown in Table 5.10.4-2 for each assembly heat load limit. As an increase in cool time will also decrease the fuel source term, the strict application of increased cool time without a recalculation of fuel dose rates is conservative.

Table 5.10.4-1 CEA Dose Rate Contributions – CE 16x16

Cask / Dose Location	Maximum Dose (mrem/hr)	Average Dose (mrem/hr)
Carbon Steel Transfer Cask Radial	0.4	< 0.1
Carbon Steel Transfer Cask Bottom	396.6	131.3
CC Radial	0.5	< 0.1
CC Inlet	3.7	--

Table 5.10.4-2 Additional Assembly Cool Time (Years) Required to Load CEA

Zone:	A	B1	B2	C	Uniform
Additional Assy Cool Time:	0.8	0.1	0.1	0.4	0.3

5.10.5 Damaged Fuel

CE 16x16 damaged fuel in the four-zone preferentially loaded CC and MTC systems are evaluated in this section using the methods described in Section 5.9.9. Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. DFC slots are locations 4, 8, 30 and 34 in Figure 5.10.5-1. The damaged fuel scenarios evaluated for the CE16x16 preferential heat load pattern evaluated are those described in Section 5.8.12.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. For the preferentially loaded CE 16x16 fuel the second scenario produces bounding dose rates for all detectors.

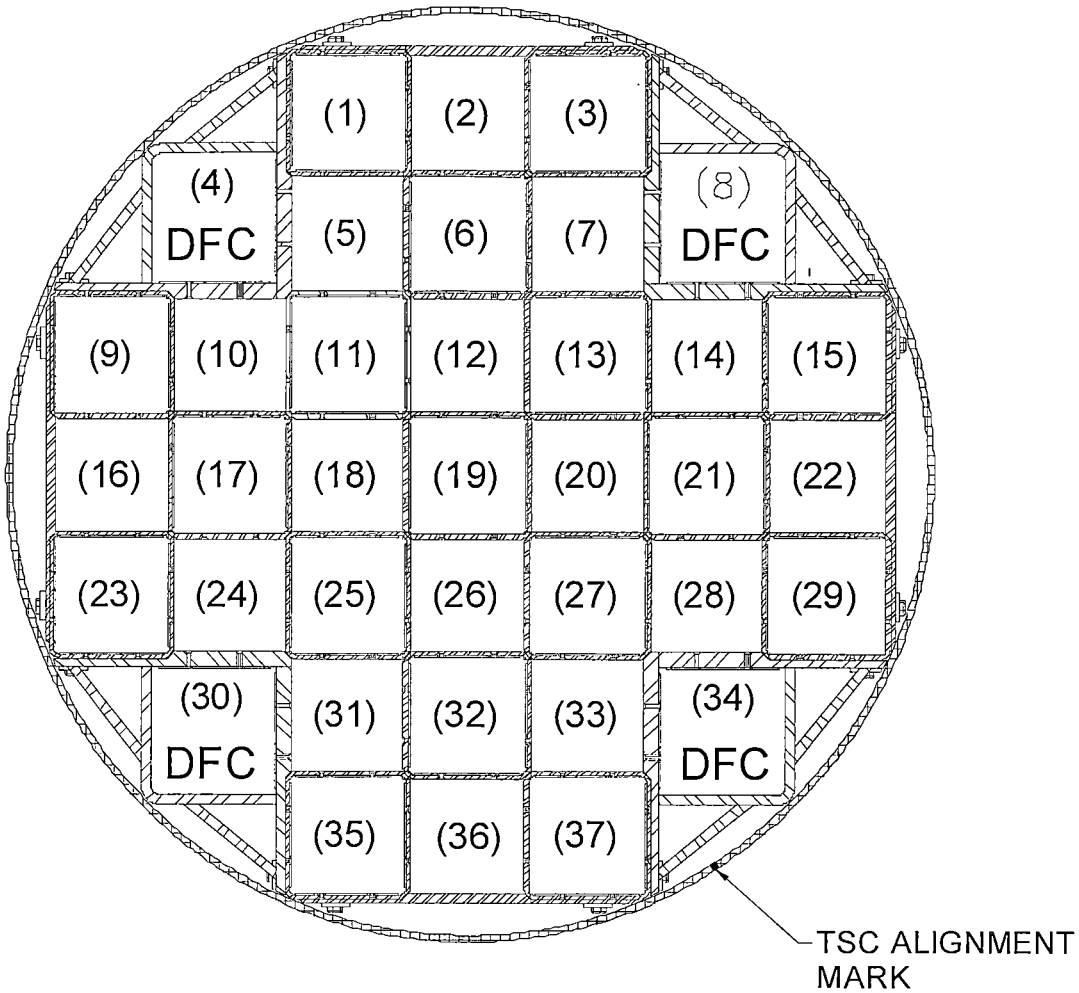
In the model, no credit is taken for the thicker plates in the corner locations of the damaged fuel basket or the thickness of the damaged fuel cans themselves.

Only zone C, where the damaged fuel is located, needs to be reevaluated under the damaged fuel scenarios. Heat load allowed in the peripheral basket locations, including DFC locations, of the preferential heat load configuration is less than that of the uniform pattern. The incremental effect of the damaged fuel in the preferential loaded pattern will therefore be less than that of the uniformly loaded basket.

The results for the preferentially loaded carbon steel MTC with damaged fuel are listed in Table 5.10.5-1. The results for the preferentially loaded CC with damaged fuel are listed in Table 5.10.5-2.

The CE 16x16 four-zone preferential loading damaged fuel dose rates are statistically unchanged or less than the bounding damaged fuel dose rates in Section 5.8.12.

Figure 5.10.5-1 Schematic of DF Basket Assembly Configuration for PWR SNF with DFCs



DFC designated locations may contain a loaded DFC or a PWR UNDAMAGED SNF ASSEMBLY.

Table 5.10.5-1 Preferentially Loaded Carbon Steel MTC Maximum Damaged CE16 Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD[a]	mrem/hr	FSD
Radial	Undamaged	899.1	0.8%	275.7	0.2%
	Damaged Neutron	11.2	1.3%	0.1	4.7%
	Damaged Gamma	63.4	6.9%	0.5	18.9%
	Total	973.7	0.8%	276.3	0.2%
Bottom	Undamaged	5,745	0.8%	2,407	1.0 %
	Damaged Neutron	118	2..2%	35	4.4%
	Damaged Gamma	183	8.7%	90	7.4%
	Total	6,046	0.8%	2,532	1.0%

[a] Fractional standard deviation.

Table 5.10.5-2 Preferentially Loaded CC Maximum Damaged CE16 Fuel Dose Rates

Detector	Source	Surface		1 meter	
		mrem/hr	FSD	mrem/hr	FSD
Radial	Undamaged	65.1	1.5%	32.1	1.6%
	Damaged Neutron	0.2	0.2%	0.1	0.3%
	Damaged Gamma	5.4	4.7%	2.1	5.6%
	Total	70.7	1.4%	34.3	1.5%
Inlet	Undamaged	379.2	0.8%	64.01	1.3%
	Damaged Neutron	4.3	0.7%	0.61	1.7%
	Damaged Gamma	36.8	2.5%	6.44	3.9%
	Total	420.3	0.8%	7.05	3.6%

5.10.6 Cool-Time Tables

PWR system performance is evaluated for a cask heat load of 35.5 kW with a four-zone preferential (1.8 kW max) heat load pattern. Minimum cool times are summarized for the preferential heat load pattern.

Allowed low burnup (up to 30,000 MWd/MTU) fuel loadings are shown in Table 5.8.9-1. Note that the listed minimum cool times at each burnup step are bounding for all fuel types and initial enrichments above the minimum enrichment specified. Collapsing the fuel type and initial enrichment-dependent minimum cool time matrix to a single value may result in a minimum cool time longer than individual values presented for higher burnups in the detailed tables that follow.

The minimum cool time tables account for potential uncertainties in the source generation abilities of SAS2H at burnups greater than 45 GWd/MTU by reducing allowed heat loads by 5 percent. Fuel assembly loading tables at greater than 45 GWd/MTU are, therefore, generated for a cask heat load of 33.725 kW with preferential (1.71 kW max) heat load patterns.

The 5% penalty adjusted four-zone preferential loading pattern is as follows.

Zone Description	Designator	Heat Load [W/assy]	Adjusted Heat Load [W/assy]	# Assemblies
Inner Ring	A	513	487	9
Middle Ring	B1	1300	1235	8
	B2	1800	1710	4
Outer Ring	C	830	788	16

Table 5.10.6-1 through Table 5.10.6-4 contain the minimum cool times for the preferential loading of $\leq$ 45 GWd/MTU with higher burnup fuel cool times listed in Table 5.10.6-5 through Table 5.10.6-8. Section 5.8.9 contains the minimum cool times for a uniform heat load of 959 W/assy.

Decay heat associated with loading nonfuel components requires an increase in the minimum fuel assembly cool time. The incremental cool time increase to allow loading of the CE 16x16 CEAs with a minimum cool time of 5 years is shown in Table 5.10.4-2.

Table 5.10.6-1 Loading Table for CE 16x16 Fuel – 513 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	4.0	-	-	-	-	-
1.5 ≤ E < 1.7	4.0	4.0	-	-	-	-
1.7 ≤ E < 1.9	4.0	4.0	4.9	-	-	-
1.9 ≤ E < 2.1	4.0	4.0	4.8	6.1	-	-
2.1 ≤ E < 2.3	4.0	4.0	4.8	6.0	8.2	10.0
2.3 ≤ E < 2.5	4.0	4.0	4.7	6.0	8.1	9.9
2.5 ≤ E < 2.7	4.0	4.0	4.7	6.0	8.1	9.8
2.7 ≤ E < 2.9	4.0	4.0	4.7	5.9	8.0	9.7
2.9 ≤ E < 3.1	4.0	4.0	4.6	5.9	7.9	9.6
3.1 ≤ E < 3.3	4.0	4.0	4.6	5.9	7.9	9.5
3.3 ≤ E < 3.5	4.0	4.0	4.6	5.8	7.9	9.4
3.5 ≤ E < 3.7	4.0	4.0	4.6	5.8	7.8	9.4
3.7 ≤ E < 3.9	4.0	4.0	4.5	5.8	7.8	9.3
3.9 ≤ E < 4.1	4.0	4.0	4.5	5.8	7.7	9.2
4.1 ≤ E < 4.3	4.0	4.0	4.5	5.8	7.7	9.2
4.3 ≤ E < 4.5	4.0	4.0	4.5	5.7	7.7	9.2
4.5 ≤ E < 4.7	4.0	4.0	4.5	5.7	7.6	9.1
4.7 ≤ E < 4.9	4.0	4.0	4.5	5.7	7.6	9.1
E ≥ 4.9	4.0	4.0	4.5	5.7	7.6	9.0

Table 5.10.6-1 Loading Table for CE 16x16 Fuel – 513 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	12.5	15.8	-	-	-	-
2.5 ≤ E < 2.7	12.3	15.6	19.2	20.7	22.2	23.7
2.7 ≤ E < 2.9	12.1	15.4	19.0	20.5	22.0	23.4
2.9 ≤ E < 3.1	12.0	15.2	18.8	20.2	21.7	23.2
3.1 ≤ E < 3.3	11.9	15.0	18.5	19.9	21.5	23.0
3.3 ≤ E < 3.5	11.8	14.8	18.4	19.8	21.3	22.8
3.5 ≤ E < 3.7	11.7	14.7	18.2	19.7	21.1	22.5
3.7 ≤ E < 3.9	11.7	14.6	18.0	19.5	20.9	22.3
3.9 ≤ E < 4.1	11.6	14.5	17.9	19.3	20.8	22.2
4.1 ≤ E < 4.3	11.5	14.4	17.8	19.2	20.7	22.1
4.3 ≤ E < 4.5	11.4	14.3	17.7	19.1	20.5	21.9
4.5 ≤ E < 4.7	11.4	14.3	17.6	19.0	20.4	21.8
4.7 ≤ E < 4.9	11.4	14.2	17.5	18.9	20.3	21.7
E ≥ 4.9	11.3	14.1	17.4	18.8	20.2	21.6

Table 5.10.6-1 Loading Table for CE 16x16 Fuel – 513 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	25.1	-
2.7 ≤ E < 2.9	24.8	26.3
2.9 ≤ E < 3.1	24.6	26.1
3.1 ≤ E < 3.3	24.4	25.8
3.3 ≤ E < 3.5	24.2	25.6
3.5 ≤ E < 3.7	24.0	25.4
3.7 ≤ E < 3.9	23.8	25.3
3.9 ≤ E < 4.1	23.7	25.0
4.1 ≤ E < 4.3	23.6	24.9
4.3 ≤ E < 4.5	23.4	24.8
4.5 ≤ E < 4.7	23.2	24.6
4.7 ≤ E < 4.9	23.1	24.5
E ≥ 4.9	23.0	24.4

Table 5.10.6-2 Loading Table for CE 16x16 Fuel – 1,300 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	4.0	-	-	-	-	-
1.5 ≤ E < 1.7	4.0	4.0	-	-	-	-
1.7 ≤ E < 1.9	4.0	4.0	4.0	-	-	-
1.9 ≤ E < 2.1	4.0	4.0	4.0	4.0	-	-
2.1 ≤ E < 2.3	4.0	4.0	4.0	4.0	4.0	4.0
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.0	4.0	4.0
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.10.6-2 Loading Table for CE 16x16 Fuel – 1,300 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	-	-	-	-
2.5 ≤ E < 2.7	4.0	4.0	4.1	4.2	4.3	4.5
2.7 ≤ E < 2.9	4.0	4.0	4.1	4.2	4.3	4.4
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.1	4.2	4.4
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.1	4.2	4.3
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.1	4.3
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.1	4.2
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.2
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.1
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.1
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.10.6-2 Loading Table for CE 16x16 Fuel – 1,300 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	4.6	-
2.7 ≤ E < 2.9	4.5	4.7
2.9 ≤ E < 3.1	4.5	4.6
3.1 ≤ E < 3.3	4.4	4.5
3.3 ≤ E < 3.5	4.4	4.5
3.5 ≤ E < 3.7	4.3	4.4
3.7 ≤ E < 3.9	4.3	4.4
3.9 ≤ E < 4.1	4.2	4.3
4.1 ≤ E < 4.3	4.2	4.3
4.3 ≤ E < 4.5	4.2	4.3
4.5 ≤ E < 4.7	4.1	4.2
4.7 ≤ E < 4.9	4.1	4.2
E ≥ 4.9	4.0	4.2

Table 5.10.6-3 Loading Table for CE 16x16 Fuel – 1,800 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	4.0	-	-	-	-	-
1.5 ≤ E < 1.7	4.0	4.0	-	-	-	-
1.7 ≤ E < 1.9	4.0	4.0	4.0	-	-	-
1.9 ≤ E < 2.1	4.0	4.0	4.0	4.0	-	-
2.1 ≤ E < 2.3	4.0	4.0	4.0	4.0	4.0	4.0
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.0	4.0	4.0
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.10.6-3 Loading Table for CE 16x16 Fuel – 1,800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	-	-	-	-
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.10.6-3 Loading Table for CE 16x16 Fuel – 1,800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	4.0	-
2.7 ≤ E < 2.9	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0
E ≥ 4.9	4.0	4.0

Table 5.10.6-4 Loading Table for CE 16x16 Fuel – 830 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	B ≤10	10< B ≤15	15< B ≤20	20< B ≤25	25< B ≤30	30< B ≤32.5
1.3 ≤ E < 1.5	4.0	-	-	-	-	-
1.5 ≤ E < 1.7	4.0	4.0	-	-	-	-
1.7 ≤ E < 1.9	4.0	4.0	4.0	-	-	-
1.9 ≤ E < 2.1	4.0	4.0	4.0	4.0	-	-
2.1 ≤ E < 2.3	4.0	4.0	4.0	4.0	4.7	5.0
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.0	4.6	5.0
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.6	4.9
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.5	4.9
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.5	4.8
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.4	4.8
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.4	4.7
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.4	4.7
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.4	4.7
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.3	4.6
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.3	4.6
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.3	4.6
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.3	4.5
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.2	4.5
E ≥ 4.9	4.0	4.0	4.0	4.0	4.2	4.5

Table 5.10.6-4 Loading Table for CE 16x16 Fuel – 830 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	32.5< B ≤35	35< B ≤37.5	37.5< B ≤40	40< B ≤41	41< B ≤42	42< B ≤43
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.5	6.0	-	-	-	-
2.5 ≤ E < 2.7	5.4	6.0	6.7	7.0	7.4	7.8
2.7 ≤ E < 2.9	5.4	5.9	6.6	6.9	7.2	7.7
2.9 ≤ E < 3.1	5.3	5.8	6.5	6.8	7.1	7.5
3.1 ≤ E < 3.3	5.2	5.8	6.4	6.7	7.0	7.4
3.3 ≤ E < 3.5	5.2	5.7	6.3	6.6	6.9	7.3
3.5 ≤ E < 3.7	5.1	5.7	6.3	6.6	6.8	7.2
3.7 ≤ E < 3.9	5.1	5.6	6.2	6.5	6.8	7.1
3.9 ≤ E < 4.1	5.0	5.6	6.1	6.4	6.7	7.0
4.1 ≤ E < 4.3	5.0	5.5	6.0	6.4	6.7	6.9
4.3 ≤ E < 4.5	5.0	5.5	6.0	6.3	6.6	6.9
4.5 ≤ E < 4.7	4.9	5.5	6.0	6.2	6.5	6.8
4.7 ≤ E < 4.9	4.9	5.4	5.9	6.2	6.5	6.8
E ≥ 4.9	4.9	5.4	5.9	6.1	6.4	6.7

Table 5.10.6-4 Loading Table for CE 16x16 Fuel – 830 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU	
	43< B ≤44	44< B ≤45
1.3 ≤ E < 1.5	-	-
1.5 ≤ E < 1.7	-	-
1.7 ≤ E < 1.9	-	-
1.9 ≤ E < 2.1	-	-
2.1 ≤ E < 2.3	-	-
2.3 ≤ E < 2.5	-	-
2.5 ≤ E < 2.7	8.2	-
2.7 ≤ E < 2.9	8.0	8.6
2.9 ≤ E < 3.1	7.9	8.4
3.1 ≤ E < 3.3	7.8	8.2
3.3 ≤ E < 3.5	7.7	8.1
3.5 ≤ E < 3.7	7.6	8.0
3.7 ≤ E < 3.9	7.5	7.9
3.9 ≤ E < 4.1	7.4	7.8
4.1 ≤ E < 4.3	7.3	7.7
4.3 ≤ E < 4.5	7.2	7.6
4.5 ≤ E < 4.7	7.1	7.5
4.7 ≤ E < 4.9	7.0	7.4
E ≥ 4.9	7.0	7.4

Table 5.10.6-5 Loading Table for CE 16x16 Fuel – 487 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	30.4	31.8	33.2	34.5	-	-
2.9 ≤ E < 3.1	30.1	31.6	32.9	34.3	35.5	36.8
3.1 ≤ E < 3.3	30.0	31.4	32.7	34.1	35.4	36.7
3.3 ≤ E < 3.5	29.8	31.2	32.6	33.9	35.2	36.6
3.5 ≤ E < 3.7	29.6	31.1	32.5	33.8	35.1	36.3
3.7 ≤ E < 3.9	29.4	30.8	32.3	33.6	34.9	36.3
3.9 ≤ E < 4.1	29.3	30.7	32.1	33.5	34.7	36.1
4.1 ≤ E < 4.3	29.1	30.6	32.0	33.4	34.6	35.9
4.3 ≤ E < 4.5	29.0	30.4	31.9	33.2	34.5	35.9
4.5 ≤ E < 4.7	28.9	30.2	31.7	33.1	34.4	35.7
4.7 ≤ E < 4.9	28.8	30.2	31.5	33.0	34.3	35.6
E ≥ 4.9	28.7	30.1	31.4	32.8	34.2	35.4

Table 5.10.6-5 Loading Table for CE 16x16 Fuel – 487 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	38.1	39.3	40.5	-	-	-
3.1 ≤ E < 3.3	38.0	39.2	40.3	41.5	42.1	43.1
3.3 ≤ E < 3.5	37.8	39.1	40.2	41.4	41.9	43.1
3.5 ≤ E < 3.7	37.6	38.9	40.0	41.2	41.8	42.9
3.7 ≤ E < 3.9	37.6	38.7	39.9	41.1	41.7	42.8
3.9 ≤ E < 4.1	37.4	38.7	39.8	41.1	41.6	42.7
4.1 ≤ E < 4.3	37.3	38.6	39.7	40.9	41.4	42.6
4.3 ≤ E < 4.5	37.2	38.4	39.6	40.9	41.3	42.5
4.5 ≤ E < 4.7	37.0	38.2	39.4	40.8	41.2	42.4
4.7 ≤ E < 4.9	36.9	38.2	39.5	40.7	41.0	42.3
E ≥ 4.9	36.8	38.0	39.3	40.5	40.9	42.1

Table 5.10.6-5 Loading Table for CE 16x16 Fuel – 487 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	44.3	45.3	-
3.3 ≤ E < 3.5	44.1	45.2	46.2
3.5 ≤ E < 3.7	44.0	45.1	46.2
3.7 ≤ E < 3.9	43.9	44.9	46.1
3.9 ≤ E < 4.1	43.8	44.9	46.0
4.1 ≤ E < 4.3	43.7	44.8	45.8
4.3 ≤ E < 4.5	43.7	44.7	45.8
4.5 ≤ E < 4.7	43.5	44.6	45.7
4.7 ≤ E < 4.9	43.4	44.5	45.7
E ≥ 4.9	43.4	44.4	45.6

Table 5.10.6-6 Loading Table for CE 16x16 Fuel – 1235 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.1	5.3	5.5	5.7	-	-
2.9 ≤ E < 3.1	5.0	5.2	5.4	5.6	5.8	6.0
3.1 ≤ E < 3.3	4.9	5.1	5.3	5.5	5.7	5.9
3.3 ≤ E < 3.5	4.9	5.0	5.2	5.4	5.6	5.8
3.5 ≤ E < 3.7	4.8	5.0	5.1	5.3	5.5	5.7
3.7 ≤ E < 3.9	4.8	4.9	5.0	5.2	5.4	5.6
3.9 ≤ E < 4.1	4.7	4.9	5.0	5.2	5.4	5.6
4.1 ≤ E < 4.3	4.7	4.8	4.9	5.1	5.3	5.5
4.3 ≤ E < 4.5	4.6	4.8	4.9	5.0	5.2	5.4
4.5 ≤ E < 4.7	4.5	4.7	4.8	5.0	5.1	5.3
4.7 ≤ E < 4.9	4.5	4.7	4.8	4.9	5.1	5.3
E ≥ 4.9	4.5	4.6	4.8	4.9	5.0	5.2

Table 5.10.6-6 Loading Table for CE 16x16 Fuel – 1235 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.2	6.5	6.7	-	-	-
3.1 ≤ E < 3.3	6.1	6.3	6.6	6.8	7.0	7.3
3.3 ≤ E < 3.5	6.0	6.2	6.5	6.7	6.9	7.1
3.5 ≤ E < 3.7	5.9	6.1	6.3	6.6	6.7	7.0
3.7 ≤ E < 3.9	5.8	6.0	6.2	6.5	6.6	6.9
3.9 ≤ E < 4.1	5.7	5.9	6.1	6.4	6.5	6.8
4.1 ≤ E < 4.3	5.7	5.8	6.0	6.3	6.4	6.7
4.3 ≤ E < 4.5	5.6	5.8	5.9	6.2	6.3	6.6
4.5 ≤ E < 4.7	5.5	5.7	5.9	6.0	6.2	6.4
4.7 ≤ E < 4.9	5.5	5.6	5.8	6.0	6.1	6.4
E ≥ 4.9	5.4	5.6	5.8	5.9	6.0	6.3

Table 5.10.6-6 Loading Table for CE 16x16 Fuel – 1235 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	7.7	8.0	-
3.3 ≤ E < 3.5	7.5	7.8	8.2
3.5 ≤ E < 3.7	7.3	7.6	8.0
3.7 ≤ E < 3.9	7.1	7.5	7.8
3.9 ≤ E < 4.1	7.0	7.3	7.7
4.1 ≤ E < 4.3	6.9	7.2	7.5
4.3 ≤ E < 4.5	6.8	7.0	7.4
4.5 ≤ E < 4.7	6.7	6.9	7.2
4.7 ≤ E < 4.9	6.6	6.9	7.1
E ≥ 4.9	6.5	6.8	7.0

Table 5.10.6-7 Loading Table for CE 16x16 Fuel – 1710 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	-	-
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.1
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.1
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0

Table 5.10.6-7 Loading Table for CE 16x16 Fuel – 1710 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	4.2	4.4	4.5	-	-	-
3.1 ≤ E < 3.3	4.2	4.3	4.4	4.5	4.6	4.7
3.3 ≤ E < 3.5	4.1	4.2	4.3	4.4	4.5	4.6
3.5 ≤ E < 3.7	4.0	4.2	4.3	4.4	4.5	4.6
3.7 ≤ E < 3.9	4.0	4.1	4.2	4.3	4.4	4.5
3.9 ≤ E < 4.1	4.0	4.1	4.2	4.3	4.3	4.4
4.1 ≤ E < 4.3	4.0	4.0	4.1	4.2	4.3	4.4
4.3 ≤ E < 4.5	4.0	4.0	4.1	4.2	4.2	4.3
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.1	4.2	4.3
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.1	4.2
E ≥ 4.9	4.0	4.0	4.0	4.0	4.1	4.2

Table 5.10.6-7 Loading Table for CE 16x16 Fuel – 1710 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	4.9	5.0	-
3.3 ≤ E < 3.5	4.8	4.9	5.0
3.5 ≤ E < 3.7	4.7	4.8	5.0
3.7 ≤ E < 3.9	4.6	4.8	4.9
3.9 ≤ E < 4.1	4.5	4.7	4.8
4.1 ≤ E < 4.3	4.5	4.6	4.7
4.3 ≤ E < 4.5	4.4	4.5	4.7
4.5 ≤ E < 4.7	4.4	4.5	4.6
4.7 ≤ E < 4.9	4.3	4.4	4.5
E ≥ 4.9	4.3	4.4	4.5

Table 5.10.6-8 Loading Table for CE 16x16 Fuel – 788 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	45< B ≤46	46< B ≤47	47< B ≤48	48< B ≤49	49< B ≤50	50< B ≤51
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	10.2	11.0	11.8	12.7	-	-
2.9 ≤ E < 3.1	9.9	10.7	11.5	12.3	13.3	14.2
3.1 ≤ E < 3.3	9.8	10.5	11.2	12.0	12.9	13.9
3.3 ≤ E < 3.5	9.6	10.2	11.0	11.8	12.6	13.6
3.5 ≤ E < 3.7	9.4	10.0	10.8	11.6	12.4	13.3
3.7 ≤ E < 3.9	9.2	9.8	10.6	11.3	12.0	13.0
3.9 ≤ E < 4.1	9.1	9.7	10.4	11.1	11.9	12.8
4.1 ≤ E < 4.3	9.0	9.5	10.2	11.0	11.7	12.5
4.3 ≤ E < 4.5	8.9	9.4	10.0	10.8	11.5	12.3
4.5 ≤ E < 4.7	8.8	9.3	9.9	10.6	11.4	12.1
4.7 ≤ E < 4.9	8.7	9.2	9.8	10.5	11.2	12.0
E ≥ 4.9	8.6	9.1	9.7	10.3	11.1	11.8

Table 5.10.6-8 Loading Table for CE 16x16 Fuel – 788 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU					
	51< B ≤52	52< B ≤53	53< B ≤54	54< B ≤55	55< B ≤56	56< B ≤57
1.3 ≤ E < 1.5	-	-	-	-	-	-
1.5 ≤ E < 1.7	-	-	-	-	-	-
1.7 ≤ E < 1.9	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-
2.9 ≤ E < 3.1	15.2	16.3	17.4	-	-	-
3.1 ≤ E < 3.3	14.9	15.9	17.0	18.0	18.7	19.7
3.3 ≤ E < 3.5	14.6	15.6	16.6	17.7	18.2	19.3
3.5 ≤ E < 3.7	14.2	15.2	16.3	17.3	17.9	19.0
3.7 ≤ E < 3.9	13.9	14.9	15.9	17.0	17.5	18.6
3.9 ≤ E < 4.1	13.7	14.6	15.6	16.7	17.2	18.2
4.1 ≤ E < 4.3	13.4	14.3	15.4	16.4	16.9	18.0
4.3 ≤ E < 4.5	13.2	14.1	15.1	16.1	16.7	17.7
4.5 ≤ E < 4.7	13.0	13.9	14.9	15.8	16.4	17.4
4.7 ≤ E < 4.9	12.8	13.7	14.7	15.7	16.1	17.2
E ≥ 4.9	12.7	13.5	14.5	15.4	16.0	17.0

Table 5.10.6-8 Loading Table for CE 16x16 Fuel – 788 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	Assembly Average Burnup (B) GWd/MTU		
	57< B ≤58	58< B ≤59	59< B ≤60
1.3 ≤ E < 1.5	-	-	-
1.5 ≤ E < 1.7	-	-	-
1.7 ≤ E < 1.9	-	-	-
1.9 ≤ E < 2.1	-	-	-
2.1 ≤ E < 2.3	-	-	-
2.3 ≤ E < 2.5	-	-	-
2.5 ≤ E < 2.7	-	-	-
2.7 ≤ E < 2.9	-	-	-
2.9 ≤ E < 3.1	-	-	-
3.1 ≤ E < 3.3	20.8	21.8	-
3.3 ≤ E < 3.5	20.4	21.4	22.5
3.5 ≤ E < 3.7	20.0	21.1	22.1
3.7 ≤ E < 3.9	19.7	20.7	21.7
3.9 ≤ E < 4.1	19.3	20.3	21.4
4.1 ≤ E < 4.3	19.0	20.0	21.1
4.3 ≤ E < 4.5	18.7	19.7	20.8
4.5 ≤ E < 4.7	18.4	19.5	20.5
4.7 ≤ E < 4.9	18.2	19.2	20.2
E ≥ 4.9	17.9	19.0	20.0

Chapter 6
Criticality Evaluation

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6 CRITICALITY EVALUATION

This chapter documents the method, input, and result of the criticality analysis of the MAGNASTOR® containing PWR and BWR payloads. The results demonstrate that the effective neutron multiplication factor, k_{eff}, of the system under normal conditions, or off-normal and accident events, is less than 0.95 including biases and uncertainties. The system design meets the criticality requirements of 10 CFR 72 [1] and Chapter 6 of NUREG-1536 [2].

6.1 Discussion and Results

6.1.1 MAGNASTOR System Criticality Evaluation

MAGNASTOR consists of a TSC (Transportable Storage Canister), a transfer cask, and a concrete cask. The system is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including 4 DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

The TSC is comprised of a stainless steel canister and a basket within which fuel is loaded. The PWR and BWR system each includes two TSC lengths to store fuel assemblies without the requirement of spacers. Spacers may be employed to simplify loading or unloading operations. The TSC is loaded into the concrete cask for storage. A transfer cask is used for handling the TSC during loading of spent fuel. Fuel is loaded into the TSC contained within the transfer cask underwater in the spent fuel pool. Once loaded with fuel, the TSC closure lid is welded and the TSC is drained, dried and backfilled with helium. The transfer cask is then used to move the TSC into or out of the concrete cask. The transfer cask provides shielding during the TSC loading and transfer operations. Multiple-size concrete and transfer casks accommodate all of the PWR and BWR TSCs.

Under normal conditions, such as loading in a spent fuel pool, moderator (water) is present in the TSC during the initial stages of fuel transfer. During draining and drying operations, moderator with varying density is present. Thus, the criticality evaluation of the transfer cask includes a variation in moderator density and a determination of optimum moderator density. Cask accident conditions are bounded by inclusion in the analysis of the most reactive mechanical basket configuration as well as moderator intrusion into the fuel cladding. The PWR TSC is evaluated at minimum soluble boron levels during flooded conditions.

Structural analyses demonstrate that the TSC confinement boundary remains intact through all storage operating conditions. Therefore, moderator is not present in the TSC while it is in the concrete cask. However, access to the concrete cask interior environment is possible via the air inlets and outlets and the heat transfer annulus between the TSC and the cask steel liner. This access provides paths for moderator intrusion during a flood. Under off-normal and accident conditions, moderator intrusion into the convective heat transfer annulus is evaluated.

PWR system criticality control is achieved through a combination of neutron absorber sheets on the interior faces of the fuel tubes/developed cells and soluble boron. BWR system criticality control relies solely on the absorber sheets. Individual fuel assemblies are held in place by the fuel tubes, by developed cells formed from fuel tubes, or by a combination of fuel tubes and side or corner weldments. The neutron absorber modeled is a borated aluminum sheet. Any material meeting the physical dimension requirements specified on the License Drawings and the effective ^{10}B areal density specified in Table 6.1.1-5 will produce similar reactivity results. A combination of steel cover sheets and weld posts holds the neutron absorber sheets in place. The PWR undamaged fuel basket design includes 21 fuel tubes forming 37 fuel-assembly-sized openings while the PWR damaged fuel basket design includes 17 fuel tubes and four corner weldments forming 37 openings. A sketch of a cross-section of the damaged fuel basket is shown in figure 6.1.1-2. The BWR basket contains 45 fuel tubes forming 89 fuel-assembly-sized openings.

The combination of 45 BWR fuel tubes with four corner and four side weldments form 89 fuel-assembly-sized openings; however, two openings are below the vent and drain ports and are not loaded. For simplicity and cask symmetry, all 89 slots are modeled as filled with fuel.

An optional "86-assembly" configuration of the BWR basket is evaluated where the center basket location is left unoccupied. An optional "82-assembly" configuration of the BWR basket is evaluated, where five center openings in an "X" pattern are left unoccupied (the basket model fills the openings below the port cover and, therefore, contains 84 assemblies). An alternate 82-assembly configuration is also evaluated with the empty basket locations moved further out from the center of the basket. See Figure 6.1.1-1 for the loadable basket locations in the 82-assembly basket configuration.

Initial criticality evaluations rely on neutron absorber sheet effective ^{10}B loadings of 0.036 g/cm^2 and 0.027 g/cm^2 for the PWR and BWR system, respectively. The system is also evaluated for effective ^{10}B loading of 0.030 and 0.027 g/cm^2 for PWR baskets and 0.0225 and 0.020 g/cm^2 for BWR baskets. Depending on the PWR payload, variable soluble boron concentrations in the pool water are necessary to achieve sufficient neutron absorber content in the system. The soluble boron absorbs thermal neutrons inside the assembly, in addition to the neutrons removed by the absorber sheets on the tubes.

The minimum as-manufactured loading of the neutron absorber sheets depends on the effectiveness of the absorber and the minimum effective absorber areal density. Effectiveness of the absorber is influenced by the uniformity and quantity of the ^{10}B nuclide within the absorber base material. Table 6.1.1-5 translates the effective absorber content to absorber materials at 75% and 90% credit.

MCNP, a three-dimensional Monte Carlo code, is used in the system criticality analysis. Evaluations are primarily based on the ENDF/B-VI continuous energy neutron cross-section library [4] available in the MCNP distribution. Nuclides for which no ENDF/B-VI data is available are set to the latest cross-section sets available in the code distribution. The code and cross-section libraries are benchmarked by comparison to a range of critical experiments relevant to light water reactor fuel in storage and transport casks. An upper subcritical limit (USL) for the system is determined based on guidance given in NUREG/CR-6361 [10].

Key assembly physical characteristics, maximum initial enrichment, and soluble boron requirements (PWR only) for each PWR and BWR fuel assembly type are shown in Table 6.1.1-1, Table 6.1.1-2 and Table 6.1.1-6 for the PWR system and Table 6.1.1-3 and Table 6.1.1-4 for the BWR system. PWR results represent the bounding values for fuel assemblies with and without nonfuel inserts in the guide tubes. Maximum enrichment is defined as peak rod enrichment for PWR assemblies and the maximum peak planar-average enrichment for BWR assemblies. The maximum initial peak planar-average enrichment is the maximum planar-average enrichment at any height along the axis of the fuel assembly.

Assemblies are evaluated with a full, nominal set of fuel rods. Fuel rod (lattice) locations may contain filler rods. A filler rod must occupy, at a minimum, a volume equivalent to the fuel rod it displaces. Filler rods may be placed into the lattice after assembly in-core use or be designed to replace fuel rods prior to use, such as integral burnable absorber rods.

The assembly must contain its nominal set of guide and instrument tubes (PWR), and water rods (BWR). Analysis demonstrated that variations in the guide/instrument tube and water rod thickness and diameter have no significant effect on system reactivity.

6.1.1.1 Undamaged Fuel Criticality Results

The maximum multiplication factors ($k_{eff}+2\sigma$) are calculated, using conservative assumptions, for the transfer and concrete cask. The USL applied to the analysis results is 0.9376 per Section 6.5.2. The results of the analyses are presented in detail in Sections 6.4.3 and 6.7, and are summarized as follows.

Cask Body	Gap Condition	Operating Condition	Water Density (g/cc) Interior	Water Density (g/cc) Exterior	PWR $k_{eff} + 2\sigma$	BWR $k_{eff} + 2\sigma$
Transfer	Dry	Normal	0.9982	0.0001	0.93183	0.92900
Transfer	Wet	Normal	0.9982	0.0001	0.93712	0.93679
Transfer	Dry	Normal	0.9982	0.9982	0.92975	0.92839
Transfer	Wet	Normal	0.9982	0.9982	0.93615	0.93674
Storage	Dry	Normal	0.0001	0.0001	0.48145	0.43685
Storage	Dry	Accident	0.0001	0.9982	0.47104	0.42991

Analysis of simultaneous moderator density variation inside and outside either the transfer or concrete cask shows a monotonic decrease in reactivity with decreasing moderator density. For the BWR system, there is a statistically significant increase in reactivity when moving from void to full moderator density. In the PWR system, reactivity increases as moderator density rises from void conditions, but there is no significant reactivity difference at water densities above 0.9 g/cm^3. The use of soluble boron in PWR systems, specified in parts per million of moderator, flattens out the reactivity curve by increasing absorber quantity in conjunction with increasing moderator. The full moderator density TSC interior condition bounds any off-normal or accident condition. Analysis of moderator intrusion into the concrete cask heat transfer annulus with the dry TSC shows a slight decrease in reactivity from the completely dry condition.

6.1.1.2 Damaged PWR Fuel Criticality Results

The PWR system is designed to safely store up to 37 PWR fuel assemblies of which up to 4 may be classified as damaged and be placed into damaged fuel cans (DFCs) in the four corner basket locations. The DFC provides a screened container to prevent gross fissile material release into the TSC cavity from failed fuel rod cladding. The results of the analyses are presented in detail in Section 6.7.8 and are summarized as follows. All results are below the USL of 0.9376.

Cask Body	Gap Condition	Operating Condition	Water Density (g/cc) Interior	Water Density (g/cc) Exterior	PWR $k_{eff} + 2\sigma$
Transfer	Wet	Normal	0.9982	N/A[a]	0.93757
Storage	Dry	Normal	0.0001	0.0001	0.49142
Storage	Dry	Accident	0.0001	0.9982	0.48211

[a] Exterior moderator has been demonstrated in Section 6.7.3 to not affect system reactivity for a fully flooded TSC.

Three damaged fuel configurations are evaluated. Damaged fuel includes fuel debris. In the first configuration, undamaged fuel is loaded into a DFC to demonstrate the effect of the additional stainless steel from the DFC and the DFC corner weldments. In the second configuration, damaged fuel is postulated to lose its cladding and the array is modeled at an increased pitch. In the third configuration, mixtures of fuel and water simulate small fuel rubble inside the DFC.

Three moderator configurations are evaluated. Moderator density studies are performed on the preferentially flooded DFC, partially flooded cask, and mixture moderator density. In the preferentially flooded DFC scenario, the DFC is assumed to vary in moderator density with a wet and dry canister. A partial draindown of the TSC to the top of the active fuel is referred to as partial flooding. A study on the mixture moderator density is performed to ensure that the homogenized mixture remains undermoderated.

For each of the fuel types, with and without nonfuel inserts in the active fuel region of the undamaged assemblies, several combinations of minimum soluble boron and maximum initial enrichments are determined. The allowable loadings are documented in Table 6.1.1-6.

Figure 6.1.1-1 82-Assembly BWR Basket Configuration

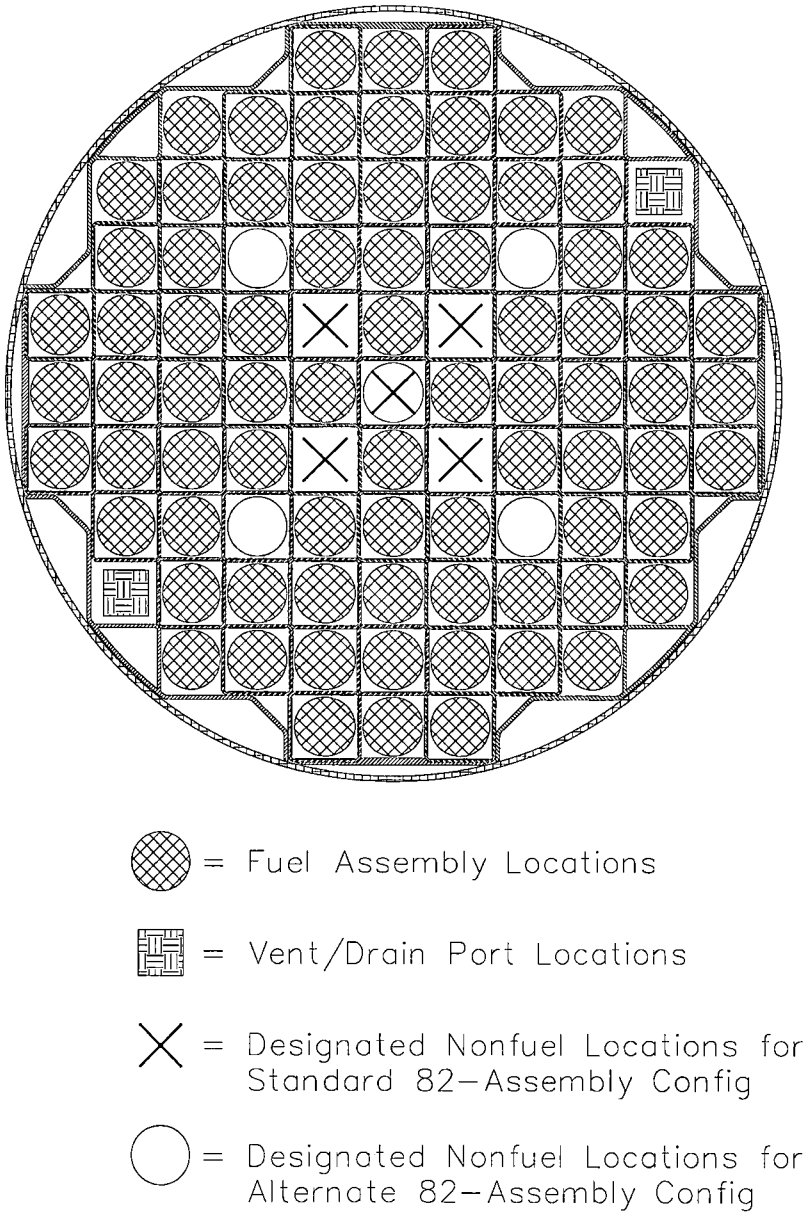


Figure 6.1.1-2 PWR Damaged Fuel Basket Configuration

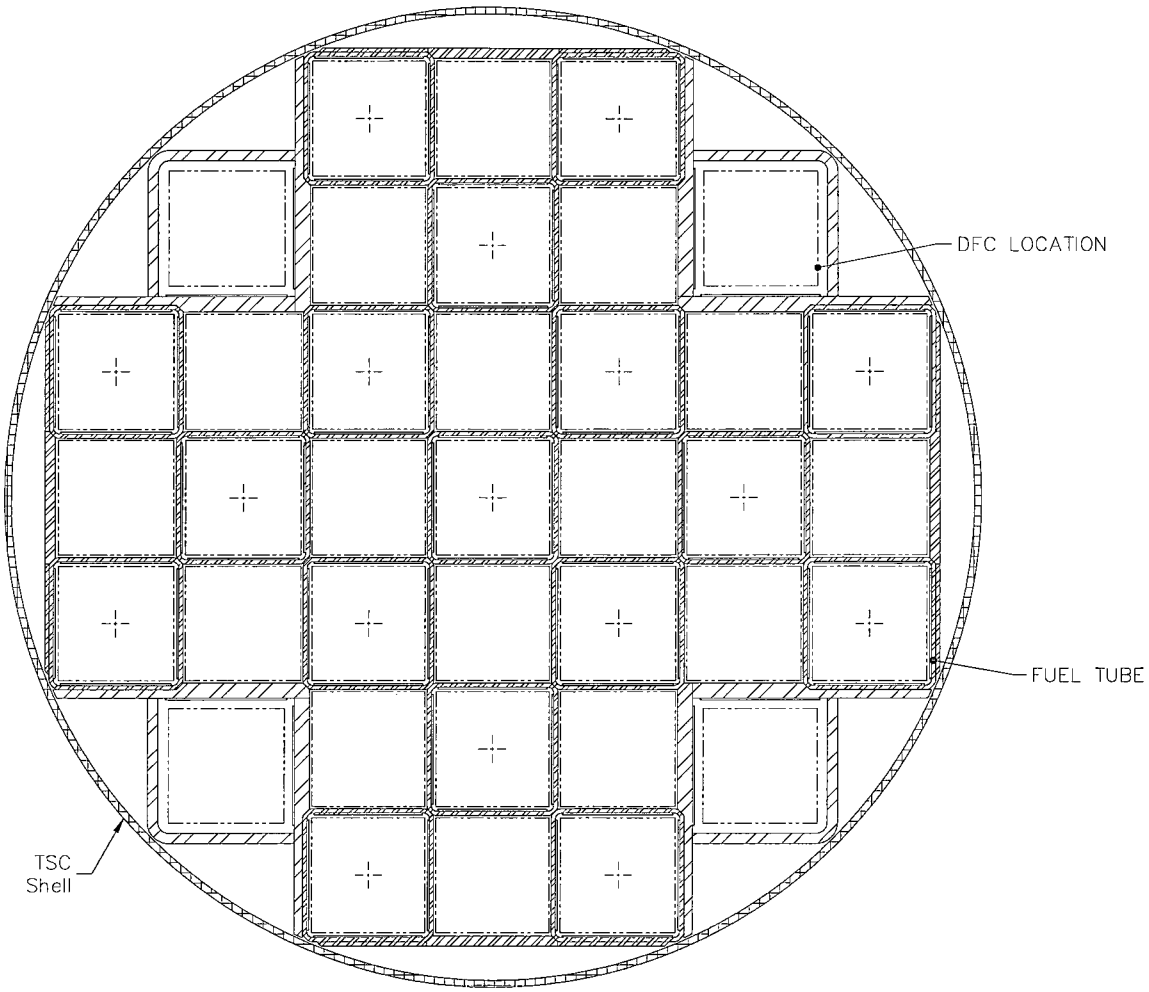


Table 6.1.1-1 Bounding PWR Fuel Assembly Loading Criteria (Assembly Description)

Assembly Type	No. of Fuel Rods	No. of Guide Tubes[a]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)
BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167
CE16H1	236	5	0.5063	0.382	0.025	0.325	150.0	0.4463
WE14H1	179	17	0.556	0.40	0.0162	0.3674	145.2	0.4188
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327

- Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Combined number of guide and instrument tubes.

Table 6.1.1-2 Undamaged Fuel Basket Bounding PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)														
	Absorber[a] 0.036 ^{10}B g/cm^2					Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.8%	4.2%	4.5%	4.8%	5.0%	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.5%	4.8%	5.0%	5.0%	5.0%	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.4%	4.8%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.7%	5.0%	5.0%	5.0%	5.0%	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.2%	4.5%	4.8%	5.0%	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	4.0%	4.4%	4.7%	5.0%	5.0%	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	4.0%	4.3%	4.7%	5.0%	5.0%	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

- Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.1.1-3 BWR Fuel Assembly Loading Criteria (Assembly Description)

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Loading (MTU)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861

Note: Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Assemblies may contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

Table 6.1.1-4 BWR Fuel Assembly Loading Criteria (Enrichment Limits)

	Max. Initial Enrichment[a] (wt % ^{235}U)					
	Absorber[b] 0.027 ^{10}B g/cm^2		Absorber 0.0225 ^{10}B g/cm^2		Absorber 0.02 ^{10}B g/cm^2	
	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket
B7_48A	4.0%	4.5%	3.7%	4.5%	3.6%	4.4%
B7_49A	3.8%	4.5%	3.6%	4.4%	3.5%	4.3%
B7_49B	3.8%	4.5%	3.6%	4.4%	3.5%	4.2%
B8_59A	3.9%	4.5%	3.7%	4.5%	3.6%	4.3%
B8_60A	3.8%	4.5%	3.7%	4.4%	3.5%	4.2%
B8_60B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_61B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_62A	3.8%	4.5%	3.6%	4.3%	3.5%	4.1%
B8_63A	3.8%	4.5%	3.6%	4.3%	3.4%	4.2%
B8_64A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_64B	3.6%	4.3%	3.4%	4.1%	3.3%	4.0%
B9_72A	3.8%	4.5%	3.6%	4.3%	3.4%	4.1%
B9_74A	3.7%[c]	4.3%	3.4%	4.1%	3.4%	4.0%
B9_76A	3.5%	4.2%	3.4%	4.0%	3.3%	3.9%
B9_79A	3.7%	4.4%	3.4%	4.2%	3.3%	4.0%
B9_80A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B10_91A	3.7%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_92A	3.8%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_96A	3.7%	4.3%	3.5%	4.1%	3.4%	4.0%
B10_100A	3.6%	4.4%	3.5%	4.1%	3.4%	4.0%

[a] Maximum planar average.

[b] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

[c] 3.85% in the 86-assembly basket configuration.

[d] 4.55% in the alternate 82-assembly basket configuration.

Table 6.1.1-5 Effective Areal Density as a Function of Absorber Credit

	Effective[a] $g^{10}B/cm^2$	75% Credit $g^{10}B/cm^2$	90% Credit $g^{10}B/cm^2$
PWR	0.036	0.048	0.040
	0.030	0.040	0.0334
	0.027	0.036	0.30
BWR	0.027	0.036	0.030
	0.0225	0.030	0.025
	0.020	0.0267	0.0223

Note: The effective column contains the ^{10}B content modeled in the criticality evaluations. The 75% and 90% credit columns contain the minimum as manufactured ^{10}B content requirements. Effective contents equals as manufactured content times the percent credit permitted (also termed percent effectiveness).

[a] The effective areal density represents the value input into the criticality model and is, therefore, the "100% credit" value.

Table 6.1.1-6 Damaged Fuel Basket Bounding PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)														
	Absorber[a] 0.036 ^{10}B g/cm^2					Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

6.2 Spent Fuel Loading

6.2.1 MAGNASTOR Spent Fuel Loading Characteristics

MAGNASTOR is designed to store TSCs containing spent fuel. Fuel assemblies to be stored in the system and their characteristics are shown in Table 6.2.1-1 (PWR) and Table 6.2.1-2 (BWR). The tables contain data summaries from a wide range of fuel assembly types. Assemblies are restricted to those with zirconium alloy-clad fuel rods; no steel-clad assemblies are included in the data summary. To arrive at the summary tables, fuel assemblies are initially grouped by core configuration (WE, CE, B&W, GE/2-3, or GE/4-6) and number of fuel rods in the lattice. Further subdivisions are then made to differentiate significant configuration changes affecting assembly reactivity. Statistically, significant assembly reactivity changes are typically associated with either moderator ratio or fuel mass changes (e.g., WE 17×17 Std to WE 17×17 OFA). Data in the tables may, therefore, represent either a single fuel assembly type or a fuel assembly group. Also included is a row containing an identifier linking each of the listed assembly types to analysis results presented in the following sections. For convenience, the fuel identifiers contain generic vendor initials. Fuels meeting the physical assembly characteristics are not restricted to any particular vendor.

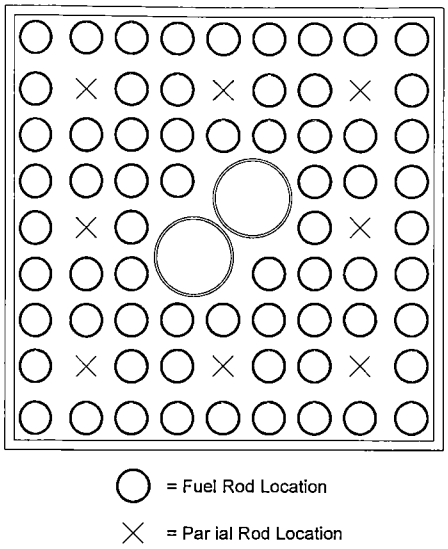
PWR fuel assemblies may include nonfuel hardware placed into the fuel assembly guide tubes and/or instrument tube. Nonfuel hardware that is located in the active fuel region is referred to as inserts in this chapter. Nonfuel components, such as thimble plugs, may not reach into the active fuel region and do not have a significant effect on system reactivity. As inserts are modeled as neutronically transparent zirconium alloy, no differentiation between insert type (e.g., RCCA, BPRA, TP, NSA, HFRA) is made in this chapter.

PWR fuel assemblies may contain axial end-blankets. These blankets are typically 6-to-8-inch long regions of low enriched or natural uranium oxide. Blankets may be constructed from solid fuel pellets, identical in geometry to fuel "midplane", or be annular in configuration (i.e., contain a central void).

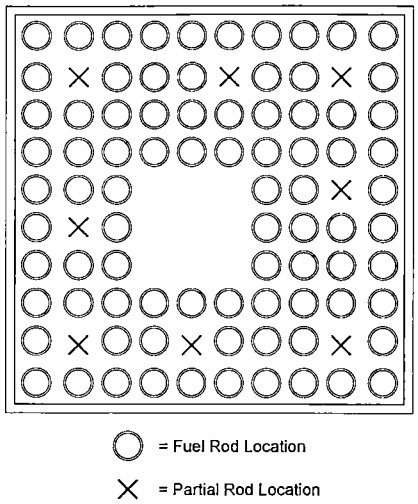
BWR fuel assemblies may contain partial-length fuel rods. Table 6.2.1-2 contains the type of BWR assembly and the number of partial-length rods included in the analysis scope. Locations for the partial-length rods within the lattice are illustrated in Figure 6.2.1-1.

Any empty lattice (fuel rod) positions must be filled by a filler rod to preclude a potential increase in reactivity. Solid filler rods must displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. Filler rods may be placed into the lattice after assembly in-core use or be designed to replace fuel rods prior to use, such as integral burnable absorber rods.

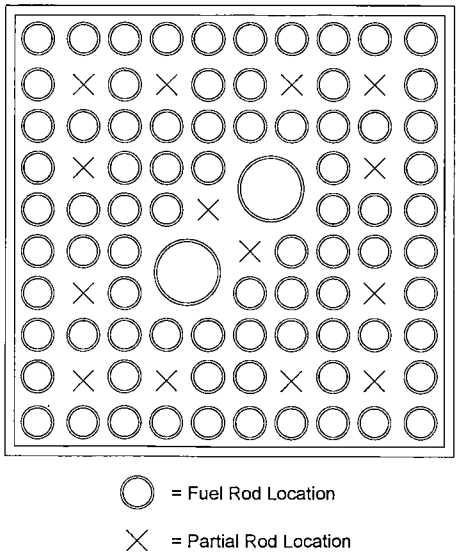
Figure 6.2.1-1 BWR Partial Length Fuel Rod Location Sketches



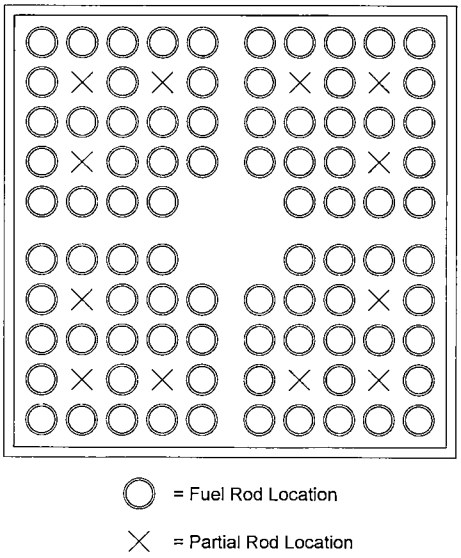
B9_74A 8 Partial Length Rods



B10_91A 8 Partial Length Rods



B10_92A 14 Partial Length Rods



B10_96A 12 Partial Length Rods

Table 6.2.1-1 PWR Fuel Assembly Characteristics

Fuel ID			CE14H1	CE16H1	WE14H1	WE15H1	WE15H2	WE17H1	WE17H2	BW15H1	BW15H2	BW15H3	BW15H4	BW17H1
No. Fuel Rods			176	236	179	204	204	264	264	208	208	208	208	264
Base Fuel Type[a]			CE,SPC	CE	W,SPC	W,SPC	W,SPC	W,SPC	W,SPC	BW,FCF	BW,FCF	BW,FCF	BW,FCF	BW,FCF
Pitch	Max	(in)	0.5800	0.5063	0.5560	0.5630	0.5630	0.4960	0.4960	0.5680	0.5680	0.5680	0.5680	0.5020
	Min	(in)	0.5800	0.5063	0.5560	0.5630	0.5630	0.4960	0.4960	0.5680	0.5680	0.5680	0.5680	0.5020
Fuel Pellet OD	Max	(in)	0.3805	0.3250	0.3674	0.3669	0.3570	0.3232	0.3088	0.3686	0.3735	0.3742	0.3622	0.3252
	Min	(in)	0.3700	0.3250	0.3444	0.3565	0.3570	0.3225	0.3030	0.3686	0.3735	0.3707	0.3622	0.3232
Fuel Rod OD	Max	(in)	0.4400	0.3820	0.4240	0.4240	0.4170	0.3740	0.3600	0.4300	0.4300	0.4280	0.4140	0.3790
	Min	(in)	0.4400	0.3820	0.4000	0.4220	0.4170	0.3720	0.3600	0.4300	0.4300	0.4280	0.4140	0.3770
Fuel Clad Thick.	Max	(in)	0.0310	0.0250	0.0300	0.0300	0.0265	0.0225	0.0250	0.0265	0.0250	0.0245	0.0220	0.0240
	Min	(in)	0.0260	0.0250	0.0162	0.0242	0.0265	0.0205	0.0225	0.0265	0.0250	0.0230	0.0220	0.0220
Guide Tube OD	Max	(in)	1.115	0.980	0.481	0.544	0.484	0.482	0.482	0.493	0.493	0.493	0.493	0.420
	Min	(in)	1.115	0.970	0.481	0.484	0.484	0.482	0.480	0.493	0.493	0.493	0.493	0.420
Guide Tube Thick.	Max	(in)	0.040	0.035	0.034	0.017	0.017	0.015	0.016	0.016	0.015	0.014	0.014	0.020
	Min	(in)	0.036	0.035	0.017	0.015	0.017	0.014	0.015	0.016	0.015	0.014	0.014	0.018
Active Fuel Length	Max	(in)	137.0	150.0	145.2	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0
	Min	(in)	134.0	150.0	142.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	143.0
Fuel Mass	Max	(MTU)	0.4167	0.4463	0.4188	0.4720	0.4469	0.4740	0.4327	0.4858	0.4988	0.5006	0.4690	0.4799
	Min	(MTU)	0.3854	0.4463	0.3599	0.4457	0.4469	0.4720	0.4166	0.4858	0.4988	0.4913	0.4690	0.4707

- Fuel assembly characteristics represent cold, unirradiated, nominal fuel dimension.
- An instrument tube may be located in the center of the assembly. The instrument tube may have slightly different diameter and thickness than the guide tubes. As the instrument tube is limited to one per assembly, dimensional variations have no significant effect on system reactivity and are not listed here.
- Guide tubes may contain "dashpots" near the bottom of the active fuel region narrowing from the listed tube dimension. Stainless steel rod inserts may be installed to displace "dashpot water." Fuel assemblies containing these stainless steel rod inserts are addressed as a fuel assembly containing a nonfuel insert.
- Assemblies may contain unenriched axial blankets.

[a] Indicates assembly and/or nuclear steam supply system (NSSS) vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor provided that the fuel assembly meets the limits listed in Table 6.4.3-1. Abbreviations are as follows: Westinghouse (W), Combustion Engineering (CE), Siemens Power Corporation (SPC), Babcock and Wilcox (BW), and Framatome Cogema Fuels (FCF).

Table 6.2.1-2 BWR Fuel Assembly Characteristics

Fuel ID			B7_48A	B7_49A	B7_49B	B8_59A	B8_60A	B8_60B	B8_61B	B8_62A	B8_63A	B8_64A	B8_64B[a]
No. Fuel Rods			48	49	49	59	60	60	61	62	63	64	64
Base Fuel Type[b]			SPC	GE	GE	GE	GE	GE	GE	SPC	SPC	GE	GE
Pitch	Max	(in)	0.7380	0.7380	0.7380	0.6400	0.6417	0.6400	0.6400	0.6417	0.6420	0.6420	0.6090
	Min	(in)	0.7380	0.7380	0.7380	0.6400	0.6378	0.6378	0.6400	0.6400	0.6400	0.6420	0.6090
Fuel Pellet OD	Max	(in)	0.4900	0.4880	0.4910	0.4160	0.4110	0.4140	0.4140	0.4160	0.4195	0.4195	0.3913
	Min	(in)	0.4900	0.4770	0.4910	0.4160	0.4095	0.4095	0.4140	0.4045	0.4045	0.4195	0.3913
Fuel Rod OD	Max	(in)	0.5700	0.5700	0.5630	0.4930	0.4843	0.4843	0.4830	0.4843	0.4930	0.4840	0.4576
	Min	(in)	0.5700	0.5630	0.5630	0.4930	0.4840	0.4830	0.4830	0.4830	0.4840	0.4840	0.4576
Fuel Clad Thick.	Max	(in)	0.0360	0.0370	0.0320	0.0340	0.0320	0.0320	0.0300	0.0360	0.0360	0.0273	0.0290
	Min	(in)	0.0360	0.0320	0.0320	0.0340	0.0315	0.0300	0.0300	0.0290	0.0273	0.0273	0.0290
No. Water Rods			1	0	0	5	1	4	3	2	1	0	0
Water Rod OD		(in)	0.5700	0.0000	0.0000	0.4930	1.2598	0.4843	0.4830	0.5910	0.4930	0.0000	0.0000
Water Rod Thick.		(in)	Solid[c]	N/A	N/A	0.0340	0.0394	N/A	N/A	N/A	0.0340	N/A	N/A
Active Fuel Length	Max	(in)	144.0	146.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
	Min	(in)	144.0	144.0	150.0	150.0	145.2	145.2	150.0	145.2	144.0	150.0	150.0
Fuel Mass	Max	(MTU)	0.1981	0.2034	0.2115	0.1828	0.1815	0.1841	0.1872	0.1921	0.1985	0.2017	0.1755
	Min	(MTU)	0.1981	0.1916	0.2115	0.1828	0.1744	0.1744	0.1872	0.1758	0.1772	0.2017	0.1755

- Assemblies may contain unenriched axial blankets.
- Water rods may occupy more than one lattice location. Square water rods are not modeled.
- Assembly lattice structure may be surrounded by a zirconium alloy channel up to 120 mil thickness.

[a] Composed of four subchanneled clusters.

[b] Indicates assembly vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor/type provided that the fuel assembly meets the limits listed in Table 6.4.3-2. Abbreviations are as follows: General Electric/Global Nuclear Fuels (GE), Exxon/Advanced Nuclear Fuels/Siemens Power Corporation (SPC).

[c] Assembly contains an inert "solid" zircaloy rod rather than the "tube" type water rod found in other BWR assembly designs.

Table 6.2.1-2 BWR Fuel Assembly Characteristics (cont.)

Fuel ID			B9_72A	B9_74A	B9_76A	B9_79A	B9_80A	B10_91A	B10_92A	B10_96A[a]	B10_100A[a]
No. Fuel Rods			72	74	76	79	80	91	92	96	100
Base Fuel Type[b]			GE	GE	SPC	SPC	GE	SPC	GE	ABB	ABB
No. Partial Length Rods[c]			N/A	8	N/A	N/A	N/A	8	14	12	N/A
Pitch	Max	(in)	0.5720	0.5720	0.5720	0.5720	0.5720	0.5100	0.5100	0.4880	0.4880
	Min	(in)	0.5720	0.5660	0.5720	0.5660	0.5720	0.5100	0.5100	0.4880	0.4880
Fuel Pellet OD	Max	(in)	0.3740	0.3760	0.3750	0.3760	0.3565	0.3420	0.3455	0.3224	0.3224
	Min	(in)	0.3740	0.3565	0.3530	0.3565	0.3565	0.3420	0.3455	0.3224	0.3224
Fuel Rod OD	Max	(in)	0.4330	0.4410	0.4430	0.4410	0.4230	0.3957	0.4040	0.3780	0.3780
	Min	(in)	0.4330	0.4240	0.4170	0.4240	0.4230	0.3957	0.4040	0.3780	0.3780
Fuel Clad Thick.	Max	(in)	0.0260	0.0300	0.0310	0.0300	0.0295	0.0239	0.0260	0.0243	0.0243
	Min	(in)	0.0260	0.0239	0.0209	0.0239	0.0295	0.0239	0.0260	0.0243	0.0243
No. Water Rods			1	2	5	2	1	1	2	0	0
Water Rod OD		(in)	1.7160	0.9843	0.4430	0.4409	0.4230	1.5300	0.8080	0.0000	0.0000
Water Rod Thick.		(in)	N/A	0.0276	0.0120	0.0280	0.0200	N/A	0.0300	0.0310[d]	0.0340[d]
Active Fuel Length	Max	(in)	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
	Min	(in)	150.0	150.0	150.0	145.2	150.0	150.0	150.0	150.0	150.0
Fuel Mass	Max	(MTU)	0.1803	0.1873	0.1914	0.2000	0.1821	0.1906	0.1966	0.1787	0.1861
	Min	(MTU)	0.1803	0.1684	0.1696	0.1740	0.1821	0.1906	0.1966	0.1787	0.1861

- Assemblies may contain unenriched axial blankets.
- Water rods may occupy more than one lattice location. Square water rods are not modeled.
- Assembly lattice structure may be surrounded by a zirconium alloy channel up to 120 mil thickness.

a Composed of four subchanneled clusters.

b Indicates assembly vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor/type provided that the fuel assembly meets the limits listed in Table 6.4.3-2. Abbreviations are as follows: General Electric/Global Nuclear Fuels (GE), Exxon/Advanced Nuclear Fuels/Siemens Power Corporation (SPC).

c Assembly may contain partial length rods. If partial length rods are used, see location sketch in Figure 6.2.1 1.

d Thickness indicated is the subchannel thickness.

6.3 Model Specification

6.3.1 Description of Calculation Model

MCNP is used to model the PWR and BWR storage and transfer casks containing a full load of fuel assemblies. The PWR cask system contains up to 37 fuel assemblies, while the BWR system is capable of storing up to 87 fuel assemblies (89 assemblies are modeled). MCNP uses combinatorial geometry, with the option to divide the model into self-contained Universes. The self-contained Universe structure can be used to separate the TSC, concrete cask, and fuel into individual components that can be easily modified and checked.

The basic MCNP geometry package is comprised of a set of general surfaces. To reduce the required user input, MCNP includes simplified expressions for cylinders and planes perpendicular to system axes and "macrobodies" (cubes, finite cylinders, wedges, etc). Models are constructed by combining geometry components (surfaces) into cells. Cells may be embedded in individual Universes to simplify modeling. A given Universe may be included in different positions within the geometry by translation. Translation allows movement in the x, y, and z directions and rotation using direction cosines.

Finite concrete cask/TSC/basket/fuel models (termed cask model henceforth) are constructed for the storage and transfer system. The cask models are constructed in a set of distinct phases. In the first phase, a fuel assembly is constructed from the basic components of the fuel assembly, i.e., fuel rod, guide tube (PWR), instrument tube (PWR), water rods (BWR), and nozzles (end-fittings). Lattice elements are discretely modeled. Assembly material homogenization is limited to the end-fitting elevations where cuboids, containing a mixture of steel and TSC cavity material (either void or water at various densities), are included. Next the basket structure is placed within the TSC cavity. The basket structure is comprised of a set of carbon steel tubes and aluminum-based neutron absorber panels surrounded by corner and side weldments. After completing the basket model, fuel assemblies are explicitly placed into the TSC cavity, with the basket structure superimposed on the cavity surrounding the assemblies using the Universe structure. The TSC shell and lid are placed around the loaded basket. The complete TSC is then placed into either the transfer or storage cask overpack. Generic basket features and TSC and cask model details are included here. Detailed basket features unique to a specific payload configuration are discussed in Section 6.7.

The basket is composed of a set of corner-locking tubes and corner and side weldments. For undamaged fuel, 21 PWR tubes and 45 BWR tubes form the openings for 37 PWR assemblies and 89 BWR assemblies, respectively. For the damaged PWR fuel basket, 17 PWR

tubes and four corner weldments form 37 openings for the PWR assemblies with up to four DFCs. Sketches of a generic tube and the developed cell are shown in Figure 6.3.3-1. Refer to Sections 6.7.1, 6.7.4 and 6.7.8 for detail on the PWR and BWR tube and basket layout and dimensions. Each of the baskets is placed into a matching TSC. The undamaged PWR and BWR baskets are designed in two lengths each, with PWR and BWR TSC differences being limited to the location of the TSC ports. The damaged PWR basket is designed in one length. Ports are not included in the criticality model. Therefore, PWR and BWR TSC models are identical and are composed of a simple set of steel cylinders. Figure 6.3.3-2 contains a sketch of the TSC model. A model sketch of the transfer cask is shown in Figure 6.3.3-3, with the concrete cask model sketch shown in Figure 6.3.3-4.

An outer cylindrical body allows reflecting boundary conditions to be applied at specified distances surrounding each cask model. Due to the size of the transfer and storage radiation shields, cask surface neutron currents are low. This, in turn, results in baskets that are neutronically isolated from cask exterior conditions and from other casks in an array configuration.

6.3.2 Model Assumptions

Key assumptions for the analytical models are as follows.

- Assemblies are modeled as fresh, unburned fuel.
- The assembly is modeled at a fuel density of 96% theoretical ($0.96 \times 10.96 = 10.52$ g/cm^3).
- A homogenous, peak planar average enrichment is applied to the BWR models. The appropriateness of this assumption is validated in Section 6.7.5.
- With the exception of the fuel assembly channels in the BWR case, no fuel assembly structural materials (i.e., spacer or mixing grids) are included in the PWR and BWR active fuel region elevations. Nonfuel components placed into guide tubes are specifically addressed in the analysis. As demonstrated in the moderator density and fuel characteristics evaluation, the fuel rod lattices are undermoderated, therefore, making this assumption conservative.
- Integral fuel assembly neutron absorbers (e.g., BWR gadolinium rods, PWR erbium, gadolinium or boron IFBAs) are excluded from the analysis, thereby substantially increasing assembly reactivity of the unburned assembly.
- Fuel assembly cladding for baseline cases is intact. In-core failure rates indicate that the vast majority of fuel loaded will not have cladding damage, allowing access to the pellet-to-clad gap. Flooding of this void space is addressed in Sections 6.7.3 and 6.7.6.

  The moderator is assumed to be water at various densities. Baseline for the analysis is water at a temperature of 293K and a density of 0.9982 g/cm^3. PWR analyses include soluble boron at various concentrations, effectively increasing water density. For a

consistent presentation, water densities are expressed at the unborated levels throughout this document unless specifically noted. The fuel, cladding, and other structural materials are assumed to be at 293K.

- Fixed neutron absorber sheets are evaluated at effective ^{10}B densities of 0.036, 0.030 and 0.027 g/cm^2 (PWR) and 0.027, 0.0225 and 0.020 g/cm^2 (BWR). Dividing by either 75% or 90% effectiveness yields the minimum absorber levels required for the sheet manufacture.
- Fuel assembly and basket will retain their structure and will not show any significant permanent deformation during normal conditions, off-normal or accident events. Per Section 3.7.1.2 and Section 3.7.2.2, hypothetical tip-over analysis, the maximum permanent set across the diagonal of the fuel tube is less than 0.01 inch. This represents less than one-half the tolerance evaluated on the fuel tube interface width in Section 6.7.3 and Section 6.7.6 and shown to be statistically insignificant (i.e., no statistically significant conclusion can be drawn from the analysis). The tube deformation, therefore, has no resolvable effect on system reactivity or allowed payload configurations.
- Regardless of the specific type of stainless or carbon steel employed in the system construction, the default SS-304 and carbon steel compositions in the SCALE 4.4 standard composition library [5] are employed. Minor alloying differences between the steel types will not affect system reactivity significantly.
- The basket tubes are modeled at their drawing specified dimensions, i.e., no potential deformations associated with the beyond design basis cask tip-over accident event are applied to the analysis model. As demonstrated in Chapter 12 there is no design basis condition that will result in the cask tip-over. Therefore there is no permanent deformation in the basket tube structure during any design basis event. The minor permanent set in the tubes discussed for the hypothetical cask tip-over in Section 3.7.2 is limited to the top regions of the basket where neutron leakage effects will reduce any reactivity affects. As discussed in Section 3.7.2, permanent set in the center regions of the basket is not significant.

6.3.3 Cask Regional Densities

The densities used in the criticality analyses are primarily SCALE 4.4 default densities. NS-4-FR is a proprietary material and the listed information reflects values defined by the material information data sheet. Fuel assembly materials are listed in Table 6.3.3-1. Basket, TSC, and cask material definitions are shown in Table 6.3.3-2.

Figure 6.3.3-1 Generic Tube Cross-Section and Developed Cell Model Sketches

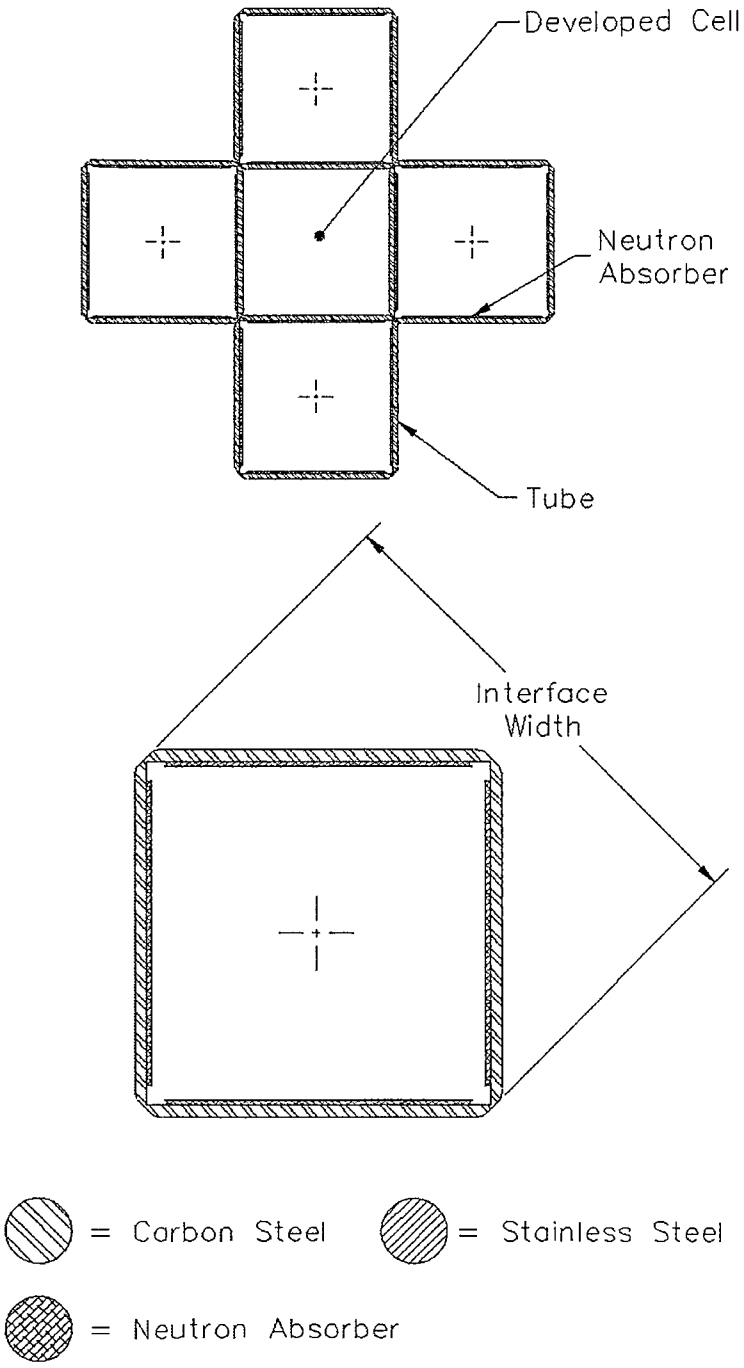
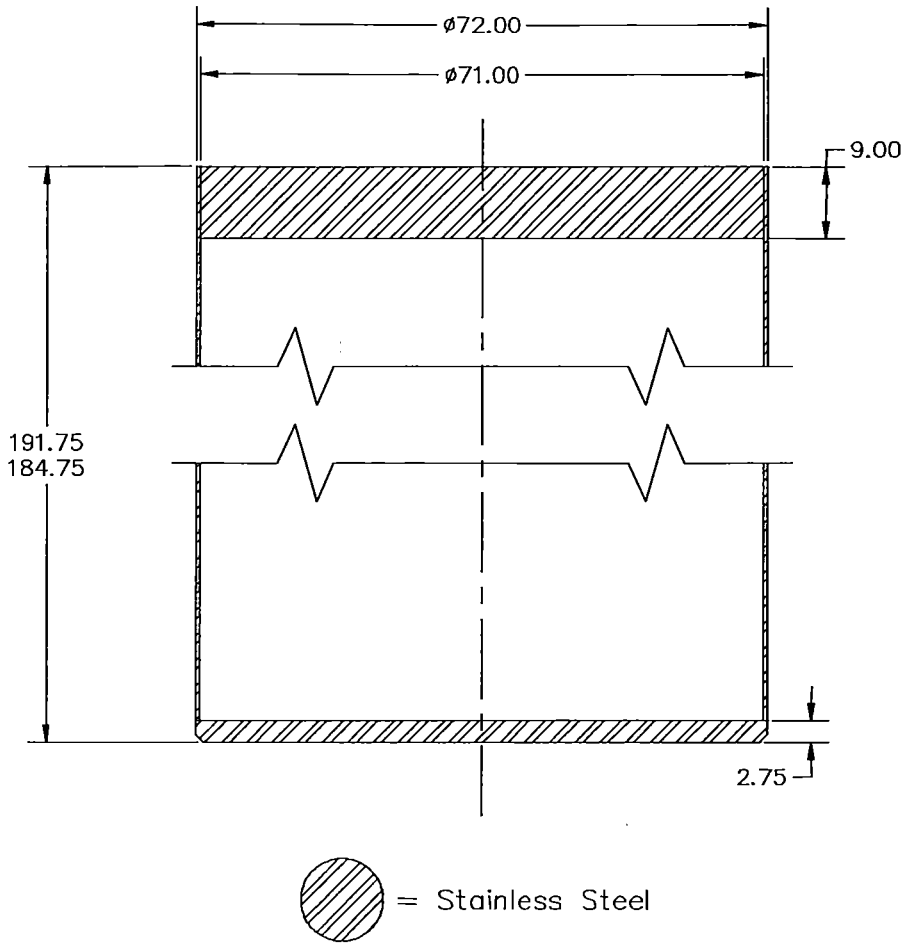
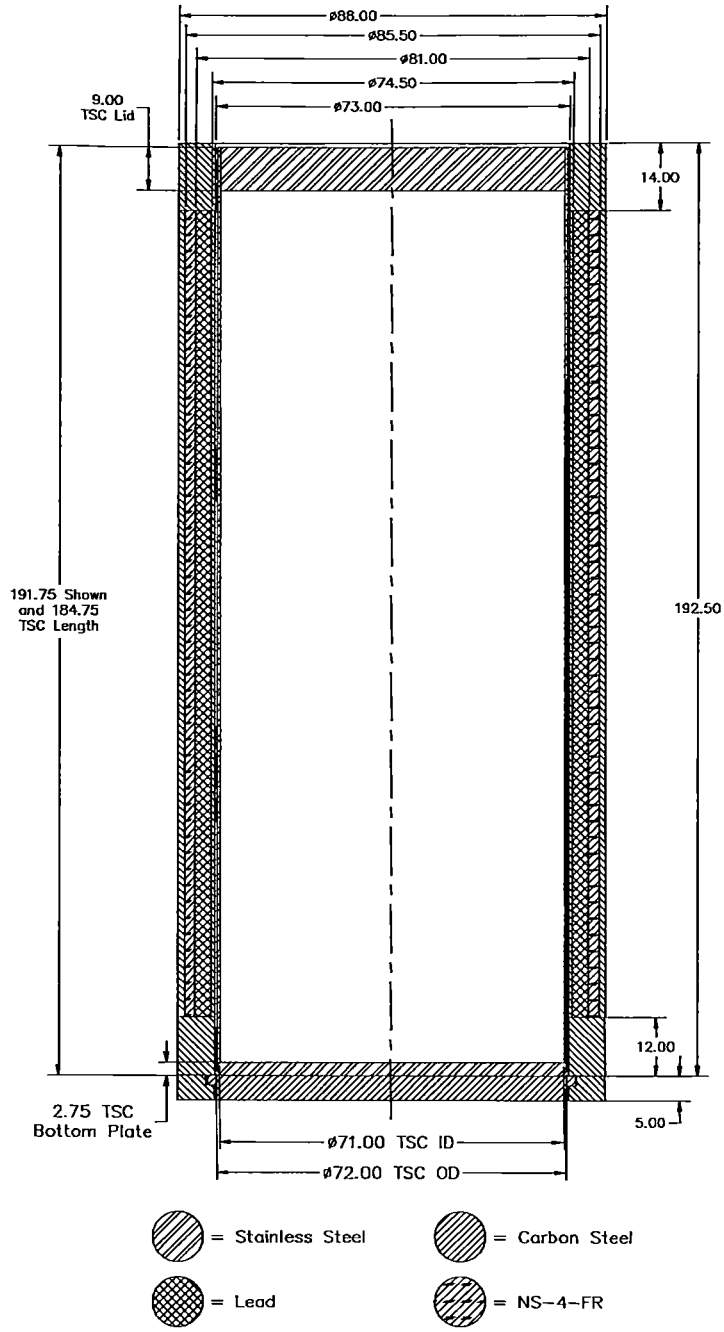


Figure 6.3.3-2 TSC Model Sketch



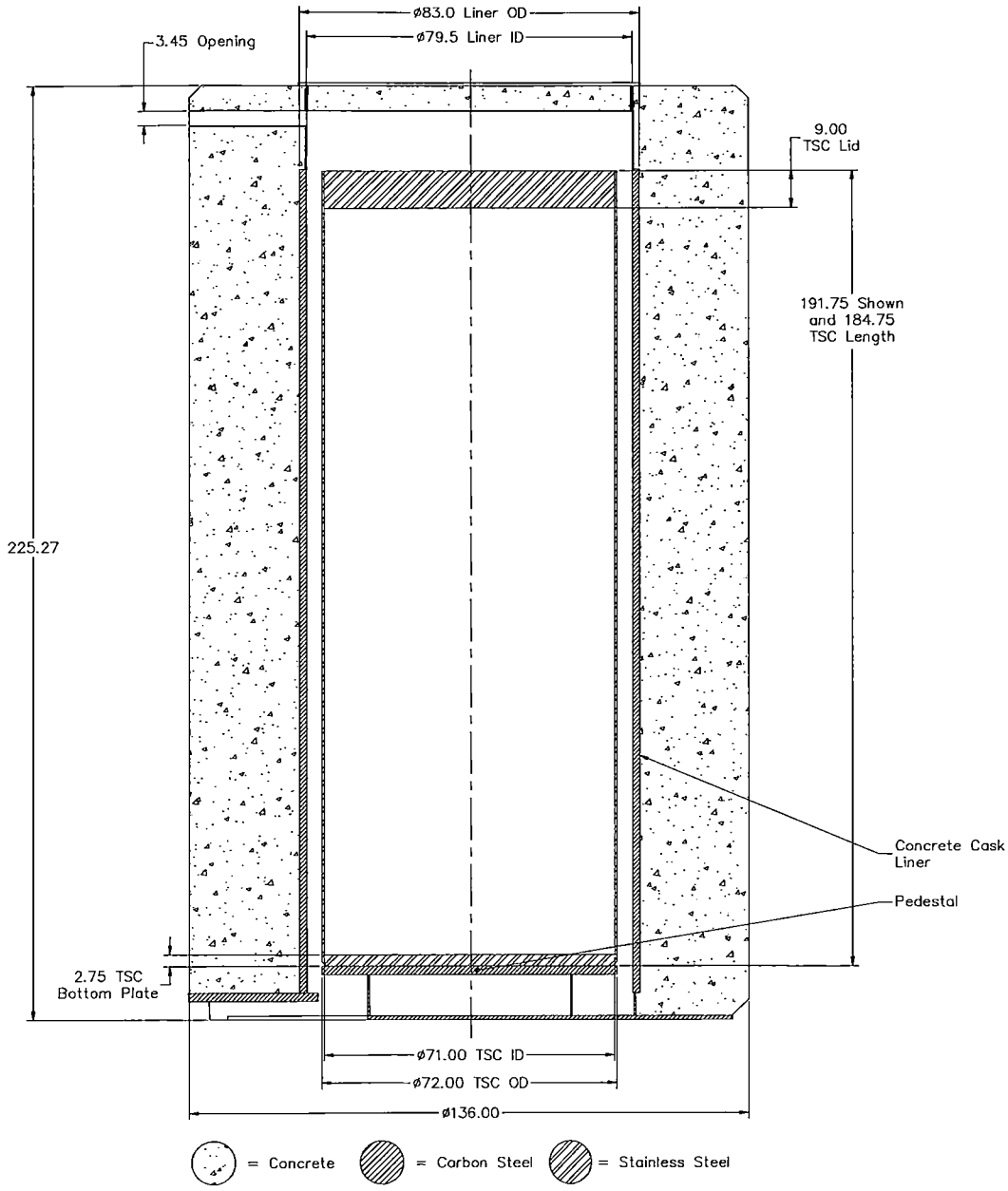
Note: Dimensions in inches

Figure 6.3.3-3 Transfer Cask Model Sketch



Note: Dimensions in inches

Figure 6.3.3-4 Storage Cask Model Sketch



Note: Dimensions in inches

Table 6.3.3-1 Fuel Assembly Material Densities and Compositions

Material	Density g/cm³	Element/ Isotope	Density atom/barn-cm
UO_2 (5 wt % ^{235}U)[a] 96% theoretical density	10.522	^{235}U	1.19E-03
		^{238}U	2.23E-02
		O	4.70E-02
Zirconium-based Alloy	6.56	Fe	8.84E-05
		Cr	7.60E-05
		N	1.41E-04
		Zr	4.25E-02
		Sn	4.99E-04
Water Full Density – No Boron	0.9982	H	6.67E-02
		O	3.34E-02
Water[b] Full Density – 2500 ppm Boron	1.0025	H	6.65E-02
		O	3.35E-02
		^{10}B	2.66E-05
		^{11}B	1.13E-04
Stainless Steel	7.94	Cr	1.75E-02
		Fe	5.95E-02
		Ni	7.74E-03
		Mn	1.74E-03

[a] System is evaluated at varying enrichment levels. Sample data is provided.

[b] Various soluble boron levels are evaluated. Listed value represents the upper end of the soluble boron range. Value was calculated based on the soluble boron source being boric acid.

Table 6.3.3-2 Basket, TSC, and Cask Material Densities and Compositions

Material	Density g/cm³	Element/ Isotope	Density atom/barn-cm
Carbon Steel	7.821	Fe	8.35E-02
		C	3.92E-03
Stainless Steel	7.94	Cr	1.75E-02
		Fe	5.95E-02
		Ni	7.74E-03
		Mn	1.74E-03
Aluminum	2.702	Al	6.03E-02
Lead	11.344	Pb	3.30E-02
NS-4-FR	1.632	H	5.8508E-02
		^{10}B	9.1385E-05
		^{11}B	3.3665E-04
		C	2.2600E-02
		N	1.3904E-03
		O	2.6107E-02
		Al	7.8003E-03
Concrete (145 lb/ft³)	2.322	H	1.3879E-02
		O	4.6522E-02
		Na	1.7643E-03
		Al	1.7625E-03
		Si	1.6783E-02
		Ca	1.5356E-03
		Fe	3.5063E-04
Neutron Absorber[a]	2.358	^{10}B	8.53E-03
		^{11}B	3.61E-02
		C	1.11E-02
		Al	2.98E-02

[a] Represents the as-modeled core density for BORAL based PWR (0.036 ^{10}B g/cm^2 effective) neutron absorber sheets. As-built neutron absorber density will vary depending on effective areal density and material choice (e.g., metal matrix composite, BORAL, borated aluminum), boron enrichment, and percent absorber credit taken (i.e., 75% or 90%).

6.4 Criticality Calculation

6.4.1 Calculation Method

System reactivity evaluations are performed with the MCNP5 three-dimensional Monte Carlo code and continuous neutron energy cross-sections [3,4]. The Monte Carlo code and neutron cross-section libraries are validated for use in fuel transport and storage cask applications through a series of calculations based on critical experiments. Validation detail is presented in Section 6.5

The criticality analysis of the system is performed in several steps.

- Establish initial reactivity effects of gap conditions, partial flooding, and inserts (PWR) for each fuel type under the assumption that the assemblies are undermoderated (typical for PWR and BWR assemblies in storage and transport configuration).
- Determine bounding fuel assembly geometric definitions in terms of maximum or minimum rod pitch, rod diameter, and clad thickness, and guide/instrument/water rod diameter and thickness.
- For the BWR systems, justify the use of planar average versus heterogeneous enrichments is justified.
- Evaluate basket mechanical perturbations and basket geometric tolerances for sample fuel assembly types.
- Construct optimum moderator density curves for sample fuel types.
- Based on the maximum reactivity configuration, determine allowable enrichments for each fuel type. System reactivity must be below the USL. For the PWR system, minimum allowable soluble boron levels are set in conjunction with the maximum allowable enrichment.

6.4.2 Fuel Loading Optimization

The fuel loading is optimized in the criticality models using the following.

- Fresh fuel at 96% theoretical density
- Bounding fuel assembly geometry
- The most reactive cask configuration

Based on the fuel characteristics documented in Section 0, bounding fuel assembly nominal characteristics are established in terms of the following.

- Fuel rod outer diameter
- Fuel rod clad thickness
- Fuel rod pitch

- Guide tube/water rod outer diameter and thickness
- Channel thickness (BWR)
- Homogenous versus heterogeneous enrichment patterns (BWR)
- Presence of nonfuel hardware insert (PWR)

Refer to Section 6.7 for the fuel type-specific details of the fuel characteristics evaluation.

The maximum reactivity cask configuration considers basket fabrication tolerances, component shifting, and moderator density evaluations. Each of these effects is evaluated individually and in combination to assure that the highest reactivity configuration is documented. Fabrication tolerances and shift effect are evaluated using representative fuel types from the major core configurations. Basket-specific evaluations determining the maximum reactivity configurations are included in Section 6.7.

Casks are evaluated at various interior and exterior flood conditions with reflective boundary conditions. Reflective boundary conditions are applied to an independently generated cylindrical body surrounding the cask body. This allows the modeling of infinite cask arrays at various cask spacings. Space between the cask surface and the reflecting body may be flooded at various moderator densities. Given the low neutron fluxes on either concrete or transfer cask bodies, no significant effect is observed from conditions outside the cask body.

6.4.2.1 Fabrication Tolerances

The basket is composed of a set of fuel tubes located in the TSC cavity with side and corner weldments. The fuel tubes are pinned together in the tube corners. Tube location in the basket is controlled by the diagonal dimension across the exterior face of the fuel tube corners as shown in Figure 6.3.3-1. This value is a key dimension for tube array and developed cell size. The tube diagonal is referred to as tube "interface width" in the analysis discussion. Tube and neutron absorber width and thickness have the potential to significantly affect the size of the tube opening and developed cell locations. Tube wall thickness is conservatively evaluated for a tolerance of ±0.03 inch (versus a tolerance of -0.01, +0.03 inch from the ASTM standard for the specified plate material), while the neutron absorber is evaluated at a thickness tolerance of -0.006, +0.016 inch for the PWR system and ± 0.006 inch for the BWR system. The side and corner weldments provide structural support to the basket during normal and accident conditions, but do not generally dictate cell size. Tolerance effects are evaluated on the fuel tube and neutron absorber. Retainer thickness tolerance was not considered relevant to the analysis since the retainer strips are only 0.015-in thick (nominal). Off-nominal material thickness for this component would not involve a significant amount of material and would, therefore, not affect system reactivities significantly.

6.4.2.2 Component Shift

In addition to the component tolerances, a reactivity study on component shifts is required. Based on the pinned tube arrangement, the only radial shift to be evaluated is the shift of the fuel assembly within the tubes. The tubes are restrained in the corner by pins, eliminating a tube movement study.

6.4.2.3 Moderator Density Study

To verify that for the borated water cases maximum reactivity occurs at the highest mixture density in the TSC cavity, a sequence of cavity water densities ranging from void (0.0001 g/cm^3) to full density (0.9998 g/cm^3) are evaluated with a void (0.0001 g/cm^3) exterior. Similar evaluations are performed with a void interior and various exterior water densities, and simultaneous variations in interior and exterior water densities. Exterior moderator is conservatively modeled as unborated water regardless of TSC interior boron content. The moderator density variation studies one fuel assembly type per basket configuration.

6.4.3 Criticality Results

6.4.3.1 Undamaged PWR 37-Assembly Reactivity Result Summary and Enrichment Limits

Results of the fuel characterization evaluation in Section 6.1.1 indicate that for each fuel assembly subset, the maximum fuel reactivity is achieved by the following.

- Maximum Pitch
- Maximum Fuel Pellet OD
- Minimum Fuel Rod OD and Clad Thickness

Insertion of nonfuel assembly hardware components into the active fuel regions affects system reactivity in the majority of cases. The level and direction of the reactivity effect depends on the level of soluble boron in the moderator and the fuel type. The effect is low for fuel rod-sized absorbers typical of Westinghouse and B&W cores, but becomes large for the guide tubes in CE cores, which typically displace four assembly lattice locations each. In the CE System 80 model, all five guide tubes are evaluated as containing nonfuel hardware. Only four of the five guide tubes are designed for control rod access from the top.

Maximum system reactivity was achieved for assemblies with an unborated water flooded pellet-to-clad gap. Flooding the gap with the minimum soluble boron content specified for the system results in no significant reactivity change from the dry gap condition.

Detailed studies in Section 6.7.3 demonstrate that no single component fabrication tolerance has a statistically significant effect on system reactivity. A radial shift of assemblies to the center of the TSC significantly increases system reactivity.

A combination of basket fabrication tolerances minimizing the tube internal free volume showed a minor positive reactivity effect. Minimum free volume removes soluble boron from the system and reduces water volume that may serve as moderator between the fuel assembly and the neutron absorber sheets. Reduced interface width also minimizes distance between assemblies. The following set of dimensions/perturbations maximizes system reactivity.

- Minimum tube interface width
- Maximum tube thickness
- Minimum absorber width and maximum thickness
- Fuel assemblies shifted to basket center

While minimum absorber width increases the tube free volume, it also reduces total system absorber content. Even at maximum soluble boron content, the neutron absorber sheets contain significantly higher absorber concentration.

As demonstrated in Section 6.7, partial flooding and exterior moderator density variations do not significantly affect the flooded TSC's reactivity. In storage conditions, flooding the TSC-to-concrete cask gap has a minor effect on system reactivity due to differences in neutron reflection between the water in the gap and the steel liner.

In the void to full density moderator range, increasing the TSC interior moderator density raises system reactivity for the cases containing soluble boron at less than 1,800 ppm. At higher soluble boron concentrations, reactivity levels off between 0.9 g/cm^3 and full density (0.9982 g/cm^3). No significant variations in reactivity occur in this area. For consistency in presentation, full moderation is listed as maximum reactivity TSC interior moderator.

For each of the fuel types, with and without nonfuel inserts in the active fuel region, several combinations of minimum soluble boron and maximum initial enrichments are determined. The allowable loadings are documented in Table 6.4.3-1 and Table 6.4.3-2 and represent the bounding values for assemblies with, and without, nonfuel hardware in the assembly guide tubes.

Maximum reactivities for normal and accident conditions for PWR fuel are listed in the following table. As there are no off-normal or accident events affecting the transfer cask reactivities, all transfer conditions are listed as normal. The USL applied is 0.9376 for all conditions.

Cask Body	Gap Condition	Operating Condition	Soluble Boron (ppm)	Enrichment (wt % ^{235}U)	Water Density (g/cc) Interior	Water Density (g/cc) Exterior	$k_{eff} + 2\sigma$
Transfer	Dry	Normal	2000	4.5	0.9982	0.0001	0.93183
Transfer	Wet	Normal	2000	4.5	0.9982	0.0001	0.93712
Transfer	Dry	Normal	2000	4.5	0.9982	0.9982	0.92975
Transfer	Wet	Normal	2000	4.5	0.9982	0.9982	0.93615
Storage	Dry	Normal	0	5.0	0.0001	0.0001	0.48145
Storage	Dry	Accident	0	5.0	0.0001	0.9982	0.47104

Note: Maximum PWR enrichment is 5.0 wt %. Transfer cask cases represent maximum reactivity cases from allowed enrichment/soluble boron content/fuel type matrix. Storage cask cases employ fuel type with maximum fissile material mass.

6.4.3.2 Undamaged BWR 87-Assembly and 82-Assembly Basket Reactivity Result Summary and Enrichment Limits

Results of the fuel characterization evaluation in Section 6.7.5 indicate that for each fuel assembly subset, the maximum fuel reactivity is achieved by the following.

- Maximum Pitch
- Maximum Fuel Pellet OD
- Minimum Fuel Rod OD and Clad Thickness
- Maximum Planar Average Enrichment
- Flooded Pellet to Clad Gap

Detailed studies in Section 6.7.6 demonstrate that no single component fabrication tolerance has a statistically significant effect on system reactivity. A radial shift of assemblies to the center of the TSC significantly increases system reactivity.

A combination of basket fabrication tolerances minimizing the tube internal free volume showed a minor positive reactivity effect. Minimum free volume reduces water volume that serves as moderator between the fuel assembly and the borated aluminum neutron absorber sheets. Reduced interface width also minimizes distance between assemblies.

The following set of dimensions/perturbations maximizes system reactivity.

- Minimum tube interface width
- Maximum tube thickness
- Minimum absorber width and maximum thickness
- Fuel assemblies shifted to basket center

Minimum absorber width reduces total system absorber content.

As demonstrated in Section 6.7, partial flooding and exterior moderator density variations do not significantly affect the flooded TSCs reactivity. In the dry TSC flooding, the TSC-to-concrete cask gap has a minor effect on system reactivity. Increases in the TSC interior moderator density raise system reactivity.

For each of the fuel types, a maximum initial enrichment is defined. The allowable loadings are documented in Table 6.4.3-3 and Table 6.4.3-4.

Maximum reactivities for normal and accident conditions for BWR fuel are listed in the following table. As there are no off-normal or accident events affecting the transfer cask reactivities, all transfer conditions are listed as normal. The USL applied is 0.9376 for all conditions.

Cask Body	Gap Condition	Operating Condition	Enrichment (wt % ^{235}U)	Water Density (g/cc) Interior	Water Density (g/cc) Exterior	$k_{eff} + 2\sigma$
Transfer	Dry	Normal	3.8	0.9982	0.0001	0.92900
Transfer	Wet	Normal	3.8	0.9982	0.0001	0.93679
Transfer	Dry	Normal	3.8	0.9982	0.9982	0.92839
Transfer	Wet	Normal	3.8	0.9982	0.9982	0.93674
Storage	Dry	Normal	4.5	0.0001	0.0001	0.43685
Storage	Dry	Accident	4.5	0.0001	0.9982	0.42991

Note: Maximum BWR enrichment is 4.5 wt %. Transfer cask cases represent maximum reactivity cases from allowed enrichment/fuel type matrix. Storage cask cases employ fuel type with maximum fissile material mass.

6.4.3.3 Damaged PWR 37-Assembly Reactivity Result Summary and Enrichment Limits

Maximum enrichments for payloads of 33 undamaged and four damaged PWR fuel assemblies in the MAGNASTOR system were determined with effective ^{10}B contents of 0.036, 0.030, and 0.027 g/cm^2 for the absorber sheets. Three variations of damaged PWR fuel are modeled in the

DFC. The undamaged assembly case contains an undamaged assembly in the DFC. In the unclad array case, an array without clad or end fittings is modeled in the DFC. Rod pitch is allowed to increase in the unclad array. The maximum size array fills the DFC cross-sectional area. The mixture case models a homogenized mixture of fuel and moderator up to various heights of the DFC cavity.

Maximum reactivities for normal and accident conditions are detailed in Section 6.7.8. Enrichment limits for PWR assemblies placed into the damaged fuel PWR basket are summarized in Table 6.4.3-5.

Table 6.4.3-1 PWR Fuel Basket Allowable Loading (Assembly Description)

Assembly Type	No. of Fuel Rods	No. of Guide Tubes[a]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167
CE16H1	236	5	0.5063	0.382	0.025	0.325	150.0	0.4463
WE14H1	179	17	0.556	0.40	0.0162	0.3674	145.2	0.4188
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327

Notes:

- Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Combined number of guide and instrument tubes.

Table 6.4.3-2 Undamaged Fuel Basket PWR Fuel Assembly Allowable Loading (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)														
	Absorber[a] 0.036 ^{10}B g/cm^2					Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.8%	4.2%	4.5%	4.8%	5.0%	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.5%	4.8%	5.0%	5.0%	5.0%	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.4%	4.8%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.7%	5.0%	5.0%	5.0%	5.0%	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.2%	4.5%	4.8%	5.0%	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	4.0%	4.4%	4.7%	5.0%	5.0%	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	4.0%	4.3%	4.7%	5.0%	5.0%	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

- Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.4.3-3 BWR Fuel Basket Allowable Loading (Assembly Description)

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Loading (MTU)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861

Note: Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Assemblies may contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

Table 6.4.3-4 BWR Fuel Basket Allowable Loading (Enrichment Limits)

	Max. Initial Enrichment[a] (wt % ^{235}U)					
	Absorber[b] 0.027 ^{10}B g/cm^2		Absorber 0.0225 ^{10}B g/cm^2		Absorber 0.02 ^{10}B g/cm^2	
	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket
B7_48A	4.0%	4.5%	3.7%	4.5%	3.6%	4.4%
B7_49A	3.8%	4.5%	3.6%	4.4%	3.5%	4.3%
B7_49B	3.8%	4.5%	3.6%	4.4%	3.5%	4.2%
B8_59A	3.9%	4.5%	3.7%	4.5%	3.6%	4.3%
B8_60A	3.8%	4.5%	3.7%	4.4%	3.5%	4.2%
B8_60B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_61B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_62A	3.8%	4.5%	3.6%	4.3%	3.5%	4.1%
B8_63A	3.8%	4.5%	3.6%	4.3%	3.4%	4.2%
B8_64A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_64B	3.6%	4.3%	3.4%	4.1%	3.3%	4.0%
B9_72A	3.8%	4.5%	3.6%	4.3%	3.4%	4.1%
B9_74A	3.7%[c]	4.3%	3.4%	4.1%	3.4%	4.0%
B9_76A	3.5%	4.2%	3.4%	4.0%	3.3%	3.9%
B9_79A	3.7%	4.4%	3.4%	4.2%	3.3%	4.0%
B9_80A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B10_91A	3.7%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_92A	3.8%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_96A	3.7%	4.3%	3.5%	4.1%	3.4%	4.0%
B10_100A	3.6%	4.4%	3.5%	4.1%	3.4%	4.0%

[a] Maximum planar average.
[b] Borated aluminum neutron absorber sheet effective areal ^{10}B density.
[c] 3.85% in the 86-assembly basket configuration.
[d] 4.55% in the alternate 82-assembly basket configuration.

Table 6.4.3-5 Damaged Fuel Basket PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)														
	Absorber[a] 0.036 ^{10}B g/cm^2					Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

6.5 Critical Benchmark Experiments

Criticality code validation is performed for the Monte Carlo evaluation code and neutron cross-section libraries. Criticality validation is required by the criticality safety standards ANSI/ANS-8.1 [6].

6.5.1 Benchmark Experiments and Applicability

NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages" (NUREG), provides a guide to LWR criticality benchmark calculations and the determination of bias and subcritical limits in critical safety evaluations. In Section 2 of the NUREG, a series of LWR critical experiments are described in sufficient detail for independent modeling. In Section 3, the critical experiments are modeled, and the results (k_{eff} values) are presented. The method utilized in the NUREG is KENO-Va with the 44-group ENDF/B-V cross-section library embedded in SCALE 4.3. In Section 4, a guide for the determination of bias and subcritical safety limits is provided based on ANSI/ANS-8.17 [7] and statistical analysis of the trending in the bias. Finally, guidelines for experiment selection and applicability are presented in Section 5. The approach outlined in Section 4 of the NUREG is described in detail herein and is implemented for MCNP5 with continuous energy ENDF/B-VI cross-sections.

The NUREG/CR-6361 implements ANSI/ANS-8.17 criticality safety criterion as follows.

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad \text{(Equation 1)}$$

where:

k_s = calculated allowable maximum multiplication factor, k_{eff}, of the system being evaluated for all normal or credible abnormal conditions or events.

k_c = mean k_{eff} that results from a calculation of benchmark criticality experiments using a particular calculation method. If the calculated k_{eff} values for the criticality experiments exhibit a trend with an independent parameter, then k_c shall be determined by extrapolation based on best fit to calculated values. 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 = allowance for the following.

- statistical or convergence uncertainties, or both, in computation of k_s
- material and fabrication tolerances
- geometric or material representations used in computational method

Δk_c = margin for uncertainty in k_c, which includes allowance for the following.

- uncertainties in critical experiments
- statistical or convergence uncertainties, or both, in computation of k_c
- uncertainties resulting from extrapolation of k_c outside range of experimental data
- uncertainties resulting from limitations in geometrical or material representations used in the computational method

Δk_m = arbitrary administrative margin to ensure subcriticality of k_s

The various uncertainties are combined statistically if they are independent. Correlated uncertainties are combined by addition.

Equation 1 can be rewritten as shown.

$$k_s \leq 1 - \Delta k_m - \Delta k_s - (1 - k_c) - \Delta k_c \qquad \text{(Equation 2)}$$

Noting that the definition of the bias is $\beta = 1 - k_c$, Equation 2 can be written as shown.

$$k_s + \Delta k_s \leq 1 - \Delta k_m - \beta - \Delta\beta \qquad \text{(Equation 3)}$$

where:

$$\Delta\beta = \Delta k_c$$

Thus, the maximum allowable value for k_{eff} plus uncertainties in the system being analyzed must be below 1 minus an administrative margin (typically 0.05), which includes the bias and the uncertainty in the bias. This can also be written as shown.

$$k_s + \Delta k_s \leq \text{Upper Subcritical Limit (USL)} \qquad \text{(Equation 4)}$$

where:

$$USL \equiv 1 - \Delta k_m - \beta - \Delta\beta \qquad \text{(Equation 5)}$$

This is the USL criterion as described in Section 4 of NUREG/CR-6361. Two methods are prescribed for the statistical determination of the USL. The "Confidence Band with Administrative Margin (USL-1)" approach is implemented here and is referred to generically as USL. A $\Delta k_m = 0.05$ and a lower confidence band are specified based on a linear regression of k_{eff} as a function of some system parameter. As recommended in NUREG/CR-6361, a simple

linear regression is performed on each system parameter, and the line with the greatest correlation is used to functionalize β.

Section 6.7.7 contains the extensive list of LWR critical benchmarks employed in the validation of MCNP with its continuous energy neutron cross-section libraries. The range of parameters included in the benchmarks is shown in Table 6.5.2-1.

Included in Section 6.7.7 are linear fits of reactivity (k_{eff}) to each of the system parameters. Experiments were chosen to reflect the fuel and basket geometry and materials, and the spent fuel cask criticality control mechanism. This includes the use of square pitched, low enriched uranium oxide fuel rods, a rectangular arrangement of assembles, light water moderation, and criticality control by spacing, borated moderator, and/or borated absorber panels and tubes. Trending in k_{eff} was evaluated for the following independent variables: wt % ^{235}U, rod pitch, H/U volume ratio, energy of the average neutron lethargy causing fission (EALCF), ^{10}B loading of the absorber sheet, and soluble boron loading. No statistically significant trends were found for any of the system parameters. USLs are, therefore, generated for each of the independent variables. A minimum USL covering the range of applicability of the benchmark set is determined as detailed in Section 6.5.2.

6.5.2 Results of Benchmark Calculations

To evaluate the relative importance of the trend analysis to the upper subcritical limits, correlation coefficients are required for all independent parameters. The linear correlation coefficient, R, is calculated by taking the square root of the R^2 value. In particular, the correlation coefficient, R, 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.

Table 6.5.2-2 contains the correlation coefficient, R, for each linear fit of k_{eff} versus experimental parameter. Linear fits and correlation constants are based on the 183 data-point evaluation sets plotted in Section 6.7.7. The cluster gap plot is limited to the 137 data points for experiments containing multiple fuel rod clusters. Single fuel rod cluster experiments documented in LEU-COMP-THERM sets 06, 14, 35 and 50, in addition to LEU-COMP-THERM experiments 01-01, 02-01 to -03, and 08-01 to -15, were therefore excluded from the cluster gap study. The 183 data points evaluated for the remaining parameters represent the complete set of experiments listed in Section 6.7.7 minus the three high energy lethargy experiments above 0.35 eV (Experiments LEU-COMP-THERM 14-05, -06 and -07). Addition of these points, while not resulting in a significant linear fit, produces a noticeable slope to the USL correlation not representative of the remaining data fits. As this increased slope results in a higher USL, it is acceptable to discard these data points. The three higher energy points are removed from all independent variables for consistency.

As there is no significant correlation to any of the independent variables, the USL for each independent variable is calculated and shown with its range of applicability in Table 6.5.2-2. A sample output for EALCF is shown in Figure 6.5.2-1. Uncertainties included in the USLSTATS evaluation are the Monte Carlo uncertainty associated with the reactivity calculation and experimental uncertainty that was provided in the literature for each of the cases.

Based on all the independent variable correlations, a lower limit constant USL of 0.9376 may be applied. The range of applicability (area of applicability) of this limit may be extended to 5 wt % enriched fuel, as the correlation shows no significant trend with enrichment between 2.35 and 4.74 wt %, and that the limited trending observed increases the USL. Extending the range of applicability for the average neutron lethargy is based on a minimal, but positive, trend of the USL versus EALCF. Studies, including additional data points up to 0.7722 eV, indicate that the trending continues to the higher energy levels.

Figure 6.5.2-1 USLSTATS Output for EALCF

```
*****************************************************************************
                        Version 1.4, April 23, 2003
                        Oak Ridge National Laboratory
*****************************************************************************
   Input to statistical treatment from file:enrich-183.in
Title: keff vs enrichment
   Proportion of the population = .995
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  183
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05
```

independent variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
2.35000E+00	9.94910E-01	3.42000E-03	2.35000E+00	9.95090E-01	3.46000E-03
2.35000E+00	9.92830E-01	3.38000E-03	2.35000E+00	9.92520E-01	3.47000E-03
2.35000E+00	9.98060E-01	3.38000E-03	2.35000E+00	9.95620E-01	3.50000E-03
2.35000E+00	9.96550E-01	3.42000E-03	2.35000E+00	9.93130E-01	3.55000E-03
2.35000E+00	9.89310E-01	3.44000E-03	2.35000E+00	9.98130E-01	3.58000E-03
2.35000E+00	9.95340E-01	3.41000E-03	2.35000E+00	9.96700E-01	3.56000E-03
2.35000E+00	9.93880E-01	3.44000E-03	2.35000E+00	9.93830E-01	3.55000E-03
2.35000E+00	9.89690E-01	3.36000E-03	2.35000E+00	9.92770E-01	3.47000E-03
4.30600E+00	9.95160E-01	2.79000E-03	2.35000E+00	9.92920E-01	3.50000E-03
4.30600E+00	9.93670E-01	2.54000E-03	2.35000E+00	9.96410E-01	3.46000E-03
4.30600E+00	9.96340E-01	2.76000E-03	2.35000E+00	9.93060E-01	3.49000E-03
4.30600E+00	9.93110E-01	2.64000E-03	2.35000E+00	9.96500E-01	3.45000E-03
4.30600E+00	9.93000E-01	2.49000E-03	2.35000E+00	9.94680E-01	3.50000E-03
2.59600E+00	9.92680E-01	2.10000E-03	2.35000E+00	9.93300E-01	3.47000E-03
2.59600E+00	9.93190E-01	2.14000E-03	2.35000E+00	9.91810E-01	3.46000E-03
2.59600E+00	9.92990E-01	2.13000E-03	2.35000E+00	9.93920E-01	3.47000E-03
2.59600E+00	9.94790E-01	2.13000E-03	2.35000E+00	9.95560E-01	3.55000E-03
2.59600E+00	9.93100E-01	2.12000E-03	2.35000E+00	9.94540E-01	3.51000E-03
2.59600E+00	9.93240E-01	2.12000E-03	2.35000E+00	9.94490E-01	3.47000E-03
2.59600E+00	9.91990E-01	2.12000E-03	2.35000E+00	9.91300E-01	3.52000E-03
2.59600E+00	9.93820E-01	2.12000E-03	2.35000E+00	9.94800E-01	3.47000E-03
2.59600E+00	9.94450E-01	2.12000E-03	2.35000E+00	9.93500E-01	3.60000E-03
2.59600E+00	9.95440E-01	2.13000E-03	2.35000E+00	9.94000E-01	3.45000E-03
2.59600E+00	9.94410E-01	2.12000E-03	2.35000E+00	9.96280E-01	3.53000E-03
2.59600E+00	9.93920E-01	2.15000E-03	2.35000E+00	9.92620E-01	3.45000E-03
2.59600E+00	9.95090E-01	2.14000E-03	2.35000E+00	9.94100E-01	3.53000E-03
2.59600E+00	9.93780E-01	2.12000E-03	2.35000E+00	9.96470E-01	3.52000E-03
2.59600E+00	9.95040E-01	2.14000E-03	2.35000E+00	9.93600E-01	3.47000E-03
2.59600E+00	9.94380E-01	2.11000E-03	2.35000E+00	9.97020E-01	3.49000E-03
2.59600E+00	9.95730E-01	2.12000E-03	2.35000E+00	9.94970E-01	3.50000E-03
2.59600E+00	9.94270E-01	2.14000E-03	2.35000E+00	9.91950E-01	3.55000E-03
2.45900E+00	9.98350E-01	1.34000E-03	2.59600E+00	9.93410E-01	1.93000E-03
2.45900E+00	9.96860E-01	1.36000E-03	2.59600E+00	9.91310E-01	2.05000E-03
2.45900E+00	9.99310E-01	1.24000E-03	4.73800E+00	9.95860E-01	4.36000E-03
2.45900E+00	9.97950E-01	1.36000E-03	4.73800E+00	9.93580E-01	4.53000E-03
2.45900E+00	9.97650E-01	1.38000E-03	4.73800E+00	9.95390E-01	4.58000E-03
2.45900E+00	9.96990E-01	1.35000E-03	4.73800E+00	9.92370E-01	4.54000E-03
2.45900E+00	9.97230E-01	1.37000E-03	4.73800E+00	9.91440E-01	4.62000E-03
2.45900E+00	9.96590E-01	1.40000E-03	4.73800E+00	9.98780E-01	4.82000E-03
2.45900E+00	9.95260E-01	1.40000E-03	4.73800E+00	9.94180E-01	4.94000E-03
2.45900E+00	9.97450E-01	1.36000E-03	4.73800E+00	9.92400E-01	4.90000E-03
2.45900E+00	9.97590E-01	1.38000E-03	4.73800E+00	9.96930E-01	4.98000E-03
2.45900E+00	9.97650E-01	1.36000E-03	4.73800E+00	9.91370E-01	5.05000E-03
2.45900E+00	9.98880E-01	1.39000E-03	2.35000E+00	9.92500E-01	2.34000E-03
2.45900E+00	9.97350E-01	1.37000E-03	2.35000E+00	9.95140E-01	2.43000E-03
2.45900E+00	9.97580E-01	1.39000E-03	2.35000E+00	9.92190E-01	2.33000E-03
2.45900E+00	9.97720E-01	1.39000E-03	2.35000E+00	9.94760E-01	2.40000E-03
2.45900E+00	9.96910E-01	1.35000E-03	2.35000E+00	9.94690E-01	3.67000E-03
4.30600E+00	9.95480E-01	2.84000E-03	2.35000E+00	9.94340E-01	2.49000E-03
4.30600E+00	9.93430E-01	2.78000E-03	2.35000E+00	9.93190E-01	2.39000E-03
4.30600E+00	9.93300E-01	2.81000E-03	4.73800E+00	9.93300E-01	1.28000E-03
4.30600E+00	9.93710E-01	2.85000E-03	4.73800E+00	9.93400E-01	1.23000E-03
4.30600E+00	9.95930E-01	2.73000E-03	4.73800E+00	9.94890E-01	1.25000E-03
4.30600E+00	9.92950E-01	2.85000E-03	4.73800E+00	9.93190E-01	1.25000E-03
4.30600E+00	9.96160E-01	2.89000E-03	4.73800E+00	9.93060E-01	1.28000E-03
4.30600E+00	9.93890E-01	2.73000E-03	2.45900E+00	9.91330E-01	2.03000E-03
4.30600E+00	9.95710E-01	2.96000E-03	2.45900E+00	9.95970E-01	2.43000E-03

Figure 6.5.2-1 USLSTATS Output for EALCF (cont'd)

```
4.30600E+00    9.93190E-01    2.60000E-03          2.45900E+00    9.95550E-01    2.42000E-03
4.30600E+00    9.93780E-01    2.75000E-03          2.45900E+00    9.94860E-01    2.42000E-03
4.30600E+00    9.92630E-01    2.84000E-03          2.45900E+00    9.95040E-01    2.42000E-03
4.30600E+00    9.95660E-01    2.75000E-03          2.45900E+00    9.95420E-01    2.42000E-03
4.30600E+00    9.94310E-01    2.82000E-03          2.45900E+00    9.95300E-01    2.42000E-03
4.30600E+00    9.96390E-01    2.95000E-03          2.45900E+00    9.95070E-01    2.42000E-03
4.30600E+00    9.96860E-01    2.79000E-03          2.45900E+00    9.93680E-01    1.93000E-03
4.30600E+00    9.97160E-01    2.68000E-03          2.45900E+00    9.92100E-01    1.93000E-03
4.30600E+00    9.92370E-01    2.86000E-03          2.45900E+00    9.94470E-01    1.93000E-03
4.30600E+00    9.97190E-01    2.81000E-03          2.45900E+00    9.90730E-01    1.93000E-03
4.30600E+00    9.94340E-01    2.76000E-03          2.45900E+00    9.86520E-01    2.23000E-03
4.30600E+00    9.96920E-01    2.79000E-03          2.45900E+00    9.86340E-01    1.93000E-03
4.30600E+00    9.96060E-01    2.83000E-03          2.45900E+00    9.90420E-01    2.42000E-03
4.30600E+00    9.97400E-01    2.94000E-03          2.45900E+00    9.89740E-01    2.03000E-03
4.30600E+00    9.92810E-01    2.69000E-03          2.45900E+00    9.91520E-01    2.72000E-03
4.30600E+00    9.92560E-01    2.88000E-03          2.45900E+00    9.90290E-01    2.13000E-03
4.30600E+00    9.93650E-01    2.88000E-03          2.45900E+00    9.89270E-01    1.93000E-03
4.30600E+00    9.94970E-01    2.85000E-03          2.60000E+00    9.95710E-01    1.42000E-03
2.45900E+00    9.94820E-01    3.21000E-03          2.60000E+00    9.96180E-01    1.42000E-03
2.45900E+00    9.94940E-01    3.21000E-03          2.60000E+00    9.95340E-01    1.52000E-03
2.45900E+00    9.95140E-01    3.21000E-03          2.60000E+00    9.95470E-01    1.52000E-03
2.45900E+00    9.95640E-01    3.21000E-03          2.60000E+00    9.96910E-01    1.42000E-03
2.45900E+00    9.95080E-01    3.21000E-03          2.60000E+00    9.96140E-01    1.42000E-03
2.45900E+00    9.95260E-01    3.21000E-03          2.60000E+00    9.95890E-01    1.42000E-03
2.45900E+00    9.95200E-01    3.21000E-03          2.60000E+00    9.96240E-01    1.62000E-03
4.30600E+00    9.94020E-01    1.92000E-03          2.60000E+00    9.96670E-01    1.52000E-03
4.30600E+00    9.94460E-01    1.91000E-03          2.60000E+00    9.96760E-01    1.62000E-03
4.30600E+00    9.93550E-01    1.91000E-03          2.60000E+00    9.96370E-01    1.62000E-03
4.30600E+00    9.94010E-01    1.91000E-03          2.60000E+00    9.96430E-01    1.72000E-03
4.30600E+00    9.92810E-01    3.27000E-03          2.60000E+00    9.97010E-01    1.62000E-03
4.30600E+00    9.94960E-01    1.91000E-03          2.60000E+00    9.96500E-01    1.62000E-03
4.30600E+00    9.93780E-01    1.90000E-03          2.60000E+00    9.96340E-01    1.62000E-03
4.30600E+00    9.96680E-01    1.95000E-03          2.60000E+00    9.96580E-01    1.71000E-03
4.30600E+00    9.85950E-01    7.71000E-03          2.60000E+00    9.96450E-01    1.62000E-03
2.35000E+00    9.94940E-01    3.54000E-03
chi =  2.5464 (upper bound = 9.49). The data tests normal.
      Output from statistical treatment
keff vs enrichment
 Number of data points (n)                          183
 Linear regression, k(X)                            0.9950 + (-1.5719E-04)*X
 Confidence on fit (1-gamma) [input]                 95.0%
 Confidence on proportion (alpha) [input]            95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]              99.5%
 Minimum value of X                                  2.3500E+00
 Maximum value of X                                  4.7380E+00
 Average value of X                                  3.0597E+00
 Average value of k                                   0.99453
 Minimum value of k                                   0.98595
 Variance of fit, s(k,X)^2                           5.0408E-06
 Within variance, s(w)^2                             7.8633E-06
 Pooled variance, s(p)^2                             1.2904E-05
 Pooled std. deviation, s(p)                         3.5922E-03
 C(alpha,rho)*s(p)                                   1.5554E-02
 student-t @ (n-2,1-gamma)                           1.64500E+00
 Confidence band width, W                            5.9793E-03
 Minimum margin of subcriticality, C*s(p)-W          9.5746E-03

 Upper subcritical limits: (  2.3500     <= X <=   4.7380    )
 ***** *********** *******
 USL Method 1 (Confidence Band with
 Administrative Margin)             USL1 = 0.9390 + (-1.5719E-04)*X
 USL Method 2 (Single-Sided Uniform
 Width Closed Interval Approach)    USL2 = 0.9795 + (-1.5719E-04)*X
 USLs Evaluated Over Range of Parameter X:
 **** ********* **** ***** ** ********* **

 X:  2.35E+0  2.69E+0  3.03E+0  3.37E+0  3.71E+0  4.06E+0  4.40E+0  4.74E+0
    ---------------------------------------------------------------------------
USL-1:   0.9387   0.9386   0.9386   0.9385   0.9385   0.9384   0.9383   0.9383
USL-2:   0.9791   0.9790   0.9790   0.9789   0.9789   0.9788   0.9788   0.9787
    ---------------------------------------------------------------------------
```

Table 6.5.2-1 Range of Applicability for Complete Set of 186 Benchmark Experiments

Parameter	Minimum	Maximum
Enrichment (wt % ^{235}U)	2.350%	4.738%
Fuel rod pitch (cm)	1.30	2.54
Fuel pellet outer diameter (cm)	0.790	1.265
Fuel rod diameter (cm)	0.9400	1.4172
$H/^{235}U$ atom ratio	72.7	403.9
Soluble boron (ppm by weight)	0	4986
Cluster Gap (cm)	1.206	13.750
Boron (^{10}B) plate loading (g/cm^2)	0.0000	0.0670
Energy of average neutron lethargy causing fission (eV)	0.09781	0.77219

Table 6.5.2-2 Correlation Coefficients and USLs for Benchmark Experiments

Variable	R^2	R	Range of Applicability	USLSTATS Correlation	USL Low	USL High
Enrichment (wt% ^{235}U)	0.00410	0.064	2.35<=X<=4.738	0.9390+-1.57E-04X	0.9382	0.9386
Fuel rod pitch (cm)	0.00150	0.039	1.3<=X<=2.54	0.9380+2.64E-04X	0.9383	0.9386
Fuel pellet outer diameter (cm)	0.00260	0.051	0.79<=X<=1.265	0.9376+8.25E-04X	0.9382	0.9386
Fuel rod diameter (cm)	0.00380	0.062	0.94<=X<=1.4172	0.9372+1.01E-03X	0.9381	0.9386
$H/^{235}U$ atom ratio	3.00E-06	0.002	106.2<=X<=403.9	0.9386-4.74E-08X	0.9385	0.9385
Soluble boron (ppm by weight)	0.01730	0.132	0<=X<=4986	0.9379+3.96E-07X	0.9379	0.9398
Cluster gap (cm)	0.01940	0.139	1.2<=X<=13.8	0.9375+9.82E-05X	0.9376	0.9388
Boron (^{10}B) plate loading (g/cm^2)	0.00006	0.008	0<=X<=0.067	0.9382-1.37E-03X	0.9381	0.9382
Energy of average neutron lethargy causing fission (eV)	0.00900	0.095	0.09781<=X<=0.3447	0.9379+3.45E-03X	0.9382	0.9390

6.6 References

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3. "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5," X-5 Monte Carlo Team, Los Alamos National Laboratory, Los Alamos, NM, April 24, 2003.
4. CC-710/MCNP: Data Libraries for MCNP5, "MCNP5 DATA: Standard Neutron, Photoatomic, Photonuclear, and Electron Data Libraries for MCNP5," February 2003.
5. CCC-545-NUREG/CR-0200, "Standard Composition Library," Petrie, L.M., et al., Rev. 6, Volume 3 Section M8, September 1998.
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9. NUREG/CR-6716, "Recommendations on Fuel Parameters for Standard Technical Specifications for Spent Fuel Storage Casks," US Nuclear Regulatory Commission, Washington, DC, March 2001.
10. NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages," US Nuclear Regulatory Commission, Washington, DC, March 1997.

6.7 Criticality Evaluation Detail

This section contains evaluation detail not found in the preceding sections.

6.7.1 PWR Model Details

The PWR system payload consists of 37 fuel assemblies that are placed into 37 openings formed by a combination of 21 fuel tubes, and 4 side and corner weldments. Discussion of the criticality model for the damaged fuel basket is included in Section 6.7.8.

Fuel assemblies are built within MCNP using rectangular parallelepipeds (RPP), right circular cylinders (RCC), and the lattice (array) feature. RPPs form the general assembly outline and end-fitting region. RCCs form the fuel rod and tube structure. The lattice structure simplifies the placement of fuel rods, instrument tubes, and guide tubes. Fuel rods are modeled as a solid fuel stack, no chamfering or dishing, a pellet to clad and plenum gap, and clad with end-plugs. Guide tubes and instrument tubes connect the top- and bottom-end fittings. For assemblies containing single lattice location instrument tubes and guide tubes, the tubes are individually modeled as Universes, similar to fuel rods, and placed within the lattice. For assemblies containing oversize guide tubes (e.g., CE core assembly size), guide and instrument tubes are inserted into the assembly model, composed of end-fitting and a space for the rod lattice, with the fuel rod lattice filling in the remaining space. Nonfuel assembly inserts are modeled by replacing the interior material definition of the guide tubes by zirconium alloy. By using a zirconium-based alloy in the tubes, no credit is taken for any remaining absorber properties of the rods. Modeling the nonfuel insert in the guide tubes bounds a configuration with nonfuel material loaded into the instrument tube active fuel region, but not guide tubes, as assemblies contain a single instrument tube versus multiple guide tubes.

Dimensioned fuel tubes forming the base configuration of the basket are shown in Figure 6.7.1-1. In the MCNP model, each of the fuel tubes is composed of a set of RPPs. One RPP is rotated 45 degrees from the chamfer on each tube corner that allows the stacking of the 21 tubes into the basket array. Neutron absorber sheet locations are limited to fuel tubes only; no absorber is located on corner and side weldments. The neutron absorber is held in place by a combination of a cover sheet (retainer) and weld posts. The weld posts, and slots for weld posts in both tube and absorber sheet, are explicitly modeled in the analysis. A cross-section of the assembled PWR basket is shown in Figure 6.7.1-2.

All fuel tubes are initially modeled as containing four neutron absorber sheets with weld post locations along the tube face for the criticality evaluations associated with maximum reactivity payload and basket configuration and optimum moderation. Final system configuration increases the number of weld posts and allows the removal of the neutron absorber sheets or replacement by aluminum sheets at up to 16 locations on the basket periphery. The reduction in the number of absorber sheets does not affect system reactivity, as demonstrated in Section

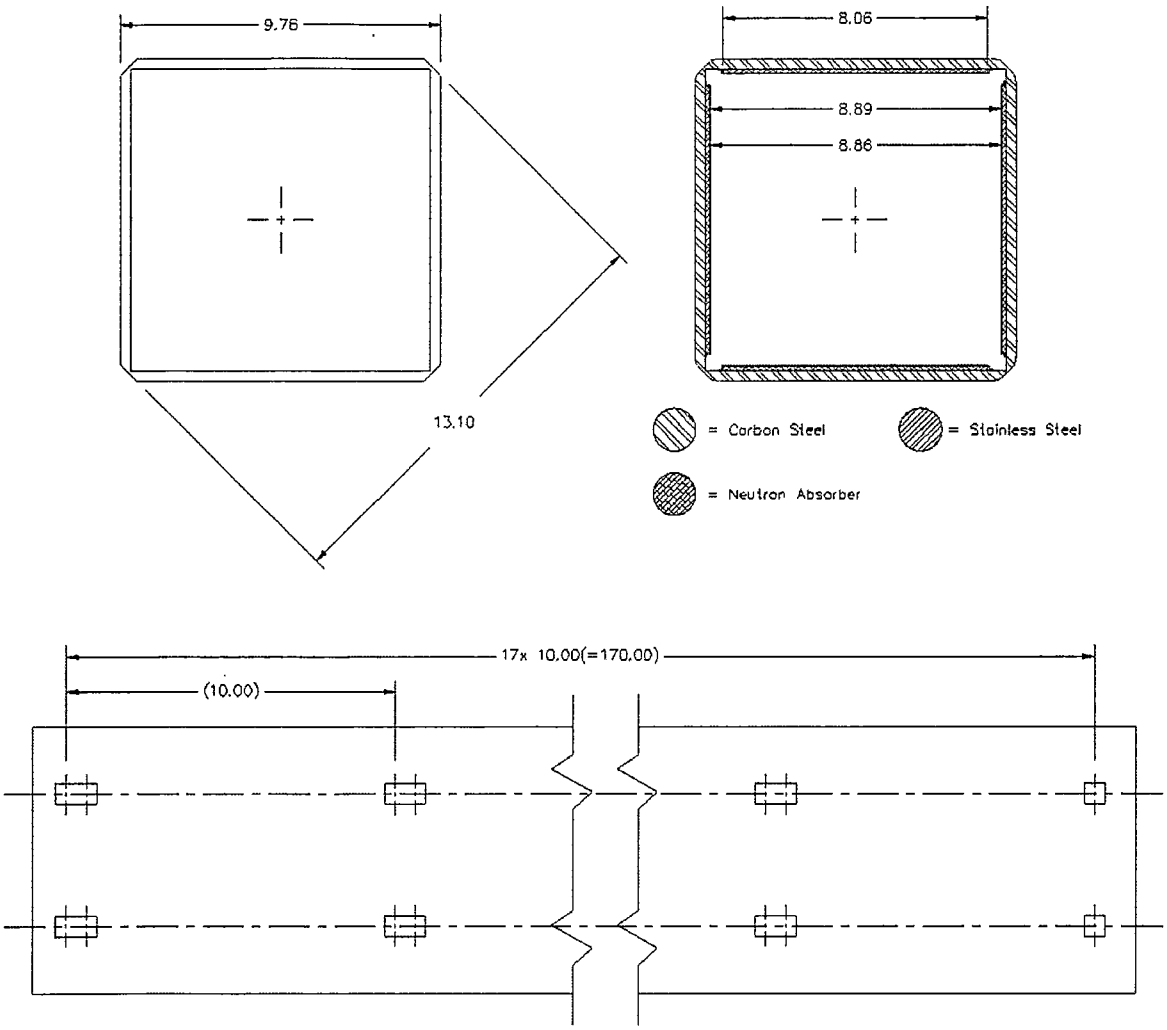
6.7.3.1. Similarly, an additional column of weld posts has no significant effect on system reactivity as shown in Section 6.7.3.1. Since the combination of a reduced number of absorber sheets and an increase in the number of weld posts has the potential for increasing k_{eff} slightly above the statistically significant level threshold, the maximum enrichments and k_{eff} in Section 6.7.3.2 are calculated using a model incorporating both design attributes.

Fuel tubes are connected by a pin design and restraint on the basket periphery by the side and corner weldment. Pins space the basket axially and provide free flow area for basket draining and natural convection cooling. The basket design will not permit preferential flooding of the basket. All tubes are designed to drain simultaneously.

To assure proper initial sampling of the fission source and to accelerate code convergence, all analyses rely on an SDEF source distribution sampling the fissile material in the cask uniformly.

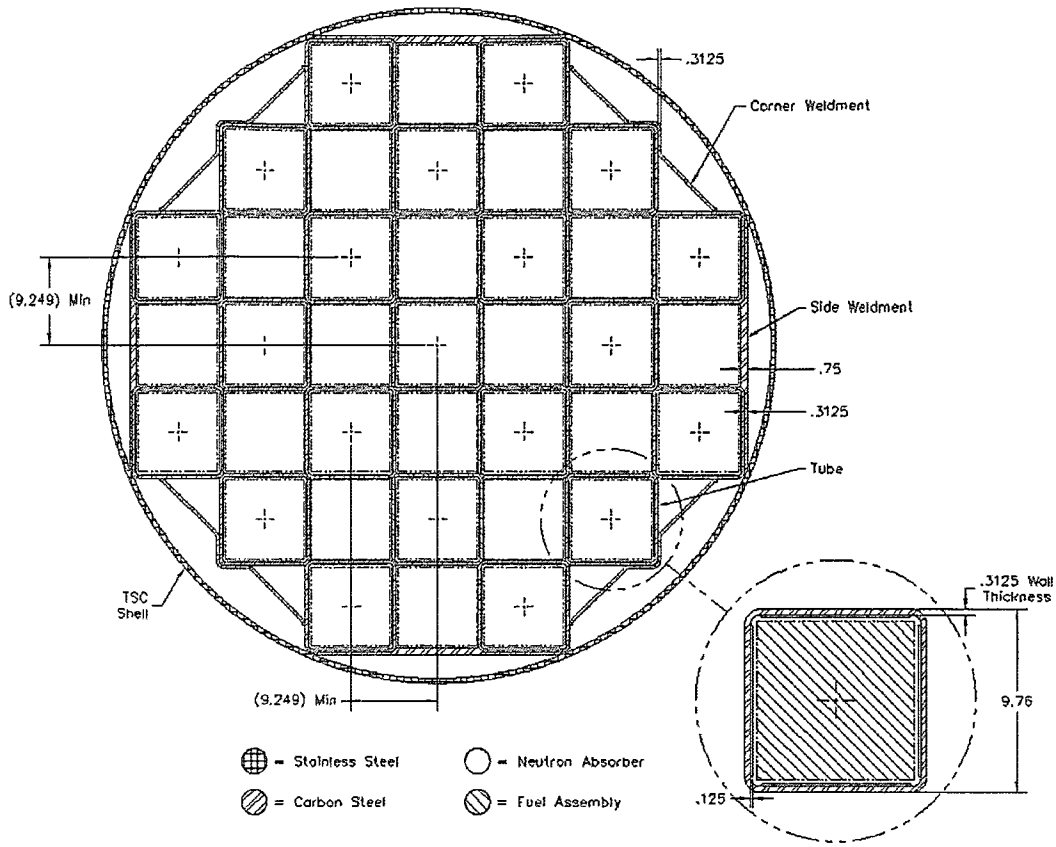
Sample input files for the transfer cask and storage cask models are shown in Figure 6.7.1-3 and Figure 6.7.1-4, respectively. The inputs provided represent the maximum reactivity configuration and include the minimum cell spacing, replacement of the optional peripheral absorbers by aluminum sheets, and the full number of weld posts illustrated in the licensing drawings. Figure 6.7.1-3 contains a Westinghouse fuel assembly payload. The storage cask input contains a model loaded with a CE core fuel assembly and displays model changes required for the CE fuel design and cask overpack.

Figure 6.7.1-1 PWR Fuel Tubes



Note: Dimensions in inches.
Number of attachments shown is for longer (Group 2) canister length.

Figure 6.7.1-2 PWR Basket Structure



Notes:

1. Dimensions in inches.
2. Assembly fuel pin array is explicitly modeled. Shown as homogenized area for illustration purposes only.
3. Represents square tube basket aligned at 45° with 13.08-inch minimum interface (diagonal flat-to-flat) width.

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
Transfer Cask Model - WE17H1
c
c  MAGNASTOR Canister Class 1
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c
c   Boron Content in Water - 2000 ppm
c   Cavity Water Density 1.0017 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Model Revision 4.70
c
c Cells - Fuel Rod - WE17H1 - WE Core - 17x17
1 1 -1.0522E+01 -1   u=12 $ Fuel
2 13 -0.9982 -2 +1  u=12 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=12 $ Clad + End Plugs
4 3 -1.0017 +3   u=12 $ Outside Fuel Rod
c Cells - Guide Tube - WE17H1 - WE Core - 17x17
5 2 -6.5600 -5       u=11 $ Inside Guide Tube
6 2 -6.56 -6 +5      u=11 $ Guide Tube
7 3 -1.0017 +6       u=11 $ Outside Guide Tube
c Cell Cards Instrument Tube - WE17H1 - WE Core - 17x17
8 3 -1.0017 -8       u=10 $ Inside Inst. Tube
9 2 -6.56 -9 +8      u=10 $ Inst. Tube
10 3 -1.0017 +9       u=10 $ Outside Inst. Tube
c Array_17x17_264
13 3 -1.0017 -13 +14 -15 +16
      trcl=(0 0 6.858)   lat=1 u=9 fill=-8:8 -8:8 0:0
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 12 12 11 12 12 11 12 12 11 12 12 12 12 12
      12 12 12 11 12 12 12 12 12 12 12 12 12 11 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 11 12 12 11 12 12 11 12 12 11 12 12 11 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 11 12 12 11 12 12 10 12 12 11 12 12 11 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 11 12 12 11 12 12 11 12 12 11 12 12 11 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 11 12 12 12 12 12 12 12 12 12 11 12 12 12
      12 12 12 12 12 11 12 12 11 12 12 11 12 12 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
      12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
c Cells - Fuel Assembly Array Inserted Into Assembly - cellPWRAssy
17 3 -1.0017 -17      fill=9 u=8 $ Array
18 3 -1.0017 -18 +17 -17.6 -17.5    u=8 $ Fuel Width Envelope
19 4 -2.6429 -18  +17.6     u=8 $ Lower Nozzle
20 5 -2.6082 -18   +17.5    u=8 $ Upper Nozzle
21 3 -1.0017 +18       u=8 $ Remaining Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=7 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=7 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=7 $ Absorber +Y
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=7 $ Absorber Clad  +Y
105 6 -7.940 -105     u=7 $ Retainer -Y
106 6 -7.940 -106     u=7 $ Retainer+Y
107 6 -7.940 -102
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=7 $ Weld Post in Absorber -Y
108 3 -1.0017 -102 #101  #102  #107   u=7 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=7 $ Weld Post in Absorber +Y
110 3 -1.0017 -104 #103  #104  #109   u=7 $ Gap Weld Post to Absorber +Y
111 12 -2.358 -210  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=7 $ Absorber -X
112 7 -2.702 -211 +210 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=7 $ Absorber Clad  -X
113 12 -2.358 -212  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=7 $ Absorber +X
114 7 -2.702 -213 +212 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=7 $ Absorber Clad  +X
115 6 -7.940 -214     u=7 $ Retainer -X
116 6 -7.940 -215     u=7 $ Retainer+X
117 6 -7.940 -211
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=7 $ Weld Post in Absorber -X
118 3 -1.0017 -211 #111  #112  #117   u=7 $ Gap Weld Post to Absorber -X
119 6 -7.940 -213
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=7 $ Weld Post in Absorber
120 3 -1.0017 -213 #113  #114  #119   u=7 $ Gap Weld Post to Absorber +X
121 3 -1.0017 -319
       +102 +104 +105 +106
       +211 +213 +214 +215     u=7 $ Space in Tube
122 8 -7.821 -320 +319
       +141 +142 +143 +144 +145 +146 +147 +148 +149
       +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162 +163 +164 +165 +166
       +167 +168 +169 +170 +171 +172 +173 +174
       +250 +251 +252 +253 +254 +255 +256 +257 +258
       +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283     +209 +318 u=7 $ Fuel Tube
123 6 -7.940 -320 +319
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208:
       -284:-285:-286:-287:-288:-289:-290:-291:-292:
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
       -293:-294:-295:-296:-297:-298:-299:-300:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317)      u=7 $ Fuel Tube Weld Posts
124 3 -1.0017 -320 +319  #122  #123
             u=7 $ Space Around Weld Posts
125 3 -1.0017 +319 +320    u=7 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=6 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=6 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=6 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=6 $ Absorber Clad  +Y
130 6 -7.940 -105     u=6 $ Retainer -Y
131 6 -7.9400 -106     u=6 $ Retainer+Y
132 6 -7.940 -102
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=6 $ Weld Post in Absorber -Y
133 3 -1.0017 -102 #126  #127  #132   u=6 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=6 $ Weld Post in Absorber +Y
135 3 -1.0017 -104 #128  #129  #134   u=6 $ Gap Weld Post to Absorber +Y
136 12 -2.358 -210  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=6 $ Absorber -X
137 7 -2.702 -211 +210 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=6 $ Absorber Clad  -X
138 7 -2.7020 -212  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=6 $ Absorber +X
139 7 -2.7020 -213 +212 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=6 $ Absorber Clad  +X
140 6 -7.940 -214     u=6 $ Retainer -X
141 6 -7.9400 -215     u=6 $ Retainer+X
142 6 -7.940 -211
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=6 $ Weld Post in Plate-X
143 3 -1.0017 -211 #136  #137  #142   u=6 $ Gap Weld Post to Plate -X
144 6 -7.9400 -213
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=6 $ Weld Post in Plate +X
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
145 3 -1.0017 -213 #138  #139  #144   u=6 $ Gap Weld Post to Plate +X
146 3 -1.0017 -319
      +102 +104 +105 +106
      +211 +213 +214 +215     u=6 $ Space in Tube
147 8 -7.821 -320 +319
      +141 +142 +143 +144 +145 +146 +147 +148 +149
      +150 +151 +152 +153 +154 +155 +156 +157
      +158 +159 +160 +161 +162 +163 +164 +165 +166
      +167 +168 +169 +170 +171 +172 +173 +174
      +250 +251 +252 +253 +254 +255 +256 +257 +258
      +259 +260 +261 +262 +263 +264 +265 +266
      +267 +268 +269 +270 +271 +272 +273 +274 +275
      +276 +277 +278 +279 +280 +281 +282 +283     +209 +318 u=6 $ Fuel Tube
148 6 -7.940 -320 +319
      (-175:-176:-177:-178:-179:-180:-181:-182:-183:
      -184:-185:-186:-187:-188:-189:-190:-191:
      -192:-193:-194:-195:-196:-197:-198:-199:-200:
      -201:-202:-203:-204:-205:-206:-207:-208:
      -284:-285:-286:-287:-288:-289:-290:-291:-292:
      -293:-294:-295:-296:-297:-298:-299:-300:
      -301:-302:-303:-304:-305:-306:-307:-308:-309:
      -310:-311:-312:-313:-314:-315:-316:-317)      u=6 $ Fuel Tube Weld Posts
149 3 -1.0017 -320 +319  #147  #148
            u=6 $ Space Around Weld Posts
150 3 -1.0017 +319 +320    u=6 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=5 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=5 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=5 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=5 $ Absorber Clad  +Y
155 6 -7.940 -105     u=5 $ Retainer -Y
156 6 -7.9400 -106     u=5 $ Retainer+Y
157 6 -7.940 -102
      (-175:-176:-177:-178:-179:-180:-181:-182:-183:
      -184:-185:-186:-187:-188:-189:-190:-191:
      -192:-193:-194:-195:-196:-197:-198:-199:-200:
      -201:-202:-203:-204:-205:-206:-207:-208)      u=5 $ Weld Post in Absorber -Y
158 3 -1.0017 -102 #151  #152  #157   u=5 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
      (-175:-176:-177:-178:-179:-180:-181:-182:-183:
      -184:-185:-186:-187:-188:-189:-190:-191:
      -192:-193:-194:-195:-196:-197:-198:-199:-200:
      -201:-202:-203:-204:-205:-206:-207:-208)      u=5 $ Weld Post in Absorber +Y
160 3 -1.0017 -104 #153  #154  #159   u=5 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -210  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=5 $ Absorber -X
162 7 -2.7020 -211 +210 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=5 $ Absorber Clad  -X
163 12 -2.358 -212  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=5 $ Absorber +X
164 7 -2.702 -213 +212 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=5 $ Absorber Clad  +X
165 6 -7.9400 -214     u=5 $ Retainer -X
166 6 -7.940 -215     u=5 $ Retainer+X
167 6 -7.9400 -211
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=5 $ Weld Post in Plate-X
168 3 -1.0017 -211 #161  #162  #167   u=5 $ Gap Weld Post to Plate -X
169 6 -7.940 -213
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=5 $ Weld Post in Plate +X
170 3 -1.0017 -213 #163  #164  #169   u=5 $ Gap Weld Post to Plate +X
171 3 -1.0017 -319
       +102 +104 +105 +106
       +211 +213 +214 +215     u=5 $ Space in Tube
172 8 -7.821 -320 +319
       +141 +142 +143 +144 +145 +146 +147 +148 +149
       +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162 +163 +164 +165 +166
       +167 +168 +169 +170 +171 +172 +173 +174
       +250 +251 +252 +253 +254 +255 +256 +257 +258
       +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283     +209 +318 u=5 $ Fuel Tube
173 6 -7.940 -320 +319
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208:
       -284:-285:-286:-287:-288:-289:-290:-291:-292:
       -293:-294:-295:-296:-297:-298:-299:-300:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317)      u=5 $ Fuel Tube Weld Posts
174 3 -1.0017 -320 +319  #172  #173
             u=5 $ Space Around Weld Posts
175 3 -1.0017 +319 +320    u=5 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=4 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=4 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=4 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=4 $ Absorber Clad  +Y
180 6 -7.9400 -105     u=4 $ Retainer -Y
181 6 -7.940 -106     u=4 $ Retainer+Y
182 6 -7.9400 -102
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=4 $ Weld Post in Absorber -Y
183 3 -1.0017 -102 #176  #177  #182   u=4 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=4 $ Weld Post in Absorber +Y
185 3 -1.0017 -104 #178  #179  #184   u=4 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -210  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=4 $ Absorber -X
187 7 -2.7020 -211 +210 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=4 $ Absorber Clad  -X
188 12 -2.358 -212  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=4 $ Absorber +X
189 7 -2.702 -213 +212 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=4 $ Absorber Clad  +X
190 6 -7.9400 -214     u=4 $ Retainer -X
191 6 -7.940 -215     u=4 $ Retainer+X
192 6 -7.9400 -211
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=4 $ Weld Post in Plate-X
193 3 -1.0017 -211 #186  #187  #192   u=4 $ Gap Weld Post to Plate -X
194 6 -7.940 -213
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=4 $ Weld Post in Plate +X
195 3 -1.0017 -213 #188  #189  #194   u=4 $ Gap Weld Post to Plate +X
196 3 -1.0017 -319
       +102 +104 +105 +106
       +211 +213 +214 +215     u=4 $ Space in Tube
197 8 -7.821 -320 +319
       +141 +142 +143 +144 +145 +146 +147 +148 +149
       +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162 +163 +164 +165 +166
       +167 +168 +169 +170 +171 +172 +173 +174
       +250 +251 +252 +253 +254 +255 +256 +257 +258
       +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283     +209 +318 u=4 $ Fuel Tube
198 6 -7.940 -320 +319
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208:
       -284:-285:-286:-287:-288:-289:-290:-291:-292:
       -293:-294:-295:-296:-297:-298:-299:-300:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317)      u=4 $ Fuel Tube Weld Posts
199 3 -1.0017 -320 +319  #197  #198
             u=4 $ Space Around Weld Posts
200 3 -1.0017 +319 +320    u=4 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=3 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=3 $ Absorber Clad  -Y
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=3 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123
          +124 +125 +126 +127 +128 +129 +130 +131 +132
          +133 +134 +135 +136 +137 +138 +139 +140  +209 u=3 $ Absorber Clad  +Y
205 6 -7.9400 -105     u=3 $ Retainer -Y
206 6 -7.940 -106     u=3 $ Retainer+Y
207 6 -7.9400 -102
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=3 $ Weld Post in Absorber -Y
208 3 -1.0017 -102 #201  #202  #207   u=3 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-175:-176:-177:-178:-179:-180:-181:-182:-183:
       -184:-185:-186:-187:-188:-189:-190:-191:
       -192:-193:-194:-195:-196:-197:-198:-199:-200:
       -201:-202:-203:-204:-205:-206:-207:-208)      u=3 $ Weld Post in Absorber +Y
210 3 -1.0017 -104 #203  #204  #209   u=3 $ Gap Weld Post to Absorber +Y
211 12 -2.358 -210  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=3 $ Absorber -X
212 7 -2.702 -211 +210 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=3 $ Absorber Clad  -X
213 7 -2.7020 -212  +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=3 $ Absorber +X
214 7 -2.7020 -213 +212 +216 +217 +218 +219 +220 +221 +222 +223 +224
          +225 +226 +227 +228 +229 +230 +231 +232
          +233 +234 +235 +236 +237 +238 +239 +240 +241
          +242 +243 +244 +245 +246 +247 +248 +249  +318 u=3 $ Absorber Clad  +X
215 6 -7.940 -214     u=3 $ Retainer -X
216 6 -7.9400 -215     u=3 $ Retainer+X
217 6 -7.940 -211
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=3 $ Weld Post in Plate-X
218 3 -1.0017 -211 #211  #212  #217   u=3 $ Gap Weld Post to Plate -X
219 6 -7.9400 -213
       (-284:-285:-286:-287:-288:-289:-290:-291:-292:
       -301:-302:-303:-304:-305:-306:-307:-308:-309:
       -310:-311:-312:-313:-314:-315:-316:-317:
       -293:-294:-295:-296:-297:-298:-299:-300)      u=3 $ Weld Post in Plate +X
220 3 -1.0017 -213 #213  #214  #219   u=3 $ Gap Weld Post to Plate +X
221 3 -1.0017 -319
       +102 +104 +105 +106
       +211 +213 +214 +215     u=3 $ Space in Tube
222 8 -7.821 -320 +319
       +141 +142 +143 +144 +145 +146 +147 +148 +149
       +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162 +163 +164 +165 +166
       +167 +168 +169 +170 +171 +172 +173 +174
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
      +250 +251 +252 +253 +254 +255 +256 +257 +258
      +259 +260 +261 +262 +263 +264 +265 +266
      +267 +268 +269 +270 +271 +272 +273 +274 +275
      +276 +277 +278 +279 +280 +281 +282 +283     +209 +318 u=3 $ Fuel Tube
223 6 -7.940 -320 +319
      (-175:-176:-177:-178:-179:-180:-181:-182:-183:
      -184:-185:-186:-187:-188:-189:-190:-191:
      -192:-193:-194:-195:-196:-197:-198:-199:-200:
      -201:-202:-203:-204:-205:-206:-207:-208:
      -284:-285:-286:-287:-288:-289:-290:-291:-292:
      -293:-294:-295:-296:-297:-298:-299:-300:
      -301:-302:-303:-304:-305:-306:-307:-308:-309:
      -310:-311:-312:-313:-314:-315:-316:-317)      u=3 $ Fuel Tube Weld Posts
224 3 -1.0017 -320 +319  #222  #223
            u=3 $ Space Around Weld Posts
225 3 -1.0017 +319 +320    u=3 $ Exterior Space
C Cells - Basket
401 3 -1.0017 -401 -402 fill=5 *trcl=( -23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 1
402 like 401 but     fill=6 *trcl=( 23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 2
403 like 401 but     fill=7 *trcl=( -46.9849 46.9849 0.0000 )   u=2 $ Tube Loc 3
404 like 401 but     fill=7 *trcl=( 0.0000 46.9849 0.0000 )   u=2 $ Tube Loc 4
405 like 401 but     fill=7 *trcl=( 46.9849 46.9849 0.0000 )   u=2 $ Tube Loc 5
406 like 401 but     fill=5 *trcl=( -70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 6
407 like 401 but     fill=7 *trcl=( -23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 7
408 like 401 but     fill=7 *trcl=( 23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 8
409 like 401 but     fill=6 *trcl=( 70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 9
410 like 401 but     fill=7 *trcl=( -46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 10
411 like 401 but     fill=7 *trcl=( 0.0000 0.0000 0.0000 )   u=2 $ Tube Loc 11
412 like 401 but     fill=7 *trcl=( 46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 12
413 like 401 but     fill=4 *trcl=( -70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 13
414 like 401 but     fill=7 *trcl=( -23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 14
415 like 401 but     fill=7 *trcl=( 23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 15
416 like 401 but     fill=3 *trcl=( 70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 16
417 like 401 but     fill=7 *trcl=( -46.9849 -46.9849 0.0000 )   u=2 $ Tube Loc 17
418 like 401 but     fill=7 *trcl=( 0.0000 -46.9849 0.0000 )   u=2 $ Tube Loc 18
419 like 401 but     fill=7 *trcl=( 46.9849 -46.9849 0.0000 )   u=2 $ Tube Loc 19
420 like 401 but     fill=4 *trcl=( -23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 20
421 like 401 but     fill=3 *trcl=( 23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 21
422 8 -7.821 -403 +404
                #401  #402  #420  #421    u=2 $ Side Weldment Y
423 8 -7.821 -405 +406
                #406  #413  #409  #416    u=2 $ Side Weldment X
424 8 -7.821 -407 +408 -409 +411
                #402   #409  #413   #420
                #401   #406  #416   #421  u=2 $ Corner Weldment Part 1
425 8 -7.821 -410 +411 +407    u=2 $ Corner Weldment Part 2
426 8 -7.821 -412 +413 +407    u=2 $ Corner Weldment Part 3A
427 8 -7.821 -414 +415 +407    u=2 $ Corner Weldment Part 3B
428 3 -1.0017 #401 #402 #403 #404 #405 #406 #407 #408 #409 #410 #411
      #412 #413 #414 #415 #416 #417 #418 #419 #420 #421
      #422  #423
      #424 #425 #426 #427         u=2 $ Remaining Space
c Cell Cards - Canister
501 3 -1.0017 -18 fill=8 *trcl=( -23.0621 70.0470 0.0000 )    u=1 $ Assy loc 1
502 like 501 but     *trcl=( 23.0621 70.0470 0.0000 )    u=1 $ Assy loc 2
503 like 501 but     *trcl=( -46.5546 46.5546 0.0000 )    u=1 $ Assy loc 3
504 like 501 but     *trcl=( 0.0000 46.5546 0.0000 )    u=1 $ Assy loc 4
505 like 501 but     *trcl=( 46.5546 46.5546 0.0000 )    u=1 $ Assy loc 5
506 like 501 but     *trcl=( -70.0470 23.0621 0.0000 )    u=1 $ Assy loc 6
507 like 501 but     *trcl=( -23.0621 23.0621 0.0000 )    u=1 $ Assy loc 7
508 like 501 but     *trcl=( 23.0621 23.0621 0.0000 )    u=1 $ Assy loc 8
509 like 501 but     *trcl=( 70.0470 23.0621 0.0000 )    u=1 $ Assy loc 9
510 like 501 but     *trcl=( -46.5546 0.0000 0.0000 )    u=1 $ Assy loc 10
511 like 501 but     *trcl=( 0.0000 0.0000 0.0000 )    u=1 $ Assy loc 11
512 like 501 but     *trcl=( 46.5546 0.0000 0.0000 )    u=1 $ Assy loc 12
513 like 501 but     *trcl=( -70.0470 -23.0621 0.0000 )    u=1 $ Assy loc 13
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
514 like 501 but     *trcl=( -23.0621 -23.0621 0.0000 )    u=1 $ Assy loc 14
515 like 501 but     *trcl=( 23.0621 -23.0621 0.0000 )    u=1 $ Assy loc 15
516 like 501 but     *trcl=( 70.0470 -23.0621 0.0000 )    u=1 $ Assy loc 16
517 like 501 but     *trcl=( -46.5546 -46.5546 0.0000 )    u=1 $ Assy loc 17
518 like 501 but     *trcl=( 0.0000 -46.5546 0.0000 )    u=1 $ Assy loc 18
519 like 501 but     *trcl=( 46.5546 -46.5546 0.0000 )    u=1 $ Assy loc 19
520 like 501 but     *trcl=( -23.0621 -70.0470 0.0000 )    u=1 $ Assy loc 20
521 like 501 but     *trcl=( 23.0621 -70.0470 0.0000 )    u=1 $ Assy loc 21
522 like 501 but     *trcl=( 0.0000 70.0560 0.0000 )    u=1 $ Assy loc 22
523 like 501 but     *trcl=( -23.0711 46.5636 0.0000 )    u=1 $ Assy loc 23
524 like 501 but     *trcl=( 23.0711 46.5636 0.0000 )    u=1 $ Assy loc 24
525 like 501 but     *trcl=( -46.5636 23.0711 0.0000 )    u=1 $ Assy loc 25
526 like 501 but     *trcl=( 0.0000 23.0711 0.0000 )    u=1 $ Assy loc 26
527 like 501 but     *trcl=( 46.5636 23.0711 0.0000 )    u=1 $ Assy loc 27
528 like 501 but     *trcl=( -70.0560 0.0000 0.0000 )    u=1 $ Assy loc 28
529 like 501 but     *trcl=( -23.0711 0.0000 0.0000 )    u=1 $ Assy loc 29
530 like 501 but     *trcl=( 23.0711 0.0000 0.0000 )    u=1 $ Assy loc 30
531 like 501 but     *trcl=( 70.0560 0.0000 0.0000 )    u=1 $ Assy loc 31
532 like 501 but     *trcl=( -46.5636 -23.0711 0.0000 )    u=1 $ Assy loc 32
533 like 501 but     *trcl=( 0.0000 -23.0711 0.0000 )    u=1 $ Assy loc 33
534 like 501 but     *trcl=( 46.5636 -23.0711 0.0000 )    u=1 $ Assy loc 34
535 like 501 but     *trcl=( -23.0711 -46.5636 0.0000 )    u=1 $ Assy loc 35
536 like 501 but     *trcl=( 23.0711 -46.5636 0.0000 )    u=1 $ Assy loc 36
537 like 501 but     *trcl=( 0.0000 -70.0560 0.0000 )    u=1 $ Assy loc 37
538 3 -1.0017 -501
                 #501 #502 #503 #504 #505 #506 #507 #508 #509 #510
                 #511 #512 #513 #514 #515 #516 #517 #518 #519 #520
                 #521 #522 #523 #524 #525 #526 #527 #528 #529 #530
                 #531 #532 #533 #534 #535 #536 #537      fill=2 u=1 $ Cavity
539 6 -7.940 -502 +501     u=1 $ Canister Shell / Lid / Bottom
540 13 -0.0001 +502      u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
601 13 -0.0001 -601 -602  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
602 8 -7.821 -601 +602 -606     $ Bottom plate
603 8 -7.821 -603 +602 +606 -607    $ Inner shell
604 9 -11.344 -604 +603 +606 -607    $ Lead shell
605 10 -1.632 -605 +604 +606 -607    $ NS-4-FR
606 8 -7.821 -601 +605 +606 -607    $ Outer shell
607 8 -7.821 -601 +602 +607     $ Top plate
608 8 -7.821 -608 +609  -614    $ Door rail
609 8 -7.821 -608 -610  -614    $ Door rail
610 8 -7.821 -613 -611 +612 -614    $ Door steel
611 13 -0.0001 -614 +601 #608 #609 #610      $ Exterior space to Reflector
612 0         +614       $ Exterior space

c Surfaces - Fuel Rod - WE17H1 - WE Core - 17x17
1 RCC 0.0000 0.0000 1.7399 0.0000 0.0000 365.7600 0.4105 $ Fuel pellet stack
2 RCC 0.0000 0.0000 1.7399 0.0000 0.0000 381.6604 0.4204 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 385.1402 0.4725 $ Clad + End-Caps
c Surfaces - Guide Tube - WE17H1 - WE Core - 17x17
5 CZ 0.5766       $ Guide tube inner surface
6 CZ 0.6121       $ Guide tube outer surface
c Surfaces - Instrument Tube - WE17H1 - WE Core - 17x17
8 CZ 0.5766       $ Inst tube inner surface
9 CZ 0.6121       $ Inst tube outer surface
c Surfaces - Pitch - WE17H1 - WE Core - 17x17
13 PX 0.6299       $ Lattice Cell Boundaries
14 PX -0.6299
15 PY 0.6299
16 PY -0.6299
c Surfaces - Fuel Assembly Array Inserted Into Assembly - WE17H1 - WE Core - 17x17
17 RPP -10.5509 10.5509 -10.5509 10.5509 6.8580 396.5702  $ Array
18 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 405.8920  $ Assembly Outer Dims
c Surface Cards - Tube, Absorber and Retainer
101 RPP -10.1981 10.1981 -11.4618 -11.2078 8.8900 428.6250 $ Absorber -Y
102 RPP -10.1981 10.1981 -11.4999 -11.1697 8.8900 428.6250 $ Absorber Clad  -Y
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
103 RPP -10.1981 10.1981 11.2078 11.4618 8.8900 428.6250 $ Absorber +Y
104 RPP -10.1981 10.1981 11.1697 11.4999 8.8900 428.6250 $ Absorber Clad  +Y
105 RPP -10.3378 10.3378 -11.1697 -11.1316 7.6200 430.5300 $ Retainer -Y
106 RPP -10.3378 10.3378 11.1316 11.1697 7.6200 430.5300 $ Retainer  +Y
107 RPP 4.2863 5.8738 -12.3698 12.3698 14.2812 17.4689 $ Weld Post Slot Y Absorber
108 RPP 4.2863 5.8738 -12.3698 12.3698 39.6812 42.8689 $ Weld Post Slot Y Absorber
109 RPP 4.2863 5.8738 -12.3698 12.3698 65.0812 68.2689 $ Weld Post Slot Y Absorber
110 RPP 4.2863 5.8738 -12.3698 12.3698 90.4812 93.6689 $ Weld Post Slot Y Absorber
111 RPP 4.2863 5.8738 -12.3698 12.3698 115.8812 119.0689 $ Weld Post Slot Y Absorber
112 RPP 4.2863 5.8738 -12.3698 12.3698 141.2812 144.4689 $ Weld Post Slot Y Absorber
113 RPP 4.2863 5.8738 -12.3698 12.3698 166.6812 169.8689 $ Weld Post Slot Y Absorber
114 RPP 4.2863 5.8738 -12.3698 12.3698 192.0812 195.2689 $ Weld Post Slot Y Absorber
115 RPP 4.2863 5.8738 -12.3698 12.3698 217.4812 220.6689 $ Weld Post Slot Y Absorber
116 RPP 4.2863 5.8738 -12.3698 12.3698 242.8812 246.0689 $ Weld Post Slot Y Absorber
117 RPP 4.2863 5.8738 -12.3698 12.3698 268.2812 271.4689 $ Weld Post Slot Y Absorber
118 RPP 4.2863 5.8738 -12.3698 12.3698 293.6812 296.8689 $ Weld Post Slot Y Absorber
119 RPP 4.2863 5.8738 -12.3698 12.3698 319.0812 322.2689 $ Weld Post Slot Y Absorber
120 RPP 4.2863 5.8738 -12.3698 12.3698 344.4812 347.6689 $ Weld Post Slot Y Absorber
121 RPP 4.2863 5.8738 -12.3698 12.3698 369.8812 373.0689 $ Weld Post Slot Y Absorber
122 RPP 4.2863 5.8738 -12.3698 12.3698 395.2812 398.4689 $ Weld Post Slot Y Absorber
123 RPP 4.2863 5.8738 -12.3698 12.3698 420.6812 423.8689 $ Weld Post Slot Y Absorber
124 RPP -5.8738 -4.2863 -12.3698 12.3698 14.2812 17.4689 $ Weld Post Slot Y Absorber
125 RPP -5.8738 -4.2863 -12.3698 12.3698 39.6812 42.8689 $ Weld Post Slot Y Absorber
126 RPP -5.8738 -4.2863 -12.3698 12.3698 65.0812 68.2689 $ Weld Post Slot Y Absorber
127 RPP -5.8738 -4.2863 -12.3698 12.3698 90.4812 93.6689 $ Weld Post Slot Y Absorber
128 RPP -5.8738 -4.2863 -12.3698 12.3698 115.8812 119.0689 $ Weld Post Slot Y Absorber
129 RPP -5.8738 -4.2863 -12.3698 12.3698 141.2812 144.4689 $ Weld Post Slot Y Absorber
130 RPP -5.8738 -4.2863 -12.3698 12.3698 166.6812 169.8689 $ Weld Post Slot Y Absorber
131 RPP -5.8738 -4.2863 -12.3698 12.3698 192.0812 195.2689 $ Weld Post Slot Y Absorber
132 RPP -5.8738 -4.2863 -12.3698 12.3698 217.4812 220.6689 $ Weld Post Slot Y Absorber
133 RPP -5.8738 -4.2863 -12.3698 12.3698 242.8812 246.0689 $ Weld Post Slot Y Absorber
134 RPP -5.8738 -4.2863 -12.3698 12.3698 268.2812 271.4689 $ Weld Post Slot Y Absorber
135 RPP -5.8738 -4.2863 -12.3698 12.3698 293.6812 296.8689 $ Weld Post Slot Y Absorber
136 RPP -5.8738 -4.2863 -12.3698 12.3698 319.0812 322.2689 $ Weld Post Slot Y Absorber
137 RPP -5.8738 -4.2863 -12.3698 12.3698 344.4812 347.6689 $ Weld Post Slot Y Absorber
138 RPP -5.8738 -4.2863 -12.3698 12.3698 369.8812 373.0689 $ Weld Post Slot Y Absorber
139 RPP -5.8738 -4.2863 -12.3698 12.3698 395.2812 398.4689 $ Weld Post Slot Y Absorber
140 RPP -5.8738 -4.2863 -12.3698 12.3698 420.6812 423.8689 $ Weld Post Slot Y Absorber
141 C/Y 5.0800 15.8750 0.4191    $ Weld Post Hole Y
142 C/Y 5.0800 41.2750 0.4191    $ Weld Post Hole Y
143 C/Y 5.0800 66.6750 0.4191    $ Weld Post Hole Y
144 C/Y 5.0800 92.0750 0.4191    $ Weld Post Hole Y
145 C/Y 5.0800 117.4750 0.4191    $ Weld Post Hole Y
146 C/Y 5.0800 142.8750 0.4191    $ Weld Post Hole Y
147 C/Y 5.0800 168.2750 0.4191    $ Weld Post Hole Y
148 C/Y 5.0800 193.6750 0.4191    $ Weld Post Hole Y
149 C/Y 5.0800 219.0750 0.4191    $ Weld Post Hole Y
150 C/Y 5.0800 244.4750 0.4191    $ Weld Post Hole Y
151 C/Y 5.0800 269.8750 0.4191    $ Weld Post Hole Y
152 C/Y 5.0800 295.2750 0.4191    $ Weld Post Hole Y
153 C/Y 5.0800 320.6750 0.4191    $ Weld Post Hole Y
154 C/Y 5.0800 346.0750 0.4191    $ Weld Post Hole Y
155 C/Y 5.0800 371.4750 0.4191    $ Weld Post Hole Y
156 C/Y 5.0800 396.8750 0.4191    $ Weld Post Hole Y
157 C/Y 5.0800 422.2750 0.4191    $ Weld Post Hole Y
158 C/Y -5.0800 15.8750 0.4191    $ Weld Post Hole Y
159 C/Y -5.0800 41.2750 0.4191    $ Weld Post Hole Y
160 C/Y -5.0800 66.6750 0.4191    $ Weld Post Hole Y
161 C/Y -5.0800 92.0750 0.4191    $ Weld Post Hole Y
162 C/Y -5.0800 117.4750 0.4191    $ Weld Post Hole Y
163 C/Y -5.0800 142.8750 0.4191    $ Weld Post Hole Y
164 C/Y -5.0800 168.2750 0.4191    $ Weld Post Hole Y
165 C/Y -5.0800 193.6750 0.4191    $ Weld Post Hole Y
166 C/Y -5.0800 219.0750 0.4191    $ Weld Post Hole Y
167 C/Y -5.0800 244.4750 0.4191    $ Weld Post Hole Y
168 C/Y -5.0800 269.8750 0.4191    $ Weld Post Hole Y
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
169 C/Y -5.0800 295.2750 0.4191    $ Weld Post Hole Y
170 C/Y -5.0800 320.6750 0.4191    $ Weld Post Hole Y
171 C/Y -5.0800 346.0750 0.4191    $ Weld Post Hole Y
172 C/Y -5.0800 371.4750 0.4191    $ Weld Post Hole Y
173 C/Y -5.0800 396.8750 0.4191    $ Weld Post Hole Y
174 C/Y -5.0800 422.2750 0.4191    $ Weld Post Hole Y
175 C/Y 5.0800 15.8750 0.3175    $ Weld Post Y
176 C/Y 5.0800 41.2750 0.3175    $ Weld Post Y
177 C/Y 5.0800 66.6750 0.3175    $ Weld Post Y
178 C/Y 5.0800 92.0750 0.3175    $ Weld Post Y
179 C/Y 5.0800 117.4750 0.3175    $ Weld Post Y
180 C/Y 5.0800 142.8750 0.3175    $ Weld Post Y
181 C/Y 5.0800 168.2750 0.3175    $ Weld Post Y
182 C/Y 5.0800 193.6750 0.3175    $ Weld Post Y
183 C/Y 5.0800 219.0750 0.3175    $ Weld Post Y
184 C/Y 5.0800 244.4750 0.3175    $ Weld Post Y
185 C/Y 5.0800 269.8750 0.3175    $ Weld Post Y
186 C/Y 5.0800 295.2750 0.3175    $ Weld Post Y
187 C/Y 5.0800 320.6750 0.3175    $ Weld Post Y
188 C/Y 5.0800 346.0750 0.3175    $ Weld Post Y
189 C/Y 5.0800 371.4750 0.3175    $ Weld Post Y
190 C/Y 5.0800 396.8750 0.3175    $ Weld Post Y
191 C/Y 5.0800 422.2750 0.3175    $ Weld Post Y
192 C/Y -5.0800 15.8750 0.3175    $ Weld Post Y
193 C/Y -5.0800 41.2750 0.3175    $ Weld Post Y
194 C/Y -5.0800 66.6750 0.3175    $ Weld Post Y
195 C/Y -5.0800 92.0750 0.3175    $ Weld Post Y
196 C/Y -5.0800 117.4750 0.3175    $ Weld Post Y
197 C/Y -5.0800 142.8750 0.3175    $ Weld Post Y
198 C/Y -5.0800 168.2750 0.3175    $ Weld Post Y
199 C/Y -5.0800 193.6750 0.3175    $ Weld Post Y
200 C/Y -5.0800 219.0750 0.3175    $ Weld Post Y
201 C/Y -5.0800 244.4750 0.3175    $ Weld Post Y
202 C/Y -5.0800 269.8750 0.3175    $ Weld Post Y
203 C/Y -5.0800 295.2750 0.3175    $ Weld Post Y
204 C/Y -5.0800 320.6750 0.3175    $ Weld Post Y
205 C/Y -5.0800 346.0750 0.3175    $ Weld Post Y
206 C/Y -5.0800 371.4750 0.3175    $ Weld Post Y
207 C/Y -5.0800 396.8750 0.3175    $ Weld Post Y
208 C/Y -5.0800 422.2750 0.3175    $ Weld Post Y
209 RPP -1.5875 1.5875 -12.3698 12.3698 413.6962 416.8839 $ Water Circulation Slot Y
210 RPP -11.4618 -11.2078 -10.1981 10.1981 8.8900 428.6250 $ Absorber -X
211 RPP -11.4999 -11.1697 -10.1981 10.1981 8.8900 428.6250 $ Absorber Clad  -X
212 RPP 11.2078 11.4618 -10.1981 10.1981 8.8900 428.6250 $ Absorber +X
213 RPP 11.1697 11.4999 -10.1981 10.1981 8.8900 428.6250 $ Absorber Clad  +X
214 RPP -11.1697 -11.1316 -10.3378 10.3378 7.6200 430.5300 $ Retainer -X
215 RPP 11.1316 11.1697 -10.3378 10.3378 7.6200 430.5300 $ Retainer  +X
216 RPP -12.3698 12.3698 4.2863 5.8738 14.2812 17.4689 $ Weld Post Slot X Absorber
217 RPP -12.3698 12.3698 4.2863 5.8738 39.6812 42.8689 $ Weld Post Slot X Absorber
218 RPP -12.3698 12.3698 4.2863 5.8738 65.0812 68.2689 $ Weld Post Slot X Absorber
219 RPP -12.3698 12.3698 4.2863 5.8738 90.4812 93.6689 $ Weld Post Slot X Absorber
220 RPP -12.3698 12.3698 4.2863 5.8738 115.8812 119.0689 $ Weld Post Slot X Absorber
221 RPP -12.3698 12.3698 4.2863 5.8738 141.2812 144.4689 $ Weld Post Slot X Absorber
222 RPP -12.3698 12.3698 4.2863 5.8738 166.6812 169.8689 $ Weld Post Slot X Absorber
223 RPP -12.3698 12.3698 4.2863 5.8738 192.0812 195.2689 $ Weld Post Slot X Absorber
224 RPP -12.3698 12.3698 4.2863 5.8738 217.4812 220.6689 $ Weld Post Slot X Absorber
225 RPP -12.3698 12.3698 4.2863 5.8738 242.8812 246.0689 $ Weld Post Slot X Absorber
226 RPP -12.3698 12.3698 4.2863 5.8738 268.2812 271.4689 $ Weld Post Slot X Absorber
227 RPP -12.3698 12.3698 4.2863 5.8738 293.6812 296.8689 $ Weld Post Slot X Absorber
228 RPP -12.3698 12.3698 4.2863 5.8738 319.0812 322.2689 $ Weld Post Slot X Absorber
229 RPP -12.3698 12.3698 4.2863 5.8738 344.4812 347.6689 $ Weld Post Slot X Absorber
230 RPP -12.3698 12.3698 4.2863 5.8738 369.8812 373.0689 $ Weld Post Slot X Absorber
231 RPP -12.3698 12.3698 4.2863 5.8738 395.2812 398.4689 $ Weld Post Slot X Absorber
232 RPP -12.3698 12.3698 4.2863 5.8738 420.6812 423.8689 $ Weld Post Slot X Absorber
233 RPP -12.3698 12.3698 -5.8738 -4.2863 14.2812 17.4689 $ Weld Post Slot X Absorber
234 RPP -12.3698 12.3698 -5.8738 -4.2863 39.6812 42.8689 $ Weld Post Slot X Absorber
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
235 RPP -12.3698 12.3698 -5.8738 -4.2863 65.0812 68.2689 $ Weld Post Slot X Absorber
236 RPP -12.3698 12.3698 -5.8738 -4.2863 90.4812 93.6689 $ Weld Post Slot X Absorber
237 RPP -12.3698 12.3698 -5.8738 -4.2863 115.8812 119.0689 $ Weld Post Slot X Absorber
238 RPP -12.3698 12.3698 -5.8738 -4.2863 141.2812 144.4689 $ Weld Post Slot X Absorber
239 RPP -12.3698 12.3698 -5.8738 -4.2863 166.6812 169.8689 $ Weld Post Slot X Absorber
240 RPP -12.3698 12.3698 -5.8738 -4.2863 192.0812 195.2689 $ Weld Post Slot X Absorber
241 RPP -12.3698 12.3698 -5.8738 -4.2863 217.4812 220.6689 $ Weld Post Slot X Absorber
242 RPP -12.3698 12.3698 -5.8738 -4.2863 242.8812 246.0689 $ Weld Post Slot X Absorber
243 RPP -12.3698 12.3698 -5.8738 -4.2863 268.2812 271.4689 $ Weld Post Slot X Absorber
244 RPP -12.3698 12.3698 -5.8738 -4.2863 293.6812 296.8689 $ Weld Post Slot X Absorber
245 RPP -12.3698 12.3698 -5.8738 -4.2863 319.0812 322.2689 $ Weld Post Slot X Absorber
246 RPP -12.3698 12.3698 -5.8738 -4.2863 344.4812 347.6689 $ Weld Post Slot X Absorber
247 RPP -12.3698 12.3698 -5.8738 -4.2863 369.8812 373.0689 $ Weld Post Slot X Absorber
248 RPP -12.3698 12.3698 -5.8738 -4.2863 395.2812 398.4689 $ Weld Post Slot X Absorber
249 RPP -12.3698 12.3698 -5.8738 -4.2863 420.6812 423.8689 $ Weld Post Slot X Absorber
250 C/X 5.0800 15.8750 0.4191    $ Weld Post Hole X
251 C/X 5.0800 41.2750 0.4191    $ Weld Post Hole X
252 C/X 5.0800 66.6750 0.4191    $ Weld Post Hole X
253 C/X 5.0800 92.0750 0.4191    $ Weld Post Hole X
254 C/X 5.0800 117.4750 0.4191    $ Weld Post Hole X
255 C/X 5.0800 142.8750 0.4191    $ Weld Post Hole X
256 C/X 5.0800 168.2750 0.4191    $ Weld Post Hole X
257 C/X 5.0800 193.6750 0.4191    $ Weld Post Hole X
258 C/X 5.0800 219.0750 0.4191    $ Weld Post Hole X
259 C/X 5.0800 244.4750 0.4191    $ Weld Post Hole X
260 C/X 5.0800 269.8750 0.4191    $ Weld Post Hole X
261 C/X 5.0800 295.2750 0.4191    $ Weld Post Hole X
262 C/X 5.0800 320.6750 0.4191    $ Weld Post Hole X
263 C/X 5.0800 346.0750 0.4191    $ Weld Post Hole X
264 C/X 5.0800 371.4750 0.4191    $ Weld Post Hole X
265 C/X 5.0800 396.8750 0.4191    $ Weld Post Hole X
266 C/X 5.0800 422.2750 0.4191    $ Weld Post Hole X
267 C/X -5.0800 15.8750 0.4191    $ Weld Post Hole X
268 C/X -5.0800 41.2750 0.4191    $ Weld Post Hole X
269 C/X -5.0800 66.6750 0.4191    $ Weld Post Hole X
270 C/X -5.0800 92.0750 0.4191    $ Weld Post Hole X
271 C/X -5.0800 117.4750 0.4191    $ Weld Post Hole X
272 C/X -5.0800 142.8750 0.4191    $ Weld Post Hole X
273 C/X -5.0800 168.2750 0.4191    $ Weld Post Hole X
274 C/X -5.0800 193.6750 0.4191    $ Weld Post Hole X
275 C/X -5.0800 219.0750 0.4191    $ Weld Post Hole X
276 C/X -5.0800 244.4750 0.4191    $ Weld Post Hole X
277 C/X -5.0800 269.8750 0.4191    $ Weld Post Hole X
278 C/X -5.0800 295.2750 0.4191    $ Weld Post Hole X
279 C/X -5.0800 320.6750 0.4191    $ Weld Post Hole X
280 C/X -5.0800 346.0750 0.4191    $ Weld Post Hole X
281 C/X -5.0800 371.4750 0.4191    $ Weld Post Hole X
282 C/X -5.0800 396.8750 0.4191    $ Weld Post Hole X
283 C/X -5.0800 422.2750 0.4191    $ Weld Post Hole X
284 C/X 5.0800 15.8750 0.3175    $ Weld Post X
285 C/X 5.0800 41.2750 0.3175    $ Weld Post X
286 C/X 5.0800 66.6750 0.3175    $ Weld Post X
287 C/X 5.0800 92.0750 0.3175    $ Weld Post X
288 C/X 5.0800 117.4750 0.3175    $ Weld Post X
289 C/X 5.0800 142.8750 0.3175    $ Weld Post X
290 C/X 5.0800 168.2750 0.3175    $ Weld Post X
291 C/X 5.0800 193.6750 0.3175    $ Weld Post X
292 C/X 5.0800 219.0750 0.3175    $ Weld Post X
293 C/X 5.0800 244.4750 0.3175    $ Weld Post X
294 C/X 5.0800 269.8750 0.3175    $ Weld Post X
295 C/X 5.0800 295.2750 0.3175    $ Weld Post X
296 C/X 5.0800 320.6750 0.3175    $ Weld Post X
297 C/X 5.0800 346.0750 0.3175    $ Weld Post X
298 C/X 5.0800 371.4750 0.3175    $ Weld Post X
299 C/X 5.0800 396.8750 0.3175    $ Weld Post X
300 C/X 5.0800 422.2750 0.3175    $ Weld Post X
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
301 C/X -5.0800 15.8750 0.3175    $ Weld Post X
302 C/X -5.0800 41.2750 0.3175    $ Weld Post X
303 C/X -5.0800 66.6750 0.3175    $ Weld Post X
304 C/X -5.0800 92.0750 0.3175    $ Weld Post X
305 C/X -5.0800 117.4750 0.3175    $ Weld Post X
306 C/X -5.0800 142.8750 0.3175    $ Weld Post X
307 C/X -5.0800 168.2750 0.3175    $ Weld Post X
308 C/X -5.0800 193.6750 0.3175    $ Weld Post X
309 C/X -5.0800 219.0750 0.3175    $ Weld Post X
310 C/X -5.0800 244.4750 0.3175    $ Weld Post X
311 C/X -5.0800 269.8750 0.3175    $ Weld Post X
312 C/X -5.0800 295.2750 0.3175    $ Weld Post X
313 C/X -5.0800 320.6750 0.3175    $ Weld Post X
314 C/X -5.0800 346.0750 0.3175    $ Weld Post X
315 C/X -5.0800 371.4750 0.3175    $ Weld Post X
316 C/X -5.0800 396.8750 0.3175    $ Weld Post X
317 C/X -5.0800 422.2750 0.3175    $ Weld Post X
318 RPP -12.3698 12.3698 -1.5875 1.5875 413.6962 416.8839 $ Water Circulation Slot X
319 RPP -11.4999 11.4999 -11.4999 11.4999 0.0000 440.6900 $  Space inside tube - cavity extent
320 RPP -12.3698 12.3698 -12.3698 12.3698 7.6200 430.5300 $  Fuel tube
C Surfaces - Basket
401  RPP -12.3698 12.3698 -12.3698 12.3698 0.0000 440.6900  $ Tube Cavity Height
402 1 RPP -16.6116 16.6116 -16.6116 16.6116 0.0000 440.6900  $ Tube Corner Cuts
403  RPP -33.9471 33.9471 -83.6409 83.6409 7.6200 430.5300  $ Outer Surface Side Weld.
404  RPP -33.9471 33.9471 -81.7359 81.7359 7.6200 430.5300  $ Inner Surface Side Weld.
405  RPP -83.6409 83.6409 -33.9471 33.9471 7.6200 430.5300  $ Outer Surface Side Weld.
406  RPP -81.7359 81.7359 -33.9471 33.9471 7.6200 430.5300  $ Inner Surface Side Weld.
407 1 RPP -80.1366 80.1366 -80.1366 80.1366 7.6200 430.5300  $ Outer Surface Corner Weld.
408 1 RPP -79.3428 79.3428 -79.3428 79.3428 7.6200 430.5300  $ Inner Surface Corner Weld.
409  RPP -82.8472 82.8472 -82.8472 82.8472 7.6200 430.5300  $ Corner Weld. Cut Surface
410  RPP -60.1485 60.1485 -60.1485 60.1485 7.6200 430.5300  $ Outer Surface Corner Weld.
411  RPP -59.3547 59.3547 -59.3547 59.3547 7.6200 430.5300  $ Inner Surface Corner Weld.
412  RPP -82.1868 82.1868 -36.6560 36.6560 7.6200 430.5300  $ Outer Surface Corner Weld.
413  RPP -82.1868 82.1868 -35.8623 35.8623 7.6200 430.5300  $ Inner Surface Corner Weld.
414  RPP -36.6560 36.6560 -82.1868 82.1868 7.6200 430.5300  $ Outer Surface Corner Weld.
415  RPP -35.8623 35.8623 -82.1868 82.1868 7.6200 430.5300  $ Inner Surface Corner Weld.
c Surface Cards - Canister
501 RCC 0.0000 0.0000 0.0000 0.0000 440.6900  90.1700 $ Canister cavity
502 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 469.2650  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
601 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
602 CZ 92.7100        $ Cask cavity radius
603 CZ 94.6150        $ Inner shell OR
604 CZ 102.7430        $ Lead shell OR
605 CZ 108.5850        $ Outer shell IR
606 PZ 30.4800        $ Top of bottom plate
607 PZ 453.3900        $ Bottom of top plate
608 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
609 PY 97.0026        $ Inside rail surface
610 PY -97.0026        $ Inside rail surface
611 PY 96.52        $ Door surface
612 PY -96.52        $ Door surface
613 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*614 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
c Fuel Pellet Material  4.40%  Weight UO2 [amu]  269.9175
m1    92235.66c -3.878E-02 92238.66c -8.427E-01  8016.62c -1.186E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.106E-01  8016.62c -8.779E-01
       1001.62c -5.589E-04  8016.62c -8.870E-03  5010.66c -3.535E-04
                                                  5011.66c -1.646E-03
mt3  lwtr.01t
c Lower Nozzle Material
m4
       1001.62c -3.201E-02  8016.62c -2.540E-01
       1001.62c -1.617E-04  8016.62c -2.567E-03  5010.66c -1.023E-04
                                                  5011.66c -4.764E-04
      24050.62c -5.642E-03 26054.62c -2.791E-02 28058.62c -4.537E-02
      24052.62c -1.130E-01 26056.62c -4.539E-01 28060.62c -1.807E-02
      24053.62c -1.306E-02 26057.62c -1.068E-02 28061.62c -7.990E-04
      24054.62c -3.306E-03 26058.62c -1.435E-03 28062.62c -2.586E-03
                                                28064.62c -6.839E-04
      25055.62c -1.421E-02
mt4  lwtr.01t
c Upper Nozzle Material
m5
       1001.62c -3.265E-02  8016.62c -2.591E-01
       1001.62c -1.649E-04  8016.62c -2.618E-03  5010.66c -1.043E-04
                                                  5011.66c -4.859E-04
      24050.62c -5.596E-03 26054.62c -2.768E-02 28058.62c -4.500E-02
      24052.62c -1.121E-01 26056.62c -4.502E-01 28060.62c -1.793E-02
      24053.62c -1.295E-02 26057.62c -1.059E-02 28061.62c -7.925E-04
      24054.62c -3.279E-03 26058.62c -1.423E-03 28062.62c -2.565E-03
                                                28064.62c -6.783E-04
      25055.62c -1.410E-02
mt5  lwtr.01t
c SS304
m6    24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                28064.62c -9.623E-04
      25055.62c -2.000E-02
c Aluminum
m7    13027.62c -1.000E+00
c Carbon Steel
m8    26054.62c -5.594E-02  6000.66c -1.000E-02
      26056.62c -9.098E-01
      26057.62c -2.140E-02
      26058.62c -2.876E-03
c Lead
m9    82206.66c -2.534E-01
      82207.66c -2.207E-01
      82208.66c -5.259E-01
c NS-F-FR
m10    5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
       5011.66c -3.772E-03  7015.66c -7.852E-05
      13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11   26054.62c -7.911E-04 14000.60c -3.370E-01
      26056.62c -1.287E-02
      26057.62c -3.026E-04
      26058.62c -4.067E-05
       1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
       8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12    5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
       5011.66c -2.799E-01
c Water Exterior
m13    1001.62c 2.0
       8016.62c 1.0
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
c
c Cell Importances
c
mode n
imp:n 1 219r 0
c
c
c Criticality Controls
c
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= 601 : D2 : 17 : 13 : -1
      ERG= D1
      POS= 0.0000 0.00 1.7399
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          1        d
      501 1
      502 1
      503 1
      504 1
      505 1
      506 1
      507 1
      508 1
      509 1
      510 1
      511 1
      512 1
      513 1
      514 1
      515 1
      516 1
      517 1
      518 1
      519 1
```

Figure 6.7.1-3 MCNP Transfer Cask Model – PWR 37-Assembly Basket

```
      520 1
      521 1
      522 1
      523 1
      524 1
      525 1
      526 1
      527 1
      528 1
      529 1
      530 1
      531 1
      532 1
      533 1
      534 1
      535 1
      536 1
      537 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4105 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      365.76 1.0
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
Storage Cask Model - CE16H1
c
c  MAGNASTOR Canister Class 2
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c
c   Boron Content in Water - 0 ppm
c   Cavity Water Density 0.0001 g/cc
c
c   Fuel to Clad Gap - Dry
c   Exterior Water Density 0.0001 g/cc
c
c   Model Revision 4.70
c
c Cells - Fuel Rod - CE16H1 - CE Core - 16x16
1 1 -1.0522E+01 -1   u=10 $ Fuel
2 0          -2 +1  u=10 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=10 $ Clad + End Plugs
4 3 -0.0001 +3   u=10 $ Outside Fuel Rod
c Array_16x16_236
7 3 -0.0001 -7 +8 -9 +10
      trcl=(0.643 0.643 9.6825)   lat=1 u=9 fill=-8:7 -8:7 0:0
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 9 9 10 10 10 10 10 10 9 9 10 10 10
      10 10 10 9 9 10 10 10 10 10 10 9 9 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 9 9 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 9 9 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 9 9 10 10 10 10 10 10 9 9 10 10 10
      10 10 10 9 9 10 10 10 10 10 10 9 9 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
      10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
c Cells - Fuel Assembly Array Inserted Into Assembly - cellCEAssy
11 3 -0.0001 -11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21      fill=9 u=8 $ Array
12 3 -0.0001 -5  -11     u=8 $ Inside CE Guide
13 2 -6.56 -6 +5 -11     u=8 $ CE Guide Tube
14 like 12 but   *trcl=( 5.1440 5.1440 0.0000 )       u=8 $ Inside CE Guide
15 like 13 but   *trcl=( 5.1440 5.1440 0.0000 )       u=8 $ CE Guide Tube
16 like 12 but   *trcl=( -5.1440 5.1440 0.0000 )       u=8 $ Inside CE Guide
17 like 13 but   *trcl=( -5.1440 5.1440 0.0000 )       u=8 $ CE Guide Tube
18 like 12 but   *trcl=( 5.1440 -5.1440 0.0000 )       u=8 $ Inside CE Guide
19 like 13 but   *trcl=( 5.1440 -5.1440 0.0000 )       u=8 $ CE Guide Tube
20 like 12 but   *trcl=( -5.1440 -5.1440 0.0000 )       u=8 $ Inside CE Guide
21 like 13 but   *trcl=( -5.1440 -5.1440 0.0000 )       u=8 $ CE Guide Tube
22 3 -0.0001 -12 +11 -11.6 -11.5    u=8 $ Fuel Width Envelope
23 4 -1.4722 -12  +11.6     u=8 $ Lower Nozzle
24 5 -1.3872 -12   +11.5    u=8 $ Upper Nozzle
25 3 -0.0001 +12       u=8 $ Remaining Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=7 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=7 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=7 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=7 $ Absorber Clad  +Y
105 6 -7.940 -105     u=7 $ Retainer -Y
106 6 -7.940 -106     u=7 $ Retainer+Y
107 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber -Y
108 3 -0.0001 -102 #101  #102  #107   u=7 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber +Y
110 3 -0.0001 -104 #103  #104  #109   u=7 $ Gap Weld Post to Absorber +Y
111 12 -2.358 -216  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=7 $ Absorber -X
112 7 -2.702 -217 +216 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=7 $ Absorber Clad  -X
113 12 -2.358 -218  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=7 $ Absorber +X
114 7 -2.702 -219 +218 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=7 $ Absorber Clad  +X
115 6 -7.940 -220     u=7 $ Retainer -X
116 6 -7.940 -221     u=7 $ Retainer+X
117 6 -7.940 -217
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=7 $ Weld Post in Absorber -X
118 3 -0.0001 -217 #111  #112  #117   u=7 $ Gap Weld Post to Absorber -X
119 6 -7.940 -219
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=7 $ Weld Post in Absorber
120 3 -0.0001 -219 #113  #114  #119   u=7 $ Gap Weld Post to Absorber +X
121 3 -0.0001 -331
       +102 +104 +105 +106
       +217 +219 +220 +221     u=7 $ Space in Tube
122 8 -7.821 -332 +331
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +258 +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283 +284
       +285 +286 +287 +288 +289 +290 +291 +292 +293     +215 +330 u=7 $ Fuel Tube
123 6 -7.940 -332 +331
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
       -294:-295:-296:-297:-298:-299:-300:-301:-302:
       -303:-304:-305:-306:-307:-308:-309:-310:-311:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329)      u=7 $ Fuel Tube Weld Posts
124 3 -0.0001 -332 +331  #122  #123
             u=7 $ Space Around Weld Posts
125 3 -0.0001 +331 +332    u=7 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=6 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=6 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=6 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=6 $ Absorber Clad  +Y
130 6 -7.940 -105     u=6 $ Retainer -Y
131 6 -7.9400 -106     u=6 $ Retainer+Y
132 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber -Y
133 3 -0.0001 -102 #126  #127  #132   u=6 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber +Y
135 3 -0.0001 -104 #128  #129  #134   u=6 $ Gap Weld Post to Absorber +Y
136 12 -2.358 -216  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=6 $ Absorber -X
137 7 -2.702 -217 +216 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=6 $ Absorber Clad  -X
138 7 -2.7020 -218  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=6 $ Absorber +X
139 7 -2.7020 -219 +218 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=6 $ Absorber Clad  +X
140 6 -7.940 -220     u=6 $ Retainer -X
141 6 -7.9400 -221     u=6 $ Retainer+X
142 6 -7.940 -217
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=6 $ Weld Post in Plate-X
143 3 -0.0001 -217 #136  #137  #142   u=6 $ Gap Weld Post to Plate -X
144 6 -7.9400 -219
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
      -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=6 $ Weld Post in Plate +X
145 3 -0.0001 -219 #138  #139  #144   u=6 $ Gap Weld Post to Plate +X
146 3 -0.0001 -331
      +102 +104 +105 +106
      +217 +219 +220 +221     u=6 $ Space in Tube
147 8 -7.821 -332 +331
      +143 +144 +145 +146 +147 +148 +149 +150 +151
      +152 +153 +154 +155 +156 +157 +158 +159 +160
      +161 +162 +163 +164 +165 +166 +167 +168 +169
      +170 +171 +172 +173 +174 +175 +176 +177 +178
      +258 +259 +260 +261 +262 +263 +264 +265 +266
      +267 +268 +269 +270 +271 +272 +273 +274 +275
      +276 +277 +278 +279 +280 +281 +282 +283 +284
      +285 +286 +287 +288 +289 +290 +291 +292 +293     +215 +330 u=6 $ Fuel Tube
148 6 -7.940 -332 +331
      (-179:-180:-181:-182:-183:-184:-185:-186:-187:
      -188:-189:-190:-191:-192:-193:-194:-195:-196:
      -197:-198:-199:-200:-201:-202:-203:-204:-205:
      -206:-207:-208:-209:-210:-211:-212:-213:-214:
      -294:-295:-296:-297:-298:-299:-300:-301:-302:
      -303:-304:-305:-306:-307:-308:-309:-310:-311:
      -312:-313:-314:-315:-316:-317:-318:-319:-320:
      -321:-322:-323:-324:-325:-326:-327:-328:-329)      u=6 $ Fuel Tube Weld Posts
149 3 -0.0001 -332 +331  #147  #148
            u=6 $ Space Around Weld Posts
150 3 -0.0001 +331 +332    u=6 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120 +121 +122 +123 +124
         +125 +126 +127 +128 +129 +130 +131 +132 +133
         +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=5 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120 +121 +122 +123 +124
         +125 +126 +127 +128 +129 +130 +131 +132 +133
         +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=5 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120 +121 +122 +123 +124
         +125 +126 +127 +128 +129 +130 +131 +132 +133
         +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=5 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120 +121 +122 +123 +124
         +125 +126 +127 +128 +129 +130 +131 +132 +133
         +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=5 $ Absorber Clad  +Y
155 6 -7.940 -105     u=5 $ Retainer -Y
156 6 -7.9400 -106     u=5 $ Retainer+Y
157 6 -7.940 -102
      (-179:-180:-181:-182:-183:-184:-185:-186:-187:
      -188:-189:-190:-191:-192:-193:-194:-195:-196:
      -197:-198:-199:-200:-201:-202:-203:-204:-205:
      -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber -Y
158 3 -0.0001 -102 #151  #152  #157   u=5 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
      (-179:-180:-181:-182:-183:-184:-185:-186:-187:
      -188:-189:-190:-191:-192:-193:-194:-195:-196:
      -197:-198:-199:-200:-201:-202:-203:-204:-205:
      -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber +Y
160 3 -0.0001 -104 #153  #154  #159   u=5 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -216  +222 +223 +224 +225 +226 +227 +228 +229 +230
         +231 +232 +233 +234 +235 +236 +237 +238 +239
         +240 +241 +242 +243 +244 +245 +246 +247 +248
         +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=5 $ Absorber -X
162 7 -2.7020 -217 +216 +222 +223 +224 +225 +226 +227 +228 +229 +230
         +231 +232 +233 +234 +235 +236 +237 +238 +239
         +240 +241 +242 +243 +244 +245 +246 +247 +248
         +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=5 $ Absorber Clad  -X
163 12 -2.358 -218  +222 +223 +224 +225 +226 +227 +228 +229 +230
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=5 $ Absorber +X
164 7 -2.702 -219 +218 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=5 $ Absorber Clad  +X
165 6 -7.9400 -220     u=5 $ Retainer -X
166 6 -7.940 -221     u=5 $ Retainer+X
167 6 -7.9400 -217
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=5 $ Weld Post in Plate-X
168 3 -0.0001 -217 #161  #162  #167   u=5 $ Gap Weld Post to Plate -X
169 6 -7.940 -219
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=5 $ Weld Post in Plate +X
170 3 -0.0001 -219 #163  #164  #169   u=5 $ Gap Weld Post to Plate +X
171 3 -0.0001 -331
       +102 +104 +105 +106
       +217 +219 +220 +221     u=5 $ Space in Tube
172 8 -7.821 -332 +331
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +258 +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283 +284
       +285 +286 +287 +288 +289 +290 +291 +292 +293     +215 +330 u=5 $ Fuel Tube
173 6 -7.940 -332 +331
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -294:-295:-296:-297:-298:-299:-300:-301:-302:
       -303:-304:-305:-306:-307:-308:-309:-310:-311:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329)      u=5 $ Fuel Tube Weld Posts
174 3 -0.0001 -332 +331  #172  #173
            u=5 $ Space Around Weld Posts
175 3 -0.0001 +331 +332    u=5 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=4 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=4 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=4 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=4 $ Absorber Clad  +Y
180 6 -7.9400 -105     u=4 $ Retainer -Y
181 6 -7.940 -106     u=4 $ Retainer+Y
182 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=4 $ Weld Post in Absorber -Y
183 3 -0.0001 -102 #176  #177  #182   u=4 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=4 $ Weld Post in Absorber +Y
185 3 -0.0001 -104 #178  #179  #184   u=4 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -216  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=4 $ Absorber -X
187 7 -2.7020 -217 +216 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=4 $ Absorber Clad  -X
188 12 -2.358 -218  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=4 $ Absorber +X
189 7 -2.702 -219 +218 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=4 $ Absorber Clad  +X
190 6 -7.9400 -220     u=4 $ Retainer -X
191 6 -7.940 -221     u=4 $ Retainer+X
192 6 -7.9400 -217
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=4 $ Weld Post in Plate-X
193 3 -0.0001 -217 #186  #187  #192   u=4 $ Gap Weld Post to Plate -X
194 6 -7.940 -219
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=4 $ Weld Post in Plate +X
195 3 -0.0001 -219 #188  #189  #194   u=4 $ Gap Weld Post to Plate +X
196 3 -0.0001 -331
       +102 +104 +105 +106
       +217 +219 +220 +221     u=4 $ Space in Tube
197 8 -7.821 -332 +331
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +258 +259 +260 +261 +262 +263 +264 +265 +266
       +267 +268 +269 +270 +271 +272 +273 +274 +275
       +276 +277 +278 +279 +280 +281 +282 +283 +284
       +285 +286 +287 +288 +289 +290 +291 +292 +293     +215 +330 u=4 $ Fuel Tube
198 6 -7.940 -332 +331
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -294:-295:-296:-297:-298:-299:-300:-301:-302:
       -303:-304:-305:-306:-307:-308:-309:-310:-311:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329)      u=4 $ Fuel Tube Weld Posts
199 3 -0.0001 -332 +331  #197  #198
            u=4 $ Space Around Weld Posts
200 3 -0.0001 +331 +332    u=4 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=3 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=3 $ Absorber Clad  -Y
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=3 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 u=3 $ Absorber Clad  +Y
205 6 -7.9400 -105     u=3 $ Retainer -Y
206 6 -7.940 -106     u=3 $ Retainer+Y
207 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=3 $ Weld Post in Absorber -Y
208 3 -0.0001 -102 #201  #202  #207   u=3 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=3 $ Weld Post in Absorber +Y
210 3 -0.0001 -104 #203  #204  #209   u=3 $ Gap Weld Post to Absorber +Y
211 12 -2.358 -216  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=3 $ Absorber -X
212 7 -2.702 -217 +216 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=3 $ Absorber Clad  -X
213 7 -2.7020 -218  +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=3 $ Absorber +X
214 7 -2.7020 -219 +218 +222 +223 +224 +225 +226 +227 +228 +229 +230
          +231 +232 +233 +234 +235 +236 +237 +238 +239
          +240 +241 +242 +243 +244 +245 +246 +247 +248
          +249 +250 +251 +252 +253 +254 +255 +256 +257  +330 u=3 $ Absorber Clad  +X
215 6 -7.940 -220     u=3 $ Retainer -X
216 6 -7.9400 -221     u=3 $ Retainer+X
217 6 -7.940 -217
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=3 $ Weld Post in Plate-X
218 3 -0.0001 -217 #211  #212  #217   u=3 $ Gap Weld Post to Plate -X
219 6 -7.9400 -219
       (-294:-295:-296:-297:-298:-299:-300:-301:-302:
       -312:-313:-314:-315:-316:-317:-318:-319:-320:
       -321:-322:-323:-324:-325:-326:-327:-328:-329:
       -303:-304:-305:-306:-307:-308:-309:-310:-311)      u=3 $ Weld Post in Plate +X
220 3 -0.0001 -219 #213  #214  #219   u=3 $ Gap Weld Post to Plate +X
221 3 -0.0001 -331
       +102 +104 +105 +106
       +217 +219 +220 +221     u=3 $ Space in Tube
222 8 -7.821 -332 +331
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
      +170 +171 +172 +173 +174 +175 +176 +177 +178
      +258 +259 +260 +261 +262 +263 +264 +265 +266
      +267 +268 +269 +270 +271 +272 +273 +274 +275
      +276 +277 +278 +279 +280 +281 +282 +283 +284
      +285 +286 +287 +288 +289 +290 +291 +292 +293     +215 +330 u=3 $ Fuel Tube
223 6 -7.940 -332 +331
      (-179:-180:-181:-182:-183:-184:-185:-186:-187:
      -188:-189:-190:-191:-192:-193:-194:-195:-196:
      -197:-198:-199:-200:-201:-202:-203:-204:-205:
      -206:-207:-208:-209:-210:-211:-212:-213:-214:
      -294:-295:-296:-297:-298:-299:-300:-301:-302:
      -303:-304:-305:-306:-307:-308:-309:-310:-311:
      -312:-313:-314:-315:-316:-317:-318:-319:-320:
      -321:-322:-323:-324:-325:-326:-327:-328:-329)      u=3 $ Fuel Tube Weld Posts
224 3 -0.0001 -332 +331  #222  #223
            u=3 $ Space Around Weld Posts
225 3 -0.0001 +331 +332    u=3 $ Exterior Space
C Cells - Basket
401 3 -0.0001 -401 -402 fill=5 *trcl=( -23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 1
402 like 401 but     fill=6 *trcl=( 23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 2
403 like 401 but     fill=7 *trcl=( -46.9849 46.9849 0.0000 )   u=2 $ Tube Loc 3
404 like 401 but     fill=7 *trcl=( 0.0000 46.9849 0.0000 )   u=2 $ Tube Loc 4
405 like 401 but     fill=7 *trcl=( 46.9849 46.9849 0.0000 )   u=2 $ Tube Loc 5
406 like 401 but     fill=5 *trcl=( -70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 6
407 like 401 but     fill=7 *trcl=( -23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 7
408 like 401 but     fill=7 *trcl=( 23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 8
409 like 401 but     fill=6 *trcl=( 70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 9
410 like 401 but     fill=7 *trcl=( -46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 10
411 like 401 but     fill=7 *trcl=( 0.0000 0.0000 0.0000 )   u=2 $ Tube Loc 11
412 like 401 but     fill=7 *trcl=( 46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 12
413 like 401 but     fill=4 *trcl=( -70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 13
414 like 401 but     fill=7 *trcl=( -23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 14
415 like 401 but     fill=7 *trcl=( 23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 15
416 like 401 but     fill=3 *trcl=( 70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 16
417 like 401 but     fill=7 *trcl=( -46.9849 -46.9849 0.0000 )   u=2 $ Tube Loc 17
418 like 401 but     fill=7 *trcl=( 0.0000 -46.9849 0.0000 )   u=2 $ Tube Loc 18
419 like 401 but     fill=7 *trcl=( 46.9849 -46.9849 0.0000 )   u=2 $ Tube Loc 19
420 like 401 but     fill=4 *trcl=( -23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 20
421 like 401 but     fill=3 *trcl=( 23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 21
422 8 -7.821 -403 +404
                #401  #402  #420  #421    u=2 $ Side Weldment Y
423 8 -7.821 -405 +406
                #406  #413  #409  #416    u=2 $ Side Weldment X
424 8 -7.821 -407 +408 -409 +411
                #402   #409  #413   #420
                #401   #406  #416   #421  u=2 $ Corner Weldment Part 1
425 8 -7.821 -410 +411 +407    u=2 $ Corner Weldment Part 2
426 8 -7.821 -412 +413 +407    u=2 $ Corner Weldment Part 3A
427 8 -7.821 -414 +415 +407    u=2 $ Corner Weldment Part 3B
428 3 -0.0001 #401 #402 #403 #404 #405 #406 #407 #408 #409 #410 #411
      #412 #413 #414 #415 #416 #417 #418 #419 #420 #421
      #422  #423
      #424 #425 #426 #427         u=2 $ Remaining Space
c Cell Cards - Canister
501 3 -0.0001 -12 fill=8 *trcl=( -22.6481 69.6330 0.0000 )    u=1 $ Assy loc 1
502 like 501 but     *trcl=( 22.6481 69.6330 0.0000 )    u=1 $ Assy loc 2
503 like 501 but     *trcl=( -46.1406 46.1406 0.0000 )    u=1 $ Assy loc 3
504 like 501 but     *trcl=( 0.0000 46.1406 0.0000 )    u=1 $ Assy loc 4
505 like 501 but     *trcl=( 46.1406 46.1406 0.0000 )    u=1 $ Assy loc 5
506 like 501 but     *trcl=( -69.6330 22.6481 0.0000 )    u=1 $ Assy loc 6
507 like 501 but     *trcl=( -22.6481 22.6481 0.0000 )    u=1 $ Assy loc 7
508 like 501 but     *trcl=( 22.6481 22.6481 0.0000 )    u=1 $ Assy loc 8
509 like 501 but     *trcl=( 69.6330 22.6481 0.0000 )    u=1 $ Assy loc 9
510 like 501 but     *trcl=( -46.1406 0.0000 0.0000 )    u=1 $ Assy loc 10
511 like 501 but     *trcl=( 0.0000 0.0000 0.0000 )    u=1 $ Assy loc 11
512 like 501 but     *trcl=( 46.1406 0.0000 0.0000 )    u=1 $ Assy loc 12
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
513 like 501 but     *trcl=( -69.6330 -22.6481 0.0000 )    u=1 $ Assy loc 13
514 like 501 but     *trcl=( -22.6481 -22.6481 0.0000 )    u=1 $ Assy loc 14
515 like 501 but     *trcl=( 22.6481 -22.6481 0.0000 )    u=1 $ Assy loc 15
516 like 501 but     *trcl=( 69.6330 -22.6481 0.0000 )    u=1 $ Assy loc 16
517 like 501 but     *trcl=( -46.1406 -46.1406 0.0000 )    u=1 $ Assy loc 17
518 like 501 but     *trcl=( 0.0000 -46.1406 0.0000 )    u=1 $ Assy loc 18
519 like 501 but     *trcl=( 46.1406 -46.1406 0.0000 )    u=1 $ Assy loc 19
520 like 501 but     *trcl=( -22.6481 -69.6330 0.0000 )    u=1 $ Assy loc 20
521 like 501 but     *trcl=( 22.6481 -69.6330 0.0000 )    u=1 $ Assy loc 21
522 like 501 but     *trcl=( 0.0000 69.6420 0.0000 )    u=1 $ Assy loc 22
523 like 501 but     *trcl=( -22.6571 46.1496 0.0000 )    u=1 $ Assy loc 23
524 like 501 but     *trcl=( 22.6571 46.1496 0.0000 )    u=1 $ Assy loc 24
525 like 501 but     *trcl=( -46.1496 22.6571 0.0000 )    u=1 $ Assy loc 25
526 like 501 but     *trcl=( 0.0000 22.6571 0.0000 )    u=1 $ Assy loc 26
527 like 501 but     *trcl=( 46.1496 22.6571 0.0000 )    u=1 $ Assy loc 27
528 like 501 but     *trcl=( -69.6420 0.0000 0.0000 )    u=1 $ Assy loc 28
529 like 501 but     *trcl=( -22.6571 0.0000 0.0000 )    u=1 $ Assy loc 29
530 like 501 but     *trcl=( 22.6571 0.0000 0.0000 )    u=1 $ Assy loc 30
531 like 501 but     *trcl=( 69.6420 0.0000 0.0000 )    u=1 $ Assy loc 31
532 like 501 but     *trcl=( -46.1496 -22.6571 0.0000 )    u=1 $ Assy loc 32
533 like 501 but     *trcl=( 0.0000 -22.6571 0.0000 )    u=1 $ Assy loc 33
534 like 501 but     *trcl=( 46.1496 -22.6571 0.0000 )    u=1 $ Assy loc 34
535 like 501 but     *trcl=( -22.6571 -46.1496 0.0000 )    u=1 $ Assy loc 35
536 like 501 but     *trcl=( 22.6571 -46.1496 0.0000 )    u=1 $ Assy loc 36
537 like 501 but     *trcl=( 0.0000 -69.6420 0.0000 )    u=1 $ Assy loc 37
538 3 -0.0001 -501
               #501 #502 #503 #504 #505 #506 #507 #508 #509 #510
               #511 #512 #513 #514 #515 #516 #517 #518 #519 #520
               #521 #522 #523 #524 #525 #526 #527 #528 #529 #530
               #531 #532 #533 #534 #535 #536 #537      fill=2 u=1 $ Cavity
539 6 -7.940 -502 +501     u=1 $ Canister Shell / Lid / Bottom
540 13 -0.0001 +502      u=1 $ Remaining Space
c VCC Cells
601 8 -7.8212 -601        $ Pedestal plate
602 8 -7.8212 -602 +603       $ Stand
603 8 -7.8212 -608 +609 +614 +615     $ Bottom plate outer
604 8 -7.8212 (-609 +610 -604) : (-609 +610 -605)        $ Bottom plate connector
605 8 -7.8212 -610        $ Bottom plate inner
606 8 -7.8212 (-603 -624 +625 -612) : (-603 -622 +623 +624 -612)        $ Support rail inside
stand
607 8 -7.8212 (+602 -624 +625 -612) : (+602 -622 +623 +624 -612)        $ Support rail outside
stand
608 8 -7.8212 (-619 +621 +604 +605 -613) :
               (-620 +621 +604 +605 -613 +619)        $ Air inlet top
609 8 -7.8212 (-616 +614 +618 -613 +604 +605 +608) :
               (-617 +615 +618 -613 +604 +605 +608)        $ Air inlet wall
610 8 -7.8212 (-604 +606 +602 -613 +608) : (-605 +607 +602 -613 +608)        $ Air inlet angular
wall
611 8 -7.8212 (-618 -616 +614 +604 +605 +615 +608) :
               (-618 -617 +615 +604 +605 +614 +608)        $ Air inlet remaining wall
612 11 -2.3220 -613 +611 +604 +605 +608 +619 +620 +616 +617        $ Concrete
613 8 -7.8212 -611 +612       $ Liner
614 8 -7.8212 -626 +611        $ Top flange
615 13 -0.0001 (-608 +609 -614) : (-608 +609 -615)        $ Bottom plate outer void
616 13 -0.0001 -609 +610 +604 +605     $ Bottom plate connector void
617 13 -0.0001 (-603 -625 -612) : (-603 -623 +624 -612)        $ Support rail inside stand void
618 13 -0.0001 (+602 -625 -612) : (+602 -623 +624 -612)        $ Support rail outside stand void
619 13 -0.0001 (-614 +602 +604 +605 -613 +608) :        $ Air inlet void
                (-615 +602 +604 +605 -613 +608 +614)
620 13 -0.0001 -621 +602 +604 +605        $ Air inlet top void
621 13 -0.0001 (-606 +608 +602) : (-607 +608 +602)        $ Connector void
622 13 -0.0001 -603 +622 +624        $ Stand void
623 13 -0.0001 -612 +601 +602 +622 +624   fill=1 ( 0.0000 0.0000 6.9850 )    $ Cavity
624 8 -7.8212 -628 +627       $ Lid base
625 8 -7.8212 -629 +630       $ Lid base disk
626 8 -7.8212 -631 -636.5 +637.5      $ Outlet disk
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
627 8 -7.8212 -636 +637 -640 +631      $ Outlet steel
628 13 -0.0001 -637  -640 +631     $ Outlet void
629 8 -7.8212 -638 +639 -640 +631      $ Outlet steel
630 13 -0.0001 -639  -640 +631     $ Outlet void
631 8 -7.8212 -630 +631 +636 +638      $ Lid Liner
632 13 -0.0001 -640 -631 +626 -637.5      $ Central Void
633 13 -0.0001 -627 +629 +626 +631      $ Flange / Lid Void
634 8 -7.8212 -632 +633       $ Anchor steel
635 13 -0.0001 -633        $ Anchor cavity
636 8 -7.8212 -634 +635       $ Anchor steel
637 13 -0.0001 -635        $ Anchor cavity
638 11 -2.3220 -640 +628 +629 +630  +632 +634 +636 +638  #626    $ Lid Concrete
639 13 -0.0001 -641 +613 +640      $ Exterior space to Reflector
640 0         +641        $ Exterior space

c Surfaces - Fuel Rod - CE16H1 - CE Core - 16x16
1 RCC 0.0000 0.0000 2.2631 0.0000 0.0000 381.0000 0.4128 $ Fuel pellet stack
2 RCC 0.0000 0.0000 2.2631 0.0000 0.0000 406.0876 0.4217 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 409.6207 0.4852 $ Clad + End-Caps
c Surfaces - Guide Tube - CE16H1 - CE Core - 16x16
5 CZ 1.1430       $ Guide tube inner surface
6 CZ 1.2319       $ Guide tube outer surface
c Surfaces - Pitch - CE16H1 - CE Core - 16x16
7 PX 0.6430       $ Lattice Cell Boundaries
8 PX -0.6430
9 PY 0.6430
10 PY -0.6430
c Surfaces - Fuel Assembly Array Inserted Into Assembly - CE16H1 - CE Core - 16x16
11 RPP -10.1302 10.1302 -10.1302 10.1302 9.6825 424.1758  $ Array
12 RPP -10.2870 10.2870 -10.2870 10.2870 0.0000 450.3471  $ Assembly Outer Dims
c Surface Cards - Tube, Absorber and Retainer
101 RPP -10.1981 10.1981 -11.4618 -11.2078 8.8900 446.4050 $ Absorber -Y
102 RPP -10.1981 10.1981 -11.4999 -11.1697 8.8900 446.4050 $ Absorber Clad  -Y
103 RPP -10.1981 10.1981 11.2078 11.4618 8.8900 446.4050 $ Absorber +Y
104 RPP -10.1981 10.1981 11.1697 11.4999 8.8900 446.4050 $ Absorber Clad  +Y
105 RPP -10.3378 10.3378 -11.1697 -11.1316 7.6200 448.3100 $ Retainer -Y
106 RPP -10.3378 10.3378 11.1316 11.1697 7.6200 448.3100 $ Retainer  +Y
107 RPP 4.2863 5.8738 -12.3698 12.3698 10.4712 13.6589 $ Weld Post Slot Y Absorber
108 RPP 4.2863 5.8738 -12.3698 12.3698 35.8712 39.0589 $ Weld Post Slot Y Absorber
109 RPP 4.2863 5.8738 -12.3698 12.3698 61.2712 64.4589 $ Weld Post Slot Y Absorber
110 RPP 4.2863 5.8738 -12.3698 12.3698 86.6712 89.8589 $ Weld Post Slot Y Absorber
111 RPP 4.2863 5.8738 -12.3698 12.3698 112.0712 115.2589 $ Weld Post Slot Y Absorber
112 RPP 4.2863 5.8738 -12.3698 12.3698 137.4712 140.6589 $ Weld Post Slot Y Absorber
113 RPP 4.2863 5.8738 -12.3698 12.3698 162.8712 166.0589 $ Weld Post Slot Y Absorber
114 RPP 4.2863 5.8738 -12.3698 12.3698 188.2712 191.4589 $ Weld Post Slot Y Absorber
115 RPP 4.2863 5.8738 -12.3698 12.3698 213.6712 216.8589 $ Weld Post Slot Y Absorber
116 RPP 4.2863 5.8738 -12.3698 12.3698 239.0712 242.2589 $ Weld Post Slot Y Absorber
117 RPP 4.2863 5.8738 -12.3698 12.3698 264.4712 267.6589 $ Weld Post Slot Y Absorber
118 RPP 4.2863 5.8738 -12.3698 12.3698 289.8712 293.0589 $ Weld Post Slot Y Absorber
119 RPP 4.2863 5.8738 -12.3698 12.3698 315.2712 318.4589 $ Weld Post Slot Y Absorber
120 RPP 4.2863 5.8738 -12.3698 12.3698 340.6712 343.8589 $ Weld Post Slot Y Absorber
121 RPP 4.2863 5.8738 -12.3698 12.3698 366.0712 369.2589 $ Weld Post Slot Y Absorber
122 RPP 4.2863 5.8738 -12.3698 12.3698 391.4712 394.6589 $ Weld Post Slot Y Absorber
123 RPP 4.2863 5.8738 -12.3698 12.3698 416.8712 420.0589 $ Weld Post Slot Y Absorber
124 RPP 4.2863 5.8738 -12.3698 12.3698 442.2712 445.4589 $ Weld Post Slot Y Absorber
125 RPP -5.8738 -4.2863 -12.3698 12.3698 10.4712 13.6589 $ Weld Post Slot Y Absorber
126 RPP -5.8738 -4.2863 -12.3698 12.3698 35.8712 39.0589 $ Weld Post Slot Y Absorber
127 RPP -5.8738 -4.2863 -12.3698 12.3698 61.2712 64.4589 $ Weld Post Slot Y Absorber
128 RPP -5.8738 -4.2863 -12.3698 12.3698 86.6712 89.8589 $ Weld Post Slot Y Absorber
129 RPP -5.8738 -4.2863 -12.3698 12.3698 112.0712 115.2589 $ Weld Post Slot Y Absorber
130 RPP -5.8738 -4.2863 -12.3698 12.3698 137.4712 140.6589 $ Weld Post Slot Y Absorber
131 RPP -5.8738 -4.2863 -12.3698 12.3698 162.8712 166.0589 $ Weld Post Slot Y Absorber
132 RPP -5.8738 -4.2863 -12.3698 12.3698 188.2712 191.4589 $ Weld Post Slot Y Absorber
133 RPP -5.8738 -4.2863 -12.3698 12.3698 213.6712 216.8589 $ Weld Post Slot Y Absorber
134 RPP -5.8738 -4.2863 -12.3698 12.3698 239.0712 242.2589 $ Weld Post Slot Y Absorber
135 RPP -5.8738 -4.2863 -12.3698 12.3698 264.4712 267.6589 $ Weld Post Slot Y Absorber
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
136 RPP -5.8738 -4.2863 -12.3698 12.3698 289.8712 293.0589 $ Weld Post Slot Y Absorber
137 RPP -5.8738 -4.2863 -12.3698 12.3698 315.2712 318.4589 $ Weld Post Slot Y Absorber
138 RPP -5.8738 -4.2863 -12.3698 12.3698 340.6712 343.8589 $ Weld Post Slot Y Absorber
139 RPP -5.8738 -4.2863 -12.3698 12.3698 366.0712 369.2589 $ Weld Post Slot Y Absorber
140 RPP -5.8738 -4.2863 -12.3698 12.3698 391.4712 394.6589 $ Weld Post Slot Y Absorber
141 RPP -5.8738 -4.2863 -12.3698 12.3698 416.8712 420.0589 $ Weld Post Slot Y Absorber
142 RPP -5.8738 -4.2863 -12.3698 12.3698 442.2712 445.4589 $ Weld Post Slot Y Absorber
143 C/Y 5.0800 12.0650 0.4191    $ Weld Post Hole Y
144 C/Y 5.0800 37.4650 0.4191    $ Weld Post Hole Y
145 C/Y 5.0800 62.8650 0.4191    $ Weld Post Hole Y
146 C/Y 5.0800 88.2650 0.4191    $ Weld Post Hole Y
147 C/Y 5.0800 113.6650 0.4191    $ Weld Post Hole Y
148 C/Y 5.0800 139.0650 0.4191    $ Weld Post Hole Y
149 C/Y 5.0800 164.4650 0.4191    $ Weld Post Hole Y
150 C/Y 5.0800 189.8650 0.4191    $ Weld Post Hole Y
151 C/Y 5.0800 215.2650 0.4191    $ Weld Post Hole Y
152 C/Y 5.0800 240.6650 0.4191    $ Weld Post Hole Y
153 C/Y 5.0800 266.0650 0.4191    $ Weld Post Hole Y
154 C/Y 5.0800 291.4650 0.4191    $ Weld Post Hole Y
155 C/Y 5.0800 316.8650 0.4191    $ Weld Post Hole Y
156 C/Y 5.0800 342.2650 0.4191    $ Weld Post Hole Y
157 C/Y 5.0800 367.6650 0.4191    $ Weld Post Hole Y
158 C/Y 5.0800 393.0650 0.4191    $ Weld Post Hole Y
159 C/Y 5.0800 418.4650 0.4191    $ Weld Post Hole Y
160 C/Y 5.0800 443.8650 0.4191    $ Weld Post Hole Y
161 C/Y -5.0800 12.0650 0.4191    $ Weld Post Hole Y
162 C/Y -5.0800 37.4650 0.4191    $ Weld Post Hole Y
163 C/Y -5.0800 62.8650 0.4191    $ Weld Post Hole Y
164 C/Y -5.0800 88.2650 0.4191    $ Weld Post Hole Y
165 C/Y -5.0800 113.6650 0.4191    $ Weld Post Hole Y
166 C/Y -5.0800 139.0650 0.4191    $ Weld Post Hole Y
167 C/Y -5.0800 164.4650 0.4191    $ Weld Post Hole Y
168 C/Y -5.0800 189.8650 0.4191    $ Weld Post Hole Y
169 C/Y -5.0800 215.2650 0.4191    $ Weld Post Hole Y
170 C/Y -5.0800 240.6650 0.4191    $ Weld Post Hole Y
171 C/Y -5.0800 266.0650 0.4191    $ Weld Post Hole Y
172 C/Y -5.0800 291.4650 0.4191    $ Weld Post Hole Y
173 C/Y -5.0800 316.8650 0.4191    $ Weld Post Hole Y
174 C/Y -5.0800 342.2650 0.4191    $ Weld Post Hole Y
175 C/Y -5.0800 367.6650 0.4191    $ Weld Post Hole Y
176 C/Y -5.0800 393.0650 0.4191    $ Weld Post Hole Y
177 C/Y -5.0800 418.4650 0.4191    $ Weld Post Hole Y
178 C/Y -5.0800 443.8650 0.4191    $ Weld Post Hole Y
179 C/Y 5.0800 12.0650 0.3175    $ Weld Post Y
180 C/Y 5.0800 37.4650 0.3175    $ Weld Post Y
181 C/Y 5.0800 62.8650 0.3175    $ Weld Post Y
182 C/Y 5.0800 88.2650 0.3175    $ Weld Post Y
183 C/Y 5.0800 113.6650 0.3175    $ Weld Post Y
184 C/Y 5.0800 139.0650 0.3175    $ Weld Post Y
185 C/Y 5.0800 164.4650 0.3175    $ Weld Post Y
186 C/Y 5.0800 189.8650 0.3175    $ Weld Post Y
187 C/Y 5.0800 215.2650 0.3175    $ Weld Post Y
188 C/Y 5.0800 240.6650 0.3175    $ Weld Post Y
189 C/Y 5.0800 266.0650 0.3175    $ Weld Post Y
190 C/Y 5.0800 291.4650 0.3175    $ Weld Post Y
191 C/Y 5.0800 316.8650 0.3175    $ Weld Post Y
192 C/Y 5.0800 342.2650 0.3175    $ Weld Post Y
193 C/Y 5.0800 367.6650 0.3175    $ Weld Post Y
194 C/Y 5.0800 393.0650 0.3175    $ Weld Post Y
195 C/Y 5.0800 418.4650 0.3175    $ Weld Post Y
196 C/Y 5.0800 443.8650 0.3175    $ Weld Post Y
197 C/Y -5.0800 12.0650 0.3175    $ Weld Post Y
198 C/Y -5.0800 37.4650 0.3175    $ Weld Post Y
199 C/Y -5.0800 62.8650 0.3175    $ Weld Post Y
200 C/Y -5.0800 88.2650 0.3175    $ Weld Post Y
201 C/Y -5.0800 113.6650 0.3175    $ Weld Post Y
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
202 C/Y -5.0800 139.0650 0.3175    $ Weld Post Y
203 C/Y -5.0800 164.4650 0.3175    $ Weld Post Y
204 C/Y -5.0800 189.8650 0.3175    $ Weld Post Y
205 C/Y -5.0800 215.2650 0.3175    $ Weld Post Y
206 C/Y -5.0800 240.6650 0.3175    $ Weld Post Y
207 C/Y -5.0800 266.0650 0.3175    $ Weld Post Y
208 C/Y -5.0800 291.4650 0.3175    $ Weld Post Y
209 C/Y -5.0800 316.8650 0.3175    $ Weld Post Y
210 C/Y -5.0800 342.2650 0.3175    $ Weld Post Y
211 C/Y -5.0800 367.6650 0.3175    $ Weld Post Y
212 C/Y -5.0800 393.0650 0.3175    $ Weld Post Y
213 C/Y -5.0800 418.4650 0.3175    $ Weld Post Y
214 C/Y -5.0800 443.8650 0.3175    $ Weld Post Y
215 RPP -1.5875 1.5875 -12.3698 12.3698 431.4762 434.6639 $ Water Circulation Slot Y
216 RPP -11.4618 -11.2078 -10.1981 10.1981 8.8900 446.4050 $ Absorber -X
217 RPP -11.4999 -11.1697 -10.1981 10.1981 8.8900 446.4050 $ Absorber Clad  -X
218 RPP 11.2078 11.4618 -10.1981 10.1981 8.8900 446.4050 $ Absorber +X
219 RPP 11.1697 11.4999 -10.1981 10.1981 8.8900 446.4050 $ Absorber Clad  +X
220 RPP -11.1697 -11.1316 -10.3378 10.3378 7.6200 448.3100 $ Retainer -X
221 RPP 11.1316 11.1697 -10.3378 10.3378 7.6200 448.3100 $ Retainer  +X
222 RPP -12.3698 12.3698 4.2863 5.8738 10.4712 13.6589 $ Weld Post Slot X Absorber
223 RPP -12.3698 12.3698 4.2863 5.8738 35.8712 39.0589 $ Weld Post Slot X Absorber
224 RPP -12.3698 12.3698 4.2863 5.8738 61.2712 64.4589 $ Weld Post Slot X Absorber
225 RPP -12.3698 12.3698 4.2863 5.8738 86.6712 89.8589 $ Weld Post Slot X Absorber
226 RPP -12.3698 12.3698 4.2863 5.8738 112.0712 115.2589 $ Weld Post Slot X Absorber
227 RPP -12.3698 12.3698 4.2863 5.8738 137.4712 140.6589 $ Weld Post Slot X Absorber
228 RPP -12.3698 12.3698 4.2863 5.8738 162.8712 166.0589 $ Weld Post Slot X Absorber
229 RPP -12.3698 12.3698 4.2863 5.8738 188.2712 191.4589 $ Weld Post Slot X Absorber
230 RPP -12.3698 12.3698 4.2863 5.8738 213.6712 216.8589 $ Weld Post Slot X Absorber
231 RPP -12.3698 12.3698 4.2863 5.8738 239.0712 242.2589 $ Weld Post Slot X Absorber
232 RPP -12.3698 12.3698 4.2863 5.8738 264.4712 267.6589 $ Weld Post Slot X Absorber
233 RPP -12.3698 12.3698 4.2863 5.8738 289.8712 293.0589 $ Weld Post Slot X Absorber
234 RPP -12.3698 12.3698 4.2863 5.8738 315.2712 318.4589 $ Weld Post Slot X Absorber
235 RPP -12.3698 12.3698 4.2863 5.8738 340.6712 343.8589 $ Weld Post Slot X Absorber
236 RPP -12.3698 12.3698 4.2863 5.8738 366.0712 369.2589 $ Weld Post Slot X Absorber
237 RPP -12.3698 12.3698 4.2863 5.8738 391.4712 394.6589 $ Weld Post Slot X Absorber
238 RPP -12.3698 12.3698 4.2863 5.8738 416.8712 420.0589 $ Weld Post Slot X Absorber
239 RPP -12.3698 12.3698 4.2863 5.8738 442.2712 445.4589 $ Weld Post Slot X Absorber
240 RPP -12.3698 12.3698 -5.8738 -4.2863 10.4712 13.6589 $ Weld Post Slot X Absorber
241 RPP -12.3698 12.3698 -5.8738 -4.2863 35.8712 39.0589 $ Weld Post Slot X Absorber
242 RPP -12.3698 12.3698 -5.8738 -4.2863 61.2712 64.4589 $ Weld Post Slot X Absorber
243 RPP -12.3698 12.3698 -5.8738 -4.2863 86.6712 89.8589 $ Weld Post Slot X Absorber
244 RPP -12.3698 12.3698 -5.8738 -4.2863 112.0712 115.2589 $ Weld Post Slot X Absorber
245 RPP -12.3698 12.3698 -5.8738 -4.2863 137.4712 140.6589 $ Weld Post Slot X Absorber
246 RPP -12.3698 12.3698 -5.8738 -4.2863 162.8712 166.0589 $ Weld Post Slot X Absorber
247 RPP -12.3698 12.3698 -5.8738 -4.2863 188.2712 191.4589 $ Weld Post Slot X Absorber
248 RPP -12.3698 12.3698 -5.8738 -4.2863 213.6712 216.8589 $ Weld Post Slot X Absorber
249 RPP -12.3698 12.3698 -5.8738 -4.2863 239.0712 242.2589 $ Weld Post Slot X Absorber
250 RPP -12.3698 12.3698 -5.8738 -4.2863 264.4712 267.6589 $ Weld Post Slot X Absorber
251 RPP -12.3698 12.3698 -5.8738 -4.2863 289.8712 293.0589 $ Weld Post Slot X Absorber
252 RPP -12.3698 12.3698 -5.8738 -4.2863 315.2712 318.4589 $ Weld Post Slot X Absorber
253 RPP -12.3698 12.3698 -5.8738 -4.2863 340.6712 343.8589 $ Weld Post Slot X Absorber
254 RPP -12.3698 12.3698 -5.8738 -4.2863 366.0712 369.2589 $ Weld Post Slot X Absorber
255 RPP -12.3698 12.3698 -5.8738 -4.2863 391.4712 394.6589 $ Weld Post Slot X Absorber
256 RPP -12.3698 12.3698 -5.8738 -4.2863 416.8712 420.0589 $ Weld Post Slot X Absorber
257 RPP -12.3698 12.3698 -5.8738 -4.2863 442.2712 445.4589 $ Weld Post Slot X Absorber
258 C/X 5.0800 12.0650 0.4191    $ Weld Post Hole X
259 C/X 5.0800 37.4650 0.4191    $ Weld Post Hole X
260 C/X 5.0800 62.8650 0.4191    $ Weld Post Hole X
261 C/X 5.0800 88.2650 0.4191    $ Weld Post Hole X
262 C/X 5.0800 113.6650 0.4191    $ Weld Post Hole X
263 C/X 5.0800 139.0650 0.4191    $ Weld Post Hole X
264 C/X 5.0800 164.4650 0.4191    $ Weld Post Hole X
265 C/X 5.0800 189.8650 0.4191    $ Weld Post Hole X
266 C/X 5.0800 215.2650 0.4191    $ Weld Post Hole X
267 C/X 5.0800 240.6650 0.4191    $ Weld Post Hole X
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
268 C/X 5.0800 266.0650 0.4191    $ Weld Post Hole X
269 C/X 5.0800 291.4650 0.4191    $ Weld Post Hole X
270 C/X 5.0800 316.8650 0.4191    $ Weld Post Hole X
271 C/X 5.0800 342.2650 0.4191    $ Weld Post Hole X
272 C/X 5.0800 367.6650 0.4191    $ Weld Post Hole X
273 C/X 5.0800 393.0650 0.4191    $ Weld Post Hole X
274 C/X 5.0800 418.4650 0.4191    $ Weld Post Hole X
275 C/X 5.0800 443.8650 0.4191    $ Weld Post Hole X
276 C/X -5.0800 12.0650 0.4191    $ Weld Post Hole X
277 C/X -5.0800 37.4650 0.4191    $ Weld Post Hole X
278 C/X -5.0800 62.8650 0.4191    $ Weld Post Hole X
279 C/X -5.0800 88.2650 0.4191    $ Weld Post Hole X
280 C/X -5.0800 113.6650 0.4191    $ Weld Post Hole X
281 C/X -5.0800 139.0650 0.4191    $ Weld Post Hole X
282 C/X -5.0800 164.4650 0.4191    $ Weld Post Hole X
283 C/X -5.0800 189.8650 0.4191    $ Weld Post Hole X
284 C/X -5.0800 215.2650 0.4191    $ Weld Post Hole X
285 C/X -5.0800 240.6650 0.4191    $ Weld Post Hole X
286 C/X -5.0800 266.0650 0.4191    $ Weld Post Hole X
287 C/X -5.0800 291.4650 0.4191    $ Weld Post Hole X
288 C/X -5.0800 316.8650 0.4191    $ Weld Post Hole X
289 C/X -5.0800 342.2650 0.4191    $ Weld Post Hole X
290 C/X -5.0800 367.6650 0.4191    $ Weld Post Hole X
291 C/X -5.0800 393.0650 0.4191    $ Weld Post Hole X
292 C/X -5.0800 418.4650 0.4191    $ Weld Post Hole X
293 C/X -5.0800 443.8650 0.4191    $ Weld Post Hole X
294 C/X 5.0800 12.0650 0.3175    $ Weld Post X
295 C/X 5.0800 37.4650 0.3175    $ Weld Post X
296 C/X 5.0800 62.8650 0.3175    $ Weld Post X
297 C/X 5.0800 88.2650 0.3175    $ Weld Post X
298 C/X 5.0800 113.6650 0.3175    $ Weld Post X
299 C/X 5.0800 139.0650 0.3175    $ Weld Post X
300 C/X 5.0800 164.4650 0.3175    $ Weld Post X
301 C/X 5.0800 189.8650 0.3175    $ Weld Post X
302 C/X 5.0800 215.2650 0.3175    $ Weld Post X
303 C/X 5.0800 240.6650 0.3175    $ Weld Post X
304 C/X 5.0800 266.0650 0.3175    $ Weld Post X
305 C/X 5.0800 291.4650 0.3175    $ Weld Post X
306 C/X 5.0800 316.8650 0.3175    $ Weld Post X
307 C/X 5.0800 342.2650 0.3175    $ Weld Post X
308 C/X 5.0800 367.6650 0.3175    $ Weld Post X
309 C/X 5.0800 393.0650 0.3175    $ Weld Post X
310 C/X 5.0800 418.4650 0.3175    $ Weld Post X
311 C/X 5.0800 443.8650 0.3175    $ Weld Post X
312 C/X -5.0800 12.0650 0.3175    $ Weld Post X
313 C/X -5.0800 37.4650 0.3175    $ Weld Post X
314 C/X -5.0800 62.8650 0.3175    $ Weld Post X
315 C/X -5.0800 88.2650 0.3175    $ Weld Post X
316 C/X -5.0800 113.6650 0.3175    $ Weld Post X
317 C/X -5.0800 139.0650 0.3175    $ Weld Post X
318 C/X -5.0800 164.4650 0.3175    $ Weld Post X
319 C/X -5.0800 189.8650 0.3175    $ Weld Post X
320 C/X -5.0800 215.2650 0.3175    $ Weld Post X
321 C/X -5.0800 240.6650 0.3175    $ Weld Post X
322 C/X -5.0800 266.0650 0.3175    $ Weld Post X
323 C/X -5.0800 291.4650 0.3175    $ Weld Post X
324 C/X -5.0800 316.8650 0.3175    $ Weld Post X
325 C/X -5.0800 342.2650 0.3175    $ Weld Post X
326 C/X -5.0800 367.6650 0.3175    $ Weld Post X
327 C/X -5.0800 393.0650 0.3175    $ Weld Post X
328 C/X -5.0800 418.4650 0.3175    $ Weld Post X
329 C/X -5.0800 443.8650 0.3175    $ Weld Post X
330 RPP -12.3698 12.3698 -1.5875 1.5875 431.4762 434.6639 $ Water Circulation Slot X
331 RPP -11.4999 11.4999 -11.4999 11.4999 0.0000 458.4700 $  Space inside tube - cavity extent
332 RPP -12.3698 12.3698 -12.3698 12.3698 7.6200 448.3100 $  Fuel tube
C Surfaces - Basket
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
401  RPP -12.3698 12.3698 -12.3698 12.3698 0.0000 458.4700  $ Tube Cavity Height
402 1 RPP -16.6116 16.6116 -16.6116 16.6116 0.0000 458.4700  $ Tube Corner Cuts
403  RPP -33.9471 33.9471 -83.6409 83.6409 7.6200 448.3100  $ Outer Surface Side Weld.
404  RPP -33.9471 33.9471 -81.7359 81.7359 7.6200 448.3100  $ Inner Surface Side Weld.
405  RPP -83.6409 83.6409 -33.9471 33.9471 7.6200 448.3100  $ Outer Surface Side Weld.
406  RPP -81.7359 81.7359 -33.9471 33.9471 7.6200 448.3100  $ Inner Surface Side Weld.
407 1 RPP -80.1366 80.1366 -80.1366 80.1366 7.6200 448.3100  $ Outer Surface Corner Weld.
408 1 RPP -79.3428 79.3428 -79.3428 79.3428 7.6200 448.3100  $ Inner Surface Corner Weld.
409  RPP -82.8472 82.8472 -82.8472 82.8472 7.6200 448.3100  $ Corner Weld. Cut Surface
410  RPP -60.1485 60.1485 -60.1485 60.1485 7.6200 448.3100  $ Outer Surface Corner Weld.
411  RPP -59.3547 59.3547 -59.3547 59.3547 7.6200 448.3100  $ Inner Surface Corner Weld.
412  RPP -82.1868 82.1868 -36.6560 36.6560 7.6200 448.3100  $ Outer Surface Corner Weld.
413  RPP -82.1868 82.1868 -35.8623 35.8623 7.6200 448.3100  $ Inner Surface Corner Weld.
414  RPP -36.6560 36.6560 -82.1868 82.1868 7.6200 448.3100  $ Outer Surface Corner Weld.
415  RPP -35.8623 35.8623 -82.1868 82.1868 7.6200 448.3100  $ Inner Surface Corner Weld.
c Surface Cards - Canister
501 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 458.4700  90.1700 $ Canister cavity
502 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 487.0450  91.4400 $ Canister
c VCC Surfaces
601  RCC 0.0000 0.0000 -5.0800 0.0000 0.0000 5.0800 91.4401  $ Pedestal plate
602  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 63.5000  $ Stand outer
603  RCC 0.0000 0.0000 -30.2260 0.0000 0.0000 25.1460 62.3888  $ Stand inner
604 1 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate A
605 2 RPP -100.3300 100.3300 -10.4775 10.4775 -32.7660 -16.3830   $ Connector plate B
606 1 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall A
607 2 RPP -99.0600 99.0600 -9.2075 9.2075 -32.7660 -16.3830   $ Air inlet angled wall B
608  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 172.7200  $ Bottom plate outer
609  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 100.3300  $ Connector radius
610  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 2.5400 63.5000  $ Bottom plate inner
611  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 105.41  $ VCC liner outer
612  RCC 0.0000 0.0000 -16.3830 0.0000 0.0000 504.3932 100.965  $ VCC liner inner
613  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 518.2362 172.7200  $ Concrete
614  RPP -172.7200 172.7200 -63.5000 63.5000 -32.7660 -21.4630   $ Air inlet void X
615  RPP -63.5000 63.5000 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet void Y
616  RPP -172.7200 172.7200 -64.7700 64.7700 -32.7660 -21.4630   $ Air inlet wall X
617  RPP -64.7700 64.7700 -172.7200 172.7200 -32.7660 -21.4630   $ Air inlet wall Y
618  RCC 0.0000 0.0000 -32.7660 0.0000 0.0000 11.3030 100.3300  $ Air inlet divider
619  RPP -172.7200 172.7200 -64.7700 64.7700 -21.4630 -16.3830   $ Air inlet top X
620  RPP -64.7700 64.7700 -172.7200 172.7200 -21.4630 -16.3830   $ Air inlet top Y
621  RCC 0.0000 0.0000 -21.4630 0.0000 0.0000 5.0800 93.98  $ Air inlet top plate radius
622  RPP -106.6800 106.6800 -5.7150 5.7150 -16.3830 -5.0800   $ Support rail exterior X
623  RPP -106.6800 106.6800 -4.4450 4.4450 -16.3830 -5.0800   $ Support rail interior X
624  RPP -5.7150 5.7150 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail exterior Y
625  RPP -4.4450 4.4450 -106.6800 106.6800 -16.3830 -5.0800   $ Support rail interior Y
626  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 2.5400 115.5700  $ Top flange
627  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 3.8100 116.4971  $ Lid base
628  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 3.8100 172.7200  $ Lid base outer
629  RCC 0.0000 0.0000 488.3277 0.0000 0.0000 0.9525 116.4971  $ Lid base disk
630  RCC 0.0000 0.0000 488.3277 0.0000 0.0000 35.2425 101.6  $ Lid liner outer
631  CZ       100.9650  $ Lid liner inner
632 1 RPP -15.2400 15.2400 143.5100 179.3748 489.2802 539.4452   $ Anchor cavity outer
633 1 RPP -14.6050 14.6050 144.1450 178.7398 489.2802 539.4452   $ Anchor cavity inner
634 2 RPP -15.2400 15.2400 -179.3748 -143.5100 489.2802 539.4452   $ Anchor cavity outer
635 2 RPP -14.6050 14.6050 -178.7398 -144.1450 489.2802 539.4452   $ Anchor cavity inner
636  RPP -64.7700 64.7700 -172.7200 172.7200 514.1722 524.2052   $ Air outlet steel
637  RPP -63.5000 63.5000 -172.7200 172.7200 514.8072 523.5702   $ Air outlet void
638  RPP -172.7200 172.7200 -64.7700 64.7700 514.1722 524.2052   $ Air outlet steel
639  RPP -172.7200 172.7200 -63.5000 63.5000 514.8072 523.5702   $ Air outlet void
640  RCC 0.0000 0.0000 485.4702 0.0000 0.0000 53.9750 172.7200  $ Lid container
*641  RCC 0.0000 0.0000 -52.766 0.0000 0.0000 612.2112 192.7200  $ Reflecting Boundary

c
c Materials List
c
c Fuel Pellet Material  5.00%  Weight UO2 [amu]  269.8995
m1    92235.66c -4.407E-02 92238.66c -8.374E-01  8016.62c -1.186E-01
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
c Clad Material
m2     26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
       26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
       26057.62c -2.702E-05 24053.62c -9.673E-05
       26058.62c -3.631E-06 24054.62c -2.448E-05
       40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3      1001.62c -1.119E-01  8016.62c -8.881E-01
mt3  lwtr.01t
c Lower Nozzle Material
m4
        1001.62c -6.193E-06  8016.62c -4.914E-05
       24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
       24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
       24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
       24054.62c -4.651E-03 26058.62c -2.019E-03 28062.62c -3.638E-03
                                                 28064.62c -9.622E-04
       25055.62c -2.000E-02
mt4  lwtr.01t
c Upper Nozzle Material
m5
        1001.62c -6.658E-06  8016.62c -5.284E-05
       24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
       24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
       24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
       24054.62c -4.651E-03 26058.62c -2.019E-03 28062.62c -3.638E-03
                                                 28064.62c -9.622E-04
       25055.62c -2.000E-02
mt5  lwtr.01t
c SS304
m6     24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
       24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
       24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
       24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                 28064.62c -9.623E-04
       25055.62c -2.000E-02
c Aluminum
m7     13027.62c -1.000E+00
c Carbon Steel
m8     26054.62c -5.594E-02  6000.66c -1.000E-02
       26056.62c -9.098E-01
       26057.62c -2.140E-02
       26058.62c -2.876E-03
c Lead
m9     82206.66c -2.534E-01
       82207.66c -2.207E-01
       82208.66c -5.259E-01
c NS-F-FR
m10     5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
        5011.66c -3.772E-03  7015.66c -7.852E-05
       13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11    26054.62c -7.911E-04 14000.60c -3.370E-01
       26056.62c -1.287E-02
       26057.62c -3.026E-04
       26058.62c -4.067E-05
        1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
        8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12     5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
        5011.66c -2.799E-01
c Water Exterior
m13     1001.62c 2.0
        8016.62c 1.0
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
c
c Cell Importances
c
mode n
imp:n 1 251r 0
c
c
c Criticality Controls
c
kcode 500 1.00 30 130
c
c Source Distribution for Initial Generation
SDEF  CEL= 623 : D2 : 11 : 7 : -1
      ERG= D1
      POS= 0.0000 0.00 2.2631
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          1        d
      501 1
      502 1
      503 1
      504 1
      505 1
      506 1
      507 1
      508 1
      509 1
      510 1
      511 1
      512 1
      513 1
      514 1
      515 1
      516 1
      517 1
      518 1
      519 1
      520 1
      521 1
```

Figure 6.7.1-4 MCNP Concrete Cask Model – PWR 37-Assembly Basket

```
      522 1
      523 1
      524 1
      525 1
      526 1
      527 1
      528 1
      529 1
      530 1
      531 1
      532 1
      533 1
      534 1
      535 1
      536 1
      537 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4128 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      381 1.0
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

6.7.2 PWR Fuel Characterization

Fuel definitions listed in Section 6.4 are the result of grouping the large range of commercial fuel types by core type, number of fuel rods, and key criticality characteristics. These characteristics are primarily associated with the assembly moderator ratio and fuel mass and include pellet diameter, active fuel length, fuel rod diameter and clad thickness, and guide/instrument tube diameter and thickness.

PWR fuel assemblies are typically undermoderated (H/U ratio below optimum levels). Therefore, initial criticality analysis extracts from each assembly type the following characteristics.

- Minimum fuel rod outer diameter
- Minimum clad thickness (only relevant to flooded pellet-to-clad gap scenarios)
- Minimum guide tube outer diameter and thickness
- Maximum rod pitch (assemblies are grouped by core type and, therefore, typically have single nominal pitch)

Based on the maximum H/U set of characteristics, the reactivity of each assembly is determined under various conditions. Evaluated are a dry-pellet-to-clad gap condition, a flooded-pellet-to-gap condition (with and without soluble boron in the gap), and nonfuel hardware insertion into the guide tubes. Since relative reactivity for the assembly design and flood conditions are evaluated, the models are based on nominal basket characteristics with the assemblies centered in the tube and developed cell. Comparisons are performed at a soluble boron level of 2500 ppm and a 5 wt % enrichment. A ^{235}U enrichment of 5 wt % represents the upper boundary for licensing of the system. The 2,500 ppm soluble boron level approximates the level required to maintain reactivity control in the system. The exact soluble boron level required for each assembly type, with and without insert, is determined in Section 6.7.3 at the maximum reactivity basket configuration.

Results of the analysis at various clad-to-gap conditions are shown in Table 6.7.2-1 and demonstrate that system reactivity is closely tied to fuel mass. Reactivity differences associated with improved moderator ratios (higher H/U ratio) are offset by the high soluble boron content in the moderator. This conclusion is validated by the analysis flooding the fuel-pellet-to-clad gap with borated and unborated water. Flooding the gap with borated water did not result in a significant reactivity change for any of the assembly types (judged to be significant if the $\Delta k_{eff}/\sigma > 3$). Flooding the same gap with unborated water significantly increased system reactivity for the majority of fuel types.

As illustrated in Table 6.7.2-2, the effect of the insertion of nonfuel hardware into the active fuel elevation of the guide tube varied by fuel type. The most significant effect associated with the nonfuel hardware insertion is for the CE assembly configuration. The CE core designs contain oversize tubes occupying four lattice locations. Replacing the large amount of soluble absorber in these locations significantly increases system reactivity. The effect of nonfuel hardware may differ at lower soluble boron content; therefore, licensing maximum enrichment and minimum soluble boron content runs are repeated for all assembly types at the maximum reactivity basket configuration with, and without, insert.

The evaluation presented previously assumed that the assemblies are undermoderated and that choosing the corresponding set of parameters maximizes system reactivity. This assumption is validated by evaluating a subset of the fuel assembly types for a variation in the lattice parameters. As typical assemblies loaded into the cask are expected to be intact (no leakage), the pellet-to-clad gap is specified to be dry for these analyses. Fuel assemblies are evaluated in a nominal configuration basket with fuel assemblies centered in the tube. As this evaluation is concerned with relative reactivity differences due to lattice parameter changes, the results of this analysis may be applied to the maximum reactivity basket configuration. To bound likely loading specifications, the evaluations are performed at three enrichment/boron content levels (i.e., 3 wt % and 1,100 ppm, 4 wt % and 1,800 ppm, 5 wt % and 2,500 ppm) for the nominal parameter range of each of the assembly "hybrids" (e.g., WE17H1 rod outer diameter ranges from 0.372 to 0.374 inch).

Rather than evaluating individual parameter effects separately, the fuel characteristics analysis is divided into distinct regions.

Fuel rod lattice unit cell
- H/U ratio controlled by rod pitch, rod diameter, and clad thickness

Guide/instrument tube unit cell
- H/U controlled by guide tube diameter and thickness, and

Pellet diameter (NUREG-6716 [9] indicates the possibility of a minimum pellet diameter increasing system reactivity)

Monte Carlo evaluation results of the nominal assembly parameter ranges provided limited useful information, as the majority of reactivity changes were not resolvable within a two or three sigma uncertainty band. Statistically significant results were obtained from an additional calculation set applying increased variances to each of the parameters. Refer to Table 6.7.2-3 for the result of the increased variance evaluation for the wet unborated gap, 2,500 ppm, 5.0 wt % enriched case. Similar results were obtained from the 1,100 ppm / 3 wt % ^{235}U and 1,800 ppm / 4 wt % ^{235}U analyses sets. As shown, the cases containing maximum H/U ratio in the fuel rod lattice location, maximum H/U in the guide/instrument tube location (minimum guide/instrument

tube diameter and thickness), and maximum pellet diameter produce a maximum reactivity configuration system. The result set also demonstrates that guide tube dimensions are not crucial to system criticality control (note that the absence of guide/instrument tubes may increase reactivity statistics significantly). Therefore, the number of tubes should be specified in the limiting payload description not tube dimensions. Critical assemblies characteristics are listed below.

- Number of fuel rods
- Minimum fuel rod outer diameter
- Minimum clad thickness
- Maximum rod pitch
- Maximum active fuel length (not evaluated but based on neutron leakage maximum active fuel length results in a bounding payload definition)
- Number of guide/instrument tubes

Axial Blankets

Solid pellets of lower than midplane enrichment are bounded by the primary criticality evaluations performed in subsequent sections, as they present less fissile material while not increasing potential moderator volume. Annular pellets have the potential to increase system reactivity due to increased unborated moderator under flooded rod conditions. The improved moderation may compensate for the reduced fissile material quantity. As the blankets are in the axial high neutron leakage basket locations, there is no effect on system reactivity expected. This is confirmed by sample calculations using a 12-inch fully (midplane) enriched annular end-blanket WE17H1 hybrid at low and high soluble boron concentrations. The following data confirms that annular end-blankets represent an allowable MAGNASTOR payload.

Enrichment [wt %]	Boron Content	Annular Void [%]	k_{eff} +2σ	σ	Δk	Δk/σ
3.7	1500 ppm	--	0.93608	0.00074	--	--
3.7	1500 ppm	10	0.93665	0.00075	0.00057	0.54
3.7	1500 ppm	25	0.93411	0.00071	-0.00197	-1.92
3.7	1500 ppm	40	0.93701	0.00071	0.00093	0.91
4.9	2500 ppm	--	0.93389	0.00074	--	--
4.9	2500 ppm	10	0.93511	0.00071	0.00122	1.19
4.9	2500 ppm	25	0.93351	0.00077	-0.00038	-0.36
4.9	2500 ppm	40	0.93533	0.00070	0.00144	1.41

Table 6.7.2-1 System Reactivity Response to PWR Fuel Type and Pellet to Clad Condition

Assembly Type	Dry Gap No Insert k_{eff}	Wet Borated Gap No Insert k_{eff}	Dry Gap To Wet Borated Gap $\Delta k_{eff}/\sigma$	Wet Gap No Insert k_{eff}	Dry Gap to Wet Gap $\Delta k_{eff}/\sigma$	Fuel Mass (MTU)	Water / Fuel Ratio
CE14H1	0.86225	0.86229	0.0	0.86644	3.9	0.4167	1.62
CE16H1	0.86700	0.86937	2.2	0.87280	5.5	0.4463	1.71
BW15H1	0.92089	0.92082	-0.1	0.92563	4.4	0.4858	1.66
BW15H2	0.92674	0.92640	-0.3	0.92983	3.0	0.4988	1.62
BW15H3	0.92727	0.92716	-0.1	0.93045	2.9	0.5006	1.63
BW15H4	0.91301	0.91096	-2.0	0.91601	2.8	0.4690	1.82
BW17H1	0.92595	0.92503	-0.8	0.93079	4.5	0.4799	1.69
WE14H1	0.84955	0.84864	-0.8	0.84949	-0.1	0.4188	1.73
WE15H1	0.91177	0.91132	-0.4	0.91513	3.1	0.4720	1.68
WE15H2	0.90023	0.89780	-2.3	0.90057	0.3	0.4469	1.80
WE17H1	0.91897	0.91796	-1.0	0.92366	4.4	0.4740	1.67
WE17H2	0.89962	0.89730	-2.2	0.90029	0.6	0.4327	1.93

Table 6.7.2-2 System Reactivity Response to PWR Fuel Type and Nonfuel Insert

Assembly Type	Dry Gap No Insert k_{eff}	Dry Gap Insert k_{eff}	No Insert to Insert $\Delta k_{eff}/\sigma$
CE14H1	0.86225	0.87129	8.0
CE16H1	0.86700	0.87282	5.5
BW15H1	0.92089	0.91988	-1.0
BW15H2	0.92674	0.92569	-1.0
BW15H3	0.92727	0.92887	1.5
BW15H4	0.91301	0.91644	3.2
BW17H1	0.92595	0.92508	-0.8
WE14H1	0.84955	0.84863	-0.9
WE15H1	0.91177	0.91192	0.1
WE15H2	0.90023	0.90163	1.3
WE17H1	0.91897	0.91779	-1.1
WE17H2	0.89962	0.89725	-2.2

Table 6.7.2-3 PWR Lattice Parameter Reactivity Study (Increased Variance)

	2	6	1	4	3	5	7	8
Fuel Pin Cell H/U	Max	Min	Max	Max	Max	Min	Min	Min
Pellet Dia.	Max	Max	Max	Min	Min	Max	Min	Min
GT/IT Thick & Dia.	Min	Min	Max	Min	Max	Max	Max	Min
CE14H1	0.87036	0.85678	0.86976	0.86096	0.86053	0.85797	0.84877	0.84622
CE16H1	0.87710	0.86624	0.87895	0.87731	0.87844	0.86482	0.86418	0.86368
BW15H3	0.93513	0.92519	0.93561	0.92975	0.93121	0.92601	0.92338	0.92166
BW15H4	0.91969	0.91104	0.92021	0.91758	0.91814	0.91288	0.91180	0.91159
BW17H1	0.93191	0.92268	0.93276	0.93102	0.93121	0.92161	0.91947	0.92070
WE14H1	0.85469	0.84179	0.85598	0.82962	0.82905	0.84053	0.82110	0.81996
WE15H1	0.91628	0.90791	0.91798	0.90515	0.90695	0.90862	0.89507	0.89625
WE17H1	0.92739	0.91598	0.92807	0.92813	0.92763	0.91580	0.91562	0.91582
		Case 2 To Case 6	Case 2 To Case 1	Case 2 to Case 4	Case 2 to Case 3	Case 2 to Case 5	Case 2 to Case 7	Case 2 To Case 8
		$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$
CE14H1		-13.0	-0.6	-8.9	-9.5	-11.9	-21.1	-23.0
CE16H1		-10.0	1.7	0.2	1.2	-11.3	-11.9	-12.4
BW15H3		-13.7	0.7	-7.4	-5.3	-12.5	-15.9	-18.3
BW15H4		-7.7	0.5	-1.9	-1.4	-6.1	-7.1	-7.3
BW17H1		-8.9	0.8	-0.9	-0.7	-9.6	-12.0	-10.7
WE14H1		-12.0	1.2	-23.3	-24.0	-13.3	-31.0	-31.7
WE15H1		-7.8	1.6	-10.5	-8.7	-7.0	-19.4	-18.8
WE17H1		-10.7	0.6	0.7	0.2	-10.7	-10.9	-10.7

6.7.3 PWR Undamaged Fuel Criticality Evaluation

6.7.3.1 Optimum System Configuration

Enrichment and soluble boron limits are based on a maximum reactivity configuration system. To determine the maximum reactivity system, the following system perturbations are evaluated.

TSC interior moderator elevation variations (partial flooding)

Moderator density changes from void to full density (inside and outside the TSC)

Basket fabrication tolerance

Component shift scenarios

All system perturbation analyses are based on fuel assemblies at the maximum lattice moderator (H/U) ratio. Justification for this fuel assembly configuration is provided in Section 6.1.1. Only transfer cask cases are used in these evaluations since the transfer cask is the only cask body in which TSC flooding occurs. In the dry concrete cask, the TSC has a low reactivity, $k_{eff} < 0.5$.

Initial reactivity analysis is based on a basket and neutron absorber configuration with the following characteristics:

a.) Neutron absorbers on all four sides of each tube.

b.) A single column of weld posts connecting neutron absorber to tube, with 18 weld posts per tube.

c.) A neutron absorber thickness tolerance of ±0.005 inch.

d.) Fuel tube size and tube stack-up controlled by tube outer width and "interface width."

e.) Neutron absorber sheet effective areal density of 0.036 ^{10}B g/cm^2.

f.) For "insert" cases, only guide tubes are filled with zirconium alloy. The instrument tubes in WE and b*W hybrids contain TSC moderator.

Differences in reactivity due to system configuration and tolerance changes from these characteristics are evaluated in the subsection titled "Neutron Absorber and Tube Modifications" for geometry changes and in the subsection "Instrument Tube Insert" for the fill of both guide and instrument tubes.

Changes in neutron absorber areal density are addressed in Section 6.7.3.2.

Partial Flooding

Partial flood cases drain the TSC to the top of the active fuel region. The partial flood reactivity cases investigate reactivity difference between a water reflector over the active fuel region and reflection from the steel lid. The results of the partial flooding study, documented in Table 6.7.3-1, demonstrate that there is no effect of partially flooding the TSC.

Moderator Density Variations

Moderator density variation cases are based on a cask array model generated by surrounding a single cask body with a cylindrical reflecting enclosure. The reflecting body is spaced 20 cm from the cask body to allow exterior moderator density conditions to affect the results. Reactivities calculated from the WE17H1 moderator density study are graphically illustrated in Figure 6.7.3-1 for an unborated wet pellet-to-clad gap, moderator containing 2,500 ppm boron, and an enrichment of 5 wt % ^{235}U. Reactivities for dry, unborated wet, and borated wet pellet-to-clad gap conditions under various canister cavity moderator densities are plotted in Figure 6.7.3-2. Reactivity increases in the system as TSC interior moderator density rises. Exterior moderator conditions have no significant effect on system reactivity for a flooded TSC. The k_{eff} of the dry TSC is less than 0.5 under all exterior conditions. For the flooded TSC, k_{eff} levels off at moderator density levels above 0.9 g/cm^3 (actual moderator density 0.903 g/cm^3 considering 2,500 ppm soluble boron), with no significant changes to full density 0.9982 g/cm^3 (1.0025 g/cm^3 at 2,500 ppm B). The reactivity curve levels off as increased thermalization from the moderator is offset by soluble boron neutron absorption. At a lower soluble boron level, the curve continues to rise to full moderator density.

Fabrication Tolerances and Component Shift

Fabrication tolerances and shift effect are evaluated using representative fuel types from the major core configurations (WE, CE, and B&W cores). Nominal fuel assembly characteristics are employed in the tolerance and shifting evaluations. Moderator soluble boron content is set to 2,500 ppm boron for the fabrication tolerance and component shift study.

Fabrication Tolerance

The basket is composed of a set of fuel tubes, pinned together in the tube corners, and located in the TSC cavity with side and corner weldments. Tube location in the basket is controlled by the diagonal dimension across the exterior face of the fuel tube corners. This value is a key dimension for tube array and developed cell size. The tube diagonal is referred to as tube "interface width" in the analysis discussions. Tube and neutron absorber dimensions have the potential to significantly affect the size of the tube opening and developed cell locations and are, therefore, evaluated for tolerance effects. Neutron absorber thickness studies are based on the

minimum ^{10}B areal density allowed for the design. As such, variations in neutron absorber thickness require adjustments in the sheet composition. The results of the tolerance evaluation for centered fuel assemblies and basket components are included in Table 6.7.3-2. Little statistically significant information (>3σ) is available from this study. None of the fabrication-related tolerances, with the exception of maximum tube wall thickness, produce significant reactivity increases when taken independently.

Further evaluations of the component tolerances, including combinations of tolerances, are performed in conjunction with the shifted component configuration.

Component Shift

In addition to the component tolerances, a reactivity study on component shifts is required. Based on the pinned tube arrangement, the only radial shift to be evaluated is the shift of the fuel assembly within the tubes. The tubes are restrained in the corner by pins, minimizing tube shift potential. Evaluations on tube shift are included within the Phase 3 Design Modifications subsection (pages 6.7.3-5 through 6.7.3-7). The results of shift evaluations are shown in Table 6.7.3-2, indicating that shifting the fuel assembly towards the basket center clearly increases system reactivity.

Combined Shift and Tolerance Study

This section evaluates the effect of combining various basket tolerances with the maximum reactivity shift configuration (radial in). The results for this evaluation are shown in Table 6.7.3-3. Similar to the results of the independent basket tolerance evaluation, only fuel tube thickness affects system reactivity to a statistically significant level.

While no statistically significant reactivity difference is found between the cases with and without tolerances applied, the maximum reactivity configuration chosen for the evaluations of all fuel hybrids is shown below.

Minimum tube width and interface width
Maximum tube thickness
Minimum absorber width and maximum thickness
Fuel assemblies shifted to basket center

This configuration produced reactivities within a 3σ uncertainty band of the maximum reported value for all fuel types evaluated, and provides for the minimum separation between adjacent assemblies. The minimum separation reduces the amount of moderation and the corresponding effectiveness of both the borated water and absorber sheet, which depend on the ^{10}B neutron capture cross-section in the thermal energy range.

Neutron Absorber and Tube Modifications

Phase 1 Design Modifications

Design options permit the replacement or removal of up to 16 neutron absorber sheets in basket peripheral fuel tubes. Locations for the optional absorber sheets are shown in Figure 6.7.3-3. Replacement sheets for the neutron absorber in the peripheral basket locations are composed of unborated aluminum. Using the most reactive basket and fuel assembly shifting specified in Section 6.7.3.1, three enrichment and soluble boron concentration combinations were evaluated for each PWR fuel type specified in Section 6.7.2 for neutron absorber removal or replacement. As shown in Table 6.7.3-4 and Table 6.7.3-5, no statistically significant reactivity changes are associated with the peripheral neutron absorber sheet removal or replacement by an aluminum sheet. Results were calculated using unborated water in the pellet-to-clad gap.

Design enhancements introduced after completion of the primary criticality evaluations replaced the single column of weld posts down the tube face centerline with a two-column weld post configuration. The weld post columns are located 2 inches from the tube centerline. This design change reduced the number of rows of weld posts in the Class 1 (short) tube to 17 from 18. As demonstrated in Table 6.7.3-6, the increased number of weld posts does not significantly change system reactivity. Results were calculated using unborated water in the pellet-to-clad gap.

As the combined reactivity effect of a reduced number of absorber sheets and an increased number of weld posts may exceed the statistically significant threshold ($> 3\sigma$) or potentially result in a $k_{eff} + 2\sigma > USL$ if added as a Δk, the maximum allowed enrichments are calculated in Section 6.7.3.2 with a model containing the reduced number of absorber sheets and the increased number of weld posts.

Phase 2 Design Modifications

Neutron absorbers may be manufactured at an increased tolerance band. Rather than the ±0.005-inch thickness tolerance evaluated in the previous calculations, a thickness tolerance of -0.006, +0.016 inch may be applied. Changes in the absorber thickness tolerance do not result in changes in the areal density of the ^{10}B absorber material as it is defined at its minimum value regardless of absorber thickness. The sheet thickness change within the above tolerance does affect the quantity of borated moderator between the assembly and neutron absorber sheet. Changes in this region influence system reactivity by offsetting effects. One effect is that the moderator quantity in this region thermalizes neutrons, i.e., affects the efficiency of the neutron absorber sheet. The second effect is on the quantity of soluble boron neutron absorber in the system. The focus of the revised analysis is the maximum tolerance sheet thickness effect, as the change in the minimum tolerance is 0.001 inch and is not statistically resolvable (the 0.005-inch

tolerance evaluated on the base design did not show a statistically significant change in system reactivity).

In addition to the neutron absorber tolerance change, the weld post configuration on the Class 1 (short) tube was revised to 36 weld post locations (18 rows, 2 columns) from 34 weld posts (17 rows, 2 columns) per tube face. The additional posts remove a small amount of the fixed neutron absorber panels and are, therefore, applied in the revised absorber tolerance models evaluated in Section 6.7.3.2.

To evaluate the design changes, each maximum reactivity fuel type/enrichment/soluble boron combination in Section 6.7.3.2 is evaluated at the increased sheet thickness tolerance band and modified weld post geometry. Results for this analysis are shown in Table 6.7.3-7 and Table 6.7.3-8. The average change in reactivity of updated cases was 0.86σ ($\Delta k = 0.0004$). All cases with updated absorber tolerances had resulting reactivities under the USL (0.9376).

Phase 3 Design Modifications

PWR tube drawing dimensions were modified to list the outer width as a reference dimension with the tube corner chamfer specifying a minimum and maximum quantity of material to be removed. The tube interface width is retained as a toleranced dimension (13.08-inch minimum/ 13.12-inch maximum). The drawing changes provide additional flexibility on the tube width, while ensuring criticality control is retained. Modifications of the tube dimensions and pin and slot configuration have a secondary effect of allowing increased relative shift of the tube centers. To demonstrate that this design modification does not result in significant reactivity changes, additional criticality evaluations are performed.

Variations in system configuration are evaluated that shift from the baseline model that relied on square tubes located at a 45° angle (i.e., even grind tube flats are touching at their midpoints). The 45° aligned model with relatively square tubes is expected to be the as-built configuration of the final basket assembly since the basket: (a) is assembled horizontally producing tube-to-tube contact, with a drawing limitation on the gap allowed between tubes (maximum continuous gap of 0.02 inch over a 24-inch interval); and (b) includes installation of side and corner weldments and placement of the basket into the cylindrical TSC, which would not be feasible for a significantly out-of-alignment tube array. As the basket is composed of individual fuel tubes connected by pin-slot connectors and tubes are attached to the weldment by mounting bosses, each with manufacturing tolerances and gaps, localized variations in tube spacing are allowed by the basket drawings. An additional set of analyses is performed to confirm that the interface width is the primary criticality control dimension and that changes in reactivity associated with (a) the potential tube shift away from a 45° alignment, and (b) system tolerances associated with the tube and tube-to-weldment interface are either not statistically resolvable or reduce reactivity.

In these analyses, maximum shifts in tube relative location are applied to the entire basket rather than to a localized basket area to magnify any potential reactivity effects. Applying the changes to the basket globally results in a configuration that could not be built since corner and side weldments had to be modified beyond drawing allowables to produce a model fitting into the TSC shell.

System variables were modified to produce the maximum shift from the baseline analysis dimensions. Tube minimum interface, or a face-to-face diagonal distance of 13.08 inches, is maintained during the shift/tolerance studies. Maximum perturbation from the baseline may either be a reduced orthogonal dimension (x and/or y) or a reduction in tube center-to-center diagonal spacing. Tube shift reduces the developed cell size by reducing one orthogonal dimension while increasing the other. Figure 6.7.3-4 through Figure 6.7.3-9 contain sketches for the bounding shift/tolerance configurations. There are three even grind and three biased configurations considered in this evaluation. The grind produces the flat at the tube corner and is expected to be uniform during tube fabrication, but drawings allow for a minimum 0.006-inch grind with a maximum 0.04-inch grind. The starting point for the analysis is the baseline square tube aligned at 45° with the even grind shown in Figure 6.7.3-4. This represents the configuration on which maximum allowed enrichments are calculated. Figure 6.7.3-5 modified this configuration to evaluate the impact of a biased grind while retaining the 45° alignment. Next, both even and biased grind configurations were evaluated to determine the maximum shift that could occur between square tubes. The resulting dimension sets are shown in Figure 6.7.3-6 and Figure 6.7.3-7 indicating that the biased grind condition produces the minimum tube center-to-center diagonal spacing, while the even grind condition produces the minimum orthogonal dimension. Note that without regard to the overall basket structure constraints, the developed cell opening is reduced in these scenarios. A sample graphic representation of the MCNP geometry for the shifted tube is shown in Figure 6.7.3-10 to illustrate the potential tube movement. The third set of analyses builds on the shifted tube model while considering the possibility of tubes having a rectangular rather than square cross-section. Sketches of the tube position under the rectangular tube assumption are included in Figure 6.7.3-8 and Figure 6.7.3-9. As the rectangular biased grind dimensions bound the even grind dimensions in both minimum orthogonal and diagonal center-to-center distance, only the biased grind configuration is evaluated.

To address the range of neutron absorber, soluble boron and fuel types allowed in the system, each of the configurations specified in Section 6.7.3.2 was evaluated for potential reactivity change. The fuel assembly configuration containing nonfuel hardware inserts was used in this comparison. Inclusion or removal of the nonfuel hardware from the model does not affect the conclusion of the study, as basket-related reactivity changes were studied, not absolute system reactivity. Effects of the nonfuel hardware, in relation to allowed enrichment, are accounted for

in Section 6.7.3.2. Reactivity effects in terms of $\Delta k/\sigma$ are listed in Table 6.7.3-12 for each of the scenarios, demonstrating either no statistically resolvable change in reactivity or a decrease in system reactivity occurs. A breakdown of the analysis results by fuel type and soluble boron level for the 0.036 gm/cm^2 effective absorber is shown in Table 6.7.3-13.

Based on the studies described in the previous section, the interface (tube grind flat-to-flat) width controls the critical tube spacing and, therefore, assembly spacing and system reactivity.

Instrument Tube Insert

Typically, WE and B&W instruments are accessed from the bottom of the assembly. The instrument tube is, therefore, not readily accessible for loading nonfuel hardware when considering an assembly loaded into a TSC. Therefore, all baseline analysis was based on inserts (modeled as zirconium alloy filled tubes) located in the guide tubes with the instrument tube filled by TSC moderator. CE type fuels were excepted from this modeling approach as all five guide tubes (which may also be referred to as four guide tubes and one instrument tube) were filled with zirconium alloy in the "insert" models. This subsection addresses the feasibility of loading a fuel assembly with nonfuel hardware in both instrument and guide tubes. The number of guide tubes in the fuel assembly models ranges from 16 to 24, depending on the array size of the affected assemblies versus a single instrument tube in each assembly. As the baseline analysis resulted in only small differences in reactivity between the insert and no-insert configuration, the addition of one filled tube (removal of moderator containing soluble boron) does not change system reactivity to a statistically resolvable extent. All bounding enrichment, soluble boron, and neutron absorber sheet content combinations were run for each fuel model hybrid with inserts in the guide tubes and with inserts in the guide tube and instrument tube. The absolute average change in reactivity is 0.73 $\Delta k/\sigma$ for all cases. All results remain under the USL of 0.9376. The results show that inserting zirconium alloy in the guide tube and instrument tube under the insert condition has an insignificant effect on system reactivity and meets system criticality limits.

6.7.3.2 Allowable Loading Definitions and Maximum System Reactivities

Based on the most reactive basket configuration, each of the fuel assembly types is evaluated at various enrichment levels to determine the minimum soluble boron level required with and without insert. The pellet-to-clad gap is flooded with unborated water in all cases. The goal of this evaluation is for $k_{eff} + 2\sigma$ to remain below the USL of 0.9376. Limiting physical assembly characteristics for each of the evaluated fuel types is summarized in Table 6.7.3-11. The number of guide tubes in both tables refers to the number of instrument guide tubes combined. All full geometry information is based on nominal, unirradiated dimensions. Enrichment and minimum

soluble boron load limits for the 0.036 ^{10}B g/cm^2 neutron absorber sheet configurations without insert in the active fuel region are listed in Table 6.7.3-9. Table 6.7.3-10 contains similar data for fuel with nonfuel insert in the active fuel region. A generic definition taking the bounding values from the insert and no-insert evaluation is listed in Table 6.7.3-11 in conjunction with the assembly physical characteristics. Table 6.7.3-14 lists the corresponding enrichment/soluble boron limitations for each of the assembly types at two reduced neutron absorber sheet specifications. Reduced absorber contents evaluated are effective areal densities of 0.030 and 0.027 ^{10}B g/cm^2.

Summarized as follows are maximum system reactivities. Analysis results represent maximum reactivity basket and fuel geometry. There are no design basis off-normal or accident transfer cask conditions affecting system reactivity. Therefore, only normal condition results are presented. An accident condition for the concrete cask represents a flooding of the concrete cask to canister annulus. Concrete cask results are based on the maximum fuel mass assembly at the highest allowed enrichment (5.0 wt % ^{235}U).

Condition	Pellet to Clad Gap Condition	Maximum Multiplication Factors ($k_{eff} + 2\sigma$)	
		Transfer Cask	Concrete Cask
Normal	Dry	0.93183	0.48145
Normal	Wet	0.93712	N/A
Accident / Off-Normal	Dry	N/A	0.47104

No analysis has been performed on PWR radial enrichment patterns. Therefore, the enrichment limits specified in this analysis are applied as peak rod enrichments.

Figure 6.7.3-1 PWR Water Density Variations (2500 ppm B, Unborated Wet Gap)

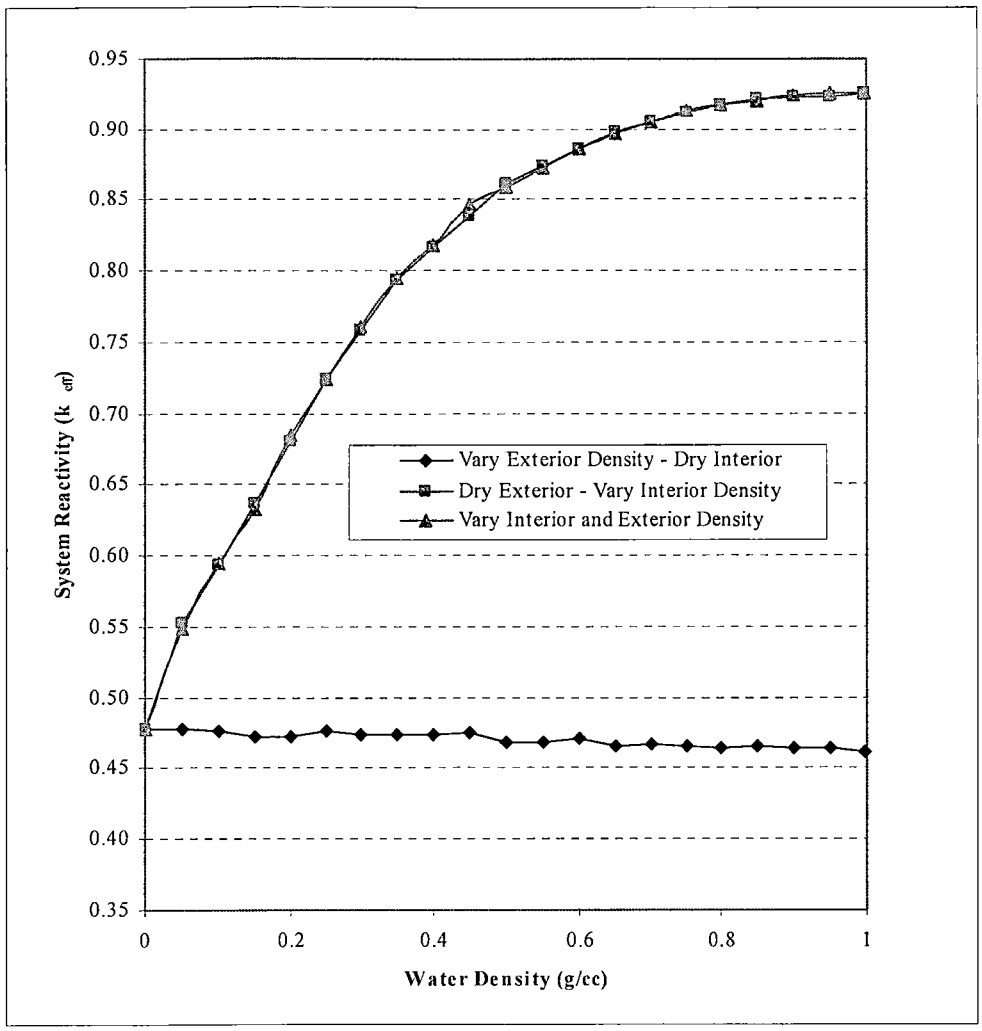


Figure 6.7.3-2 PWR Water Density Variations for Varying Gap Conditions (2500 ppm B)

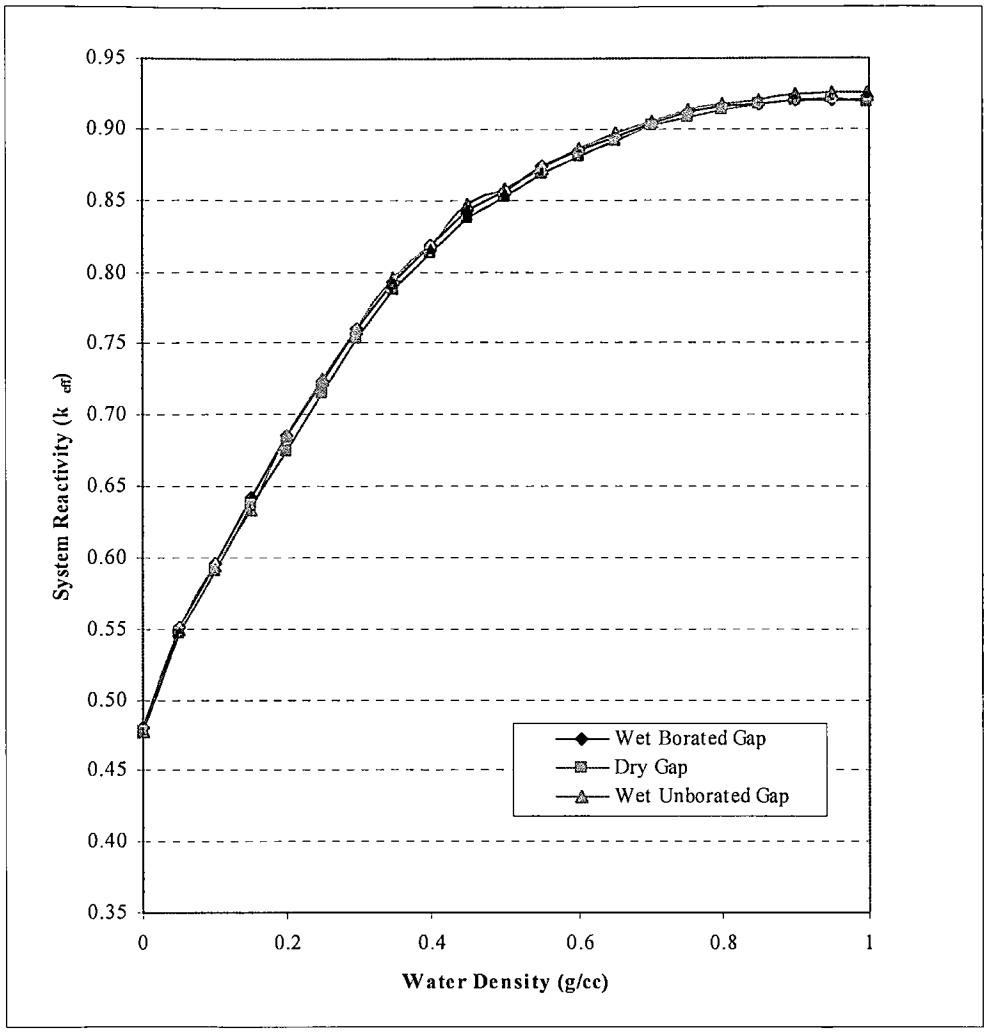
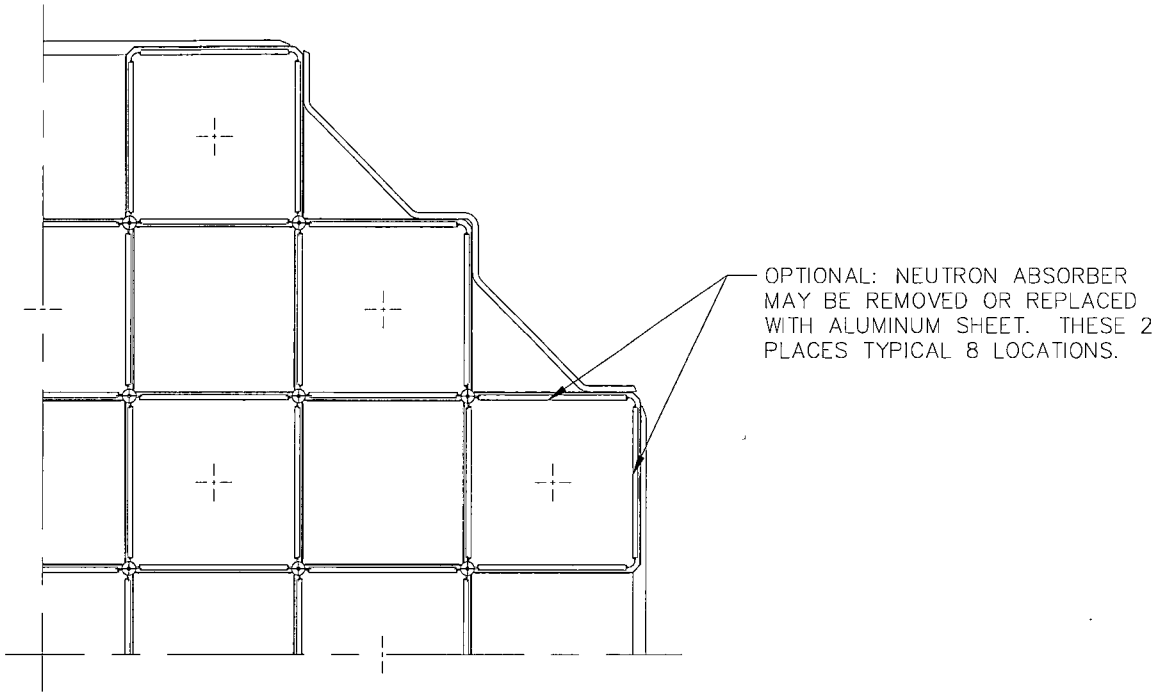


Figure 6.7.3-3 PWR Basket Optional Neutron Absorber Sheet Locations[a]



[a] Quarter basket model is shown for clarity. Symmetric locations are affected in all four basket quadrants.

Figure 6.7.3-4 PWR Minimum Tube Spacing – Baseline Configuration – Square Tube – Even Grind – 45° Aligned

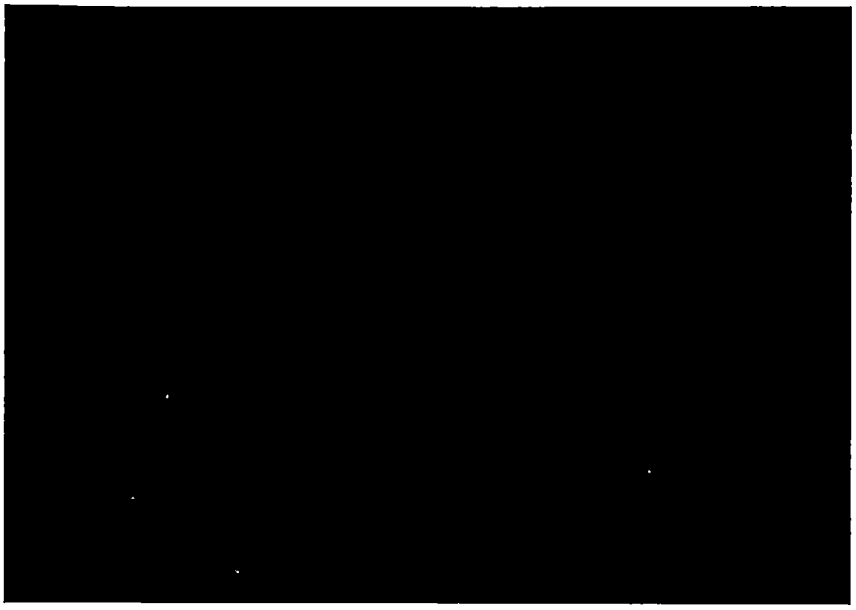


Figure 6.7.3-5 PWR Minimum Tube Spacing – Square Tube – Biased Grind – 45° Aligned

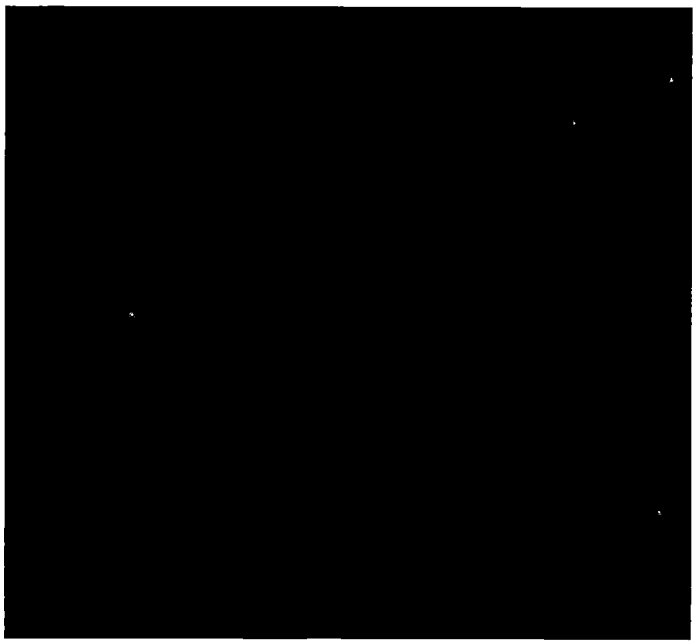


Figure 6.7.3-6 PWR Minimum Tube Spacing – Square Tube – Even Grind – Shifted

[redacted]

Figure 6.7.3-7 PWR Minimum Tube Spacing – Square Tube – Biased Grind – Shifted

[redacted]

Figure 6.7.3-8 PWR Minimum Tube Spacing – Rectangular Tube – Even Grind – Shifted

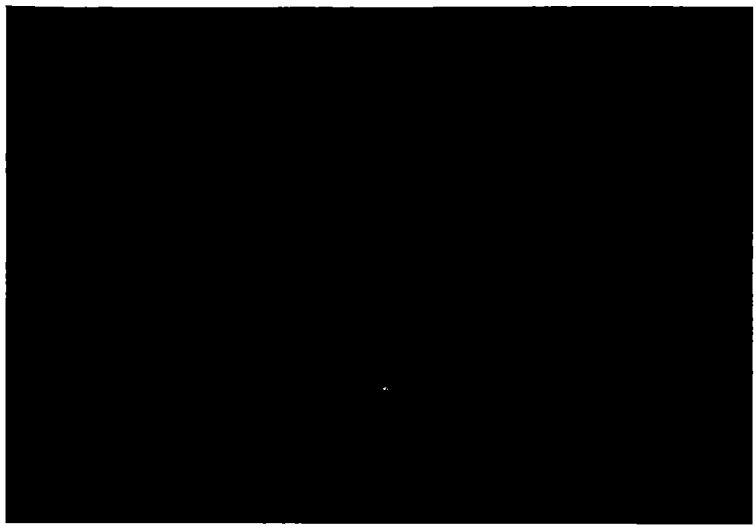


Figure 6.7.3-9 PWR Minimum Tube Spacing – Rectangular Tube – Biased Grind – Shifted

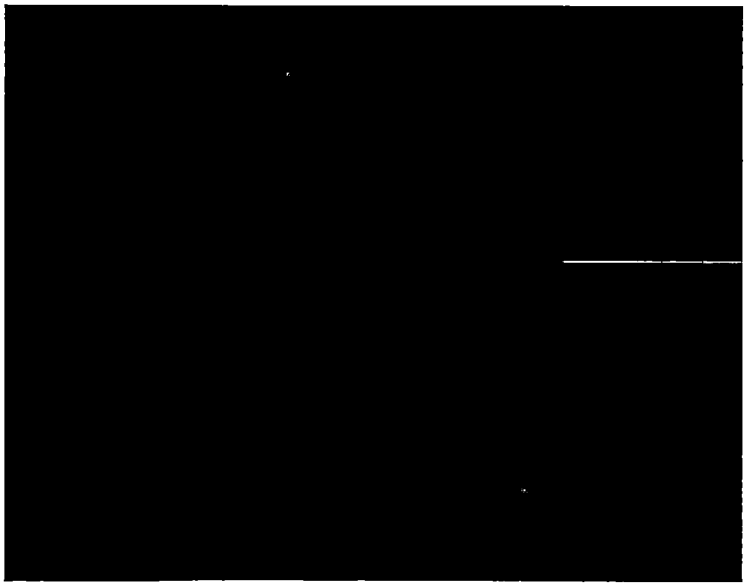


Figure 6.7.3-10 Sample VISED Image – PWR Shifted Tube

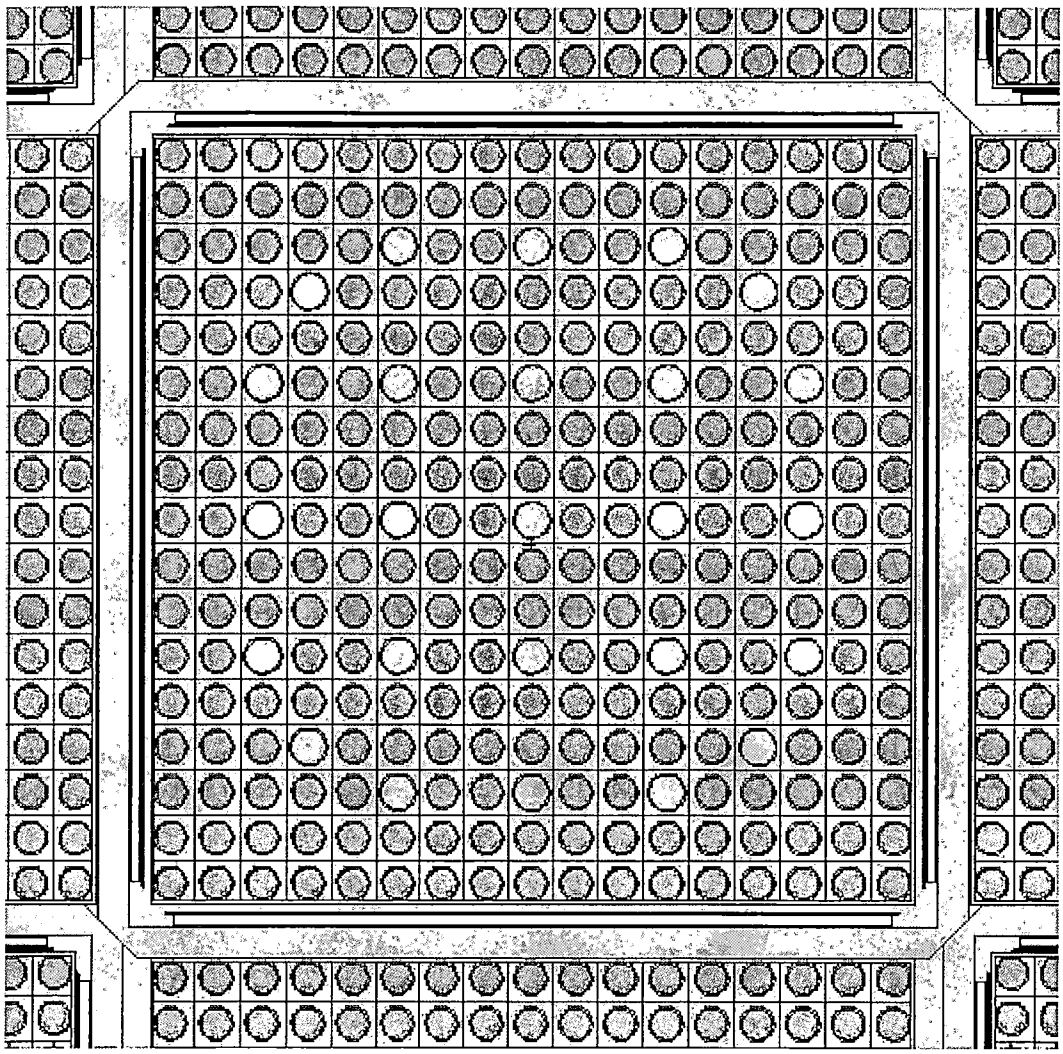


Table 6.7.3-1 PWR System Partial TSC Flood Evaluation

Assembly Type	2,500 ppm B 5.0 wt % Dry Gap No Insert k_{eff}	2,500 ppm B 5.0 wt % Dry Partial Flood k_{eff}	$\Delta k_{eff}/\sigma$
CE14H1	0.86225	0.86130	-0.9
CE16H1	0.86700	0.86614	-0.8
BW15H1	0.92089	0.92000	-0.8
BW15H2	0.92674	0.92454	-2.2
BW15H3	0.92727	0.92743	0.1
BW15H4	0.91301	0.91130	-1.6
BW17H1	0.92595	0.92743	1.3
WE14H1	0.84955	0.84950	0.0
WE15H1	0.91177	0.91244	0.6
WE15H2	0.90023	0.89936	-0.8
WE17H1	0.91897	0.91826	-0.7
WE17H2	0.89962	0.89887	-0.7

Table 6.7.3-2 PWR Basket Component Tolerance and Shift Study Results (Independent Variations)

Tube			Absorber		Shift	WE17H1		BW15H3		CE16H1	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	Centered	0.91897	--	0.92727	--	0.86700	--
Nom	Nom	Nom	Min	Nom	Centered	0.91820	-0.7	0.92779	0.7	0.86990	2.6
Nom	Nom	Nom	Max	Nom	Centered	0.91988	0.9	0.92717	-0.1	0.86969	2.5
Nom	Nom	Nom	Nom	Min	Centered	0.91935	0.4	0.92862	1.8	0.86862	1.5
Nom	Nom	Nom	Nom	Max	Centered	0.91969	0.7	0.92723	-0.1	0.86928	2.2
Min	Nom	Nom	Nom	Nom	Centered	0.91940	0.4	0.92777	0.7	0.86734	0.3
Max	Nom	Nom	Nom	Nom	Centered	0.91865	-0.3	0.92650	-1.0	0.86667	-0.3
Nom	Min	Nom	Nom	Nom	Centered	0.91637	-2.5	0.92603	-1.6	0.86569	-1.2
Nom	Max	Nom	Nom	Nom	Centered	0.91976	0.8	0.93003	3.8	0.87116	4.0
Nom	Nom	Min	Nom	Nom	Centered	0.91912	0.1	0.92839	1.5	0.86837	1.3
Nom	Nom	Max	Nom	Nom	Centered	0.91801	-0.9	0.92873	2.0	0.86646	-0.5
Nom	Nom	Nom	Nom	Nom	In	0.92342	4.3	0.93137	5.5	0.87494	7.4
Nom	Nom	Nom	Nom	Nom	Out	0.90671	-11.6	0.91903	-11.1	0.83718	-27.9

Table 6.7.3-3 PWR Basket Component Tolerance and Shift Study Results (Combined Variations; Radial In Shift)

Tube			Absorber		Shift	WE17H1		BW15H3		CE16H1	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	In	0.92342	--	0.93137	--	0.87494	--
Nom	Nom	Nom	Min	Nom	In	0.92421	0.8	0.93253	1.6	0.87493	0.0
Nom	Nom	Nom	Max	Nom	In	0.92451	1.1	0.93073	-0.9	0.87539	0.4
Nom	Nom	Nom	Nom	Min	In	0.92540	1.8	0.93350	2.9	0.87616	1.1
Nom	Nom	Nom	Nom	Max	In	0.92490	1.5	0.93292	2.1	0.87717	2.1
Min	Nom	Nom	Nom	Nom	In	0.92445	1.0	0.93111	-0.4	0.87498	0.0
Max	Nom	Nom	Nom	Nom	In	0.92504	1.6	0.93270	1.8	0.87563	0.6
Nom	Min	Nom	Nom	Nom	In	0.92209	-1.3	0.93102	-0.5	0.87505	0.1
Nom	Max	Nom	Nom	Nom	In	0.92668	3.1	0.93368	3.2	0.87864	3.5
Nom	Nom	Min	Nom	Nom	In	0.92510	1.6	0.93035	-1.4	0.87658	1.6
Nom	Nom	Max	Nom	Nom	In	0.92401	0.5	0.93214	1.0	0.87625	1.2
Min	Min	Min	Min	Min	In	0.92268	-0.7	0.93279	1.9	0.87464	-0.3
Min	Nom	Min	Min	Nom	In	0.92391	0.5	0.93335	2.6	0.87735	2.3
Max	Nom	Min	Min	Nom	In	0.92497	1.5	0.93348	2.9	0.87700	1.9
Nom	Nom	Min	Min	Nom	In	0.92531	1.8	0.93243	1.4	0.87823	3.1
Nom	Max	Nom	Nom	Max	In	0.92698	3.5	0.93303	2.3	0.87770	2.5
Min	Max	Min	Min	Max	In	0.92832	4.6	0.93373	3.1	0.88005	4.7

Table 6.7.3-4 PWR Neutron Absorber Removal Study Results

Assembly	Enrichment (wt % ^{235}U)	PPM	Nominal Absorber k_{eff}	Absorber Removal k_{eff}	Δk_{eff}	$\Delta k_{eff}/\sigma$
BW15H1	4.1	1500	0.95628	0.95700	0.00072	1.0
BW15H2	4.1	1500	0.96131	0.96122	-0.00009	-0.1
BW15H3	4.1	1500	0.96306	0.96262	-0.00044	-0.6
BW15H4	4.1	1500	0.95204	0.95077	-0.00127	-1.7
BW17H1	4.1	1500	0.95934	0.95953	0.00019	0.3
CE14H1	4.1	1500	0.90677	0.90511	-0.00166	-2.2
CE16H1	4.1	1500	0.91264	0.91224	-0.00040	-0.5
WE14H1	4.1	1500	0.89824	0.89709	-0.00115	-1.6
WE15H1	4.1	1500	0.95057	0.95214	0.00157	2.1
WE15H2	4.1	1500	0.93889	0.93913	0.00024	0.3
WE17H1	4.1	1500	0.95524	0.95621	0.00097	1.3
WE17H2	4.1	1500	0.93827	0.93869	0.00042	0.6
BW15H1	4.7	2000	0.95283	0.95367	0.00084	1.1
BW15H2	4.7	2000	0.95579	0.95655	0.00076	1.0
BW15H3	4.7	2000	0.95764	0.95937	0.00173	2.4
BW15H4	4.7	2000	0.94416	0.94346	-0.00070	-0.9
BW17H1	4.7	2000	0.95540	0.95632	0.00092	1.3
CE14H1	4.7	2000	0.89746	0.89772	0.00026	0.3
CE16H1	4.7	2000	0.90516	0.90405	-0.00111	-1.5
WE14H1	4.7	2000	0.88709	0.88928	0.00219	2.9
WE15H1	4.7	2000	0.94472	0.94687	0.00215	2.9
WE15H2	4.7	2000	0.93172	0.93213	0.00041	0.6
WE17H1	4.7	2000	0.95205	0.95331	0.00126	1.7
WE17H2	4.7	2000	0.93229	0.93178	-0.00051	-0.7
BW15H1	5.0	2500	0.92987	0.93071	0.00084	1.2
BW15H2	5.0	2500	0.93574	0.93677	0.00103	1.4
BW15H3	5.0	2500	0.93761	0.93746	-0.00015	-0.2
BW15H4	5.0	2500	0.92108	0.92159	0.00051	0.7
BW17H1	5.0	2500	0.93495	0.93465	-0.00030	-0.4
CE14H1	5.0	2500	0.87406	0.87402	-0.00004	-0.1
CE16H1	5.0	2500	0.88307	0.88259	-0.00048	-0.6
WE14H1	5.0	2500	0.86436	0.86481	0.00045	0.6
WE15H1	5.0	2500	0.92197	0.92214	0.00017	0.2
WE15H2	5.0	2500	0.90838	0.90962	0.00124	1.7
WE17H1	5.0	2500	0.93090	0.93071	-0.00019	-0.3
WE17H2	5.0	2500	0.90755	0.90832	0.00077	1.0

Table 6.7.3-5 PWR Neutron Absorber Replacement Study Results

Assembly	Enrichment (wt % ^{235}U)	PPM	Nominal Absorber k_{eff}	Absorber Replacement k_{eff}	Δk_{eff}	$\Delta k_{eff}/\sigma$
BW15H1	4.1	1500	0.95628	0.95638	0.00010	0.1
BW15H2	4.1	1500	0.96131	0.96210	0.00079	1.1
BW15H3	4.1	1500	0.96306	0.96353	0.00047	0.6
BW15H4	4.1	1500	0.95204	0.95242	0.00038	0.5
BW17H1	4.1	1500	0.95934	0.96135	0.00201	2.9
CE14H1	4.1	1500	0.90677	0.90498	-0.00179	-2.4
CE16H1	4.1	1500	0.91264	0.91071	-0.00193	-2.5
WE14H1	4.1	1500	0.89824	0.89911	0.00087	1.2
WE15H1	4.1	1500	0.95057	0.95153	0.00096	1.3
WE15H2	4.1	1500	0.93889	0.93999	0.00110	1.5
WE17H1	4.1	1500	0.95524	0.95710	0.00186	2.5
WE17H2	4.1	1500	0.93827	0.93999	0.00172	2.4
BW15H1	4.7	2000	0.95283	0.95152	-0.00131	-1.8
BW15H2	4.7	2000	0.95579	0.95610	0.00031	0.4
BW15H3	4.7	2000	0.95764	0.95910	0.00146	1.9
BW15H4	4.7	2000	0.94416	0.94404	-0.00012	-0.2
BW17H1	4.7	2000	0.95540	0.95596	0.00056	0.8
CE14H1	4.7	2000	0.89746	0.89731	-0.00015	-0.2
CE16H1	4.7	2000	0.90516	0.90482	-0.00034	-0.5
WE14H1	4.7	2000	0.88709	0.88604	-0.00105	-1.4
WE15H1	4.7	2000	0.94472	0.94447	-0.00025	-0.3
WE15H2	4.7	2000	0.93172	0.93154	-0.00018	-0.2
WE17H1	4.7	2000	0.95205	0.95160	-0.00045	-0.6
WE17H2	4.7	2000	0.93229	0.93157	-0.00072	-1.0
BW15H1	5.0	2500	0.92987	0.93182	0.00195	2.7
BW15H2	5.0	2500	0.93574	0.93579	0.00005	0.1
BW15H3	5.0	2500	0.93761	0.93805	0.00044	0.6
BW15H4	5.0	2500	0.92108	0.92183	0.00075	1.0
BW17H1	5.0	2500	0.93495	0.93666	0.00171	2.3
CE14H1	5.0	2500	0.87406	0.87526	0.00120	1.6
CE16H1	5.0	2500	0.88307	0.88408	0.00101	1.4
WE14H1	5.0	2500	0.86436	0.86399	-0.00037	-0.5
WE15H1	5.0	2500	0.92197	0.92273	0.00076	1.0
WE15H2	5.0	2500	0.90838	0.90955	0.00117	1.5
WE17H1	5.0	2500	0.93090	0.93241	0.00151	1.9
WE17H2	5.0	2500	0.90755	0.90782	0.00027	0.4

Table 6.7.3-6 PWR Neutron Absorber Attachment Study Results for Two Columns of Weld Posts

Assembly	Enrichment (wt % ^{235}U)	PPM	Single Column Base Evaluation		Two Column Modified Attachment			
			Weld Posts	k_{eff}	Weld Posts	k_{eff}	Δk	$\Delta k/\sigma$
BW15H1	5.0	2500	18	0.92987	34	0.93143	0.00156	2.1
BW15H2	5.0	2500	18	0.93574	34	0.93648	0.00074	1.0
BW15H3	4.9	2500	18	0.93244	34	0.93326	0.00082	1.1
BW15H4	5.0	2500	18	0.92108	34	0.92053	-0.00055	-0.7
BW17H1	5.0	2500	18	0.93495	34	0.93611	0.00116	1.5
CE14H1	5.0	2500	18	0.87406	34	0.87521	0.00115	1.5
CE16H1	5.0	2500	18	0.88307	36	0.88357	0.00050	0.7
WE14H1	5.0	2500	18	0.86436	34	0.86574	0.00138	1.8
WE15H1	5.0	2500	18	0.92197	34	0.92241	0.00044	0.6
WE15H2	5.0	2500	18	0.90838	34	0.90816	-0.00022	-0.3
WE17H1	5.0	2500	18	0.93090	34	0.93294	0.00204	2.7
WE17H2	5.0	2500	18	0.90755	34	0.90832	0.00077	1.0

Table 6.7.3-7 Absorber Tolerance and Tube Reactivity Change of PWR Models with No Inserts

Assembly Type	Minimum 1500 ppm B Max. Initial Enrichment		Minimum 1750 ppm B Max. Initial Enrichment		Minimum 2000 ppm B Max. Initial Enrichment		Minimum 2250 ppm B Max. Initial Enrichment		Minimum 2500 ppm B Max. Initial Enrichment	
	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ
BW15H1	-0.00067	-0.66	0.00158	1.51	-0.00009	-0.09	0.00092	0.90	-0.00016	-0.15
BW15H2	0.00027	0.27	-0.00066	-0.63	0.00114	1.11	0.00026	0.24	0.00073	0.70
BW15H3	0.00162	1.61	-0.00195	-1.91	-0.00014	-0.13	-0.00105	-1.00	0.00001	0.01
BW15H4	-0.00043	-0.42	-0.00333	-3.10	0.00078	0.77	-0.00078	-0.75	-0.00093	-0.91
BW17H1	-0.00015	-0.15	0.00048	0.46	0.00141	1.41	0.00012	0.11	0.00027	0.26
CE14H1	0.00194	1.89	0.00171	1.57	0.00022	0.21	-0.00056	-0.52	0.00057	0.52
CE16H1	-0.00021	-0.20	0.00094	0.85	0.00052	0.48	0.00299	2.80	0.00024	0.22
WE14H1	0.00009	0.09	-0.00077	-0.71	-0.00132	-1.25	-0.00036	-0.33	-0.00159	-1.52
WE15H1	0.00207	2.02	-0.00153	-1.46	0.00199	1.86	0.00158	1.51	0.00030	0.29
WE15H2	0.00048	0.45	-0.00005	-0.05	-0.00010	-0.10	0.00007	0.07	0.00174	1.72
WE17H1	-0.00070	-0.68	0.00009	0.09	0.00122	1.14	0.00026	0.26	0.00094	0.94
WE17H2	-0.00013	-0.13	-0.00012	-0.12	0.00012	0.12	0.00164	1.55	0.00080	0.78

Table 6.7.3-8 Absorber Tolerance and Tube Reactivity Change of PWR Models with Inserts

Assembly Type	Minimum 1500 ppm B Max. Initial Enrichment		Minimum 1750 ppm B Max. Initial Enrichment		Minimum 2000 ppm B Max. Initial Enrichment		Minimum 2250 ppm B Max. Initial Enrichment		Minimum 2500 ppm B Max. Initial Enrichment	
	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ	Δk	Δk/σ
BW15H1	0.00113	1.06	0.00030	0.29	0.00100	0.95	-0.00050	-0.49	0.00172	1.67
BW15H2	0.00235	2.26	0.00042	0.41	0.00238	2.27	0.00176	1.75	-0.00013	-0.12
BW15H3	0.00148	1.43	0.00111	1.06	0.00212	2.07	0.00242	2.37	0.00062	0.60
BW15H4	-0.00088	-0.83	0.00039	0.38	0.00191	1.79	-0.00050	-0.49	0.00148	1.43
BW17H1	0.00125	1.16	0.00023	0.22	-0.00001	-0.01	0.00163	1.65	-0.00020	-0.19
CE14H1	0.00126	1.14	0.00197	1.92	0.00036	0.33	-0.00048	-0.45	0.00053	0.50
CE16H1	-0.00086	-0.83	-0.00013	-0.12	-0.00078	-0.73	0.00142	1.33	0.00184	1.76
WE14H1	0.00017	0.15	0.00155	1.37	0.00067	0.62	-0.00144	-1.33	-0.00087	-0.83
WE15H1	-0.00025	-0.25	-0.00046	-0.46	0.00046	0.45	0.00216	2.02	0.00118	1.15
WE15H2	0.00038	0.36	0.00001	0.01	-0.00105	-1.06	-0.00012	-0.12	0.00211	2.03
WE17H1	0.00072	0.70	0.00133	1.30	-0.00145	-1.38	-0.00062	-0.60	-0.00017	-0.17
WE17H2	0.00148	1.48	-0.00005	-0.05	0.00001	0.01	0.00109	1.03	-0.00012	-0.12

Table 6.7.3-9 PWR System Load Limits (without Nonfuel Insert in Active Fuel Region and 0.036 ^{10}B g/cm^2 Absorber)

	Minimum 1500 ppm B		Minimum 1750 ppm B		Minimum 2000 ppm B		Minimum 2250 ppm B		Minimum 2500 ppm B	
Assembly Type	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$
BW15H1	3.70%	0.93032	4.10%	0.93514	4.40%	0.93547	4.70%	0.93489	5.00%	0.93432
BW15H2	3.70%	0.93554	4.00%	0.93451	4.30%	0.93384	4.60%	0.93295	4.90%	0.93244
BW15H3	3.70%	0.93538	4.00%	0.93613	4.30%	0.93528	4.60%	0.93569	4.90%	0.93414
BW15H4	3.80%	0.93189	4.20%	0.93697	4.50%	0.93286	4.80%	0.93228	5.00%	0.92461
BW17H1	3.70%	0.93311	4.00%	0.93204	4.30%	0.93241	4.60%	0.93215	5.00%	0.93689
CE14H1	4.50%	0.93324	4.90%	0.93148	5.00%	0.91561	5.00%	0.89718	5.00%	0.87709
CE16H1	4.40%	0.93350	4.80%	0.93457	5.00%	0.92463	5.00%	0.90197	5.00%	0.88620
WE14H1	4.70%	0.93673	5.00%	0.92958	5.00%	0.90757	5.00%	0.88721	5.00%	0.86816
WE15H1	3.80%	0.93088	4.20%	0.93699	4.50%	0.93415	4.80%	0.93224	5.00%	0.92440
WE15H2	4.00%	0.93406	4.40%	0.93674	4.70%	0.93530	5.00%	0.93129	5.00%	0.91181
WE17H1	3.70%	0.92991	4.10%	0.93553	4.40%	0.93506	4.70%	0.93425	5.00%	0.93308
WE17H2	4.00%	0.93428	4.30%	0.92952	4.70%	0.93330	5.00%	0.93079	5.00%	0.91229

Table 6.7.3-10 PWR System Load Limits (with Nonfuel Insert in Active Fuel Region and 0.036 ^{10}B g/cm^2 Absorber)

	Minimum 1500 ppm B		Minimum 1750 ppm B		Minimum 2000 ppm B		Minimum 2250 ppm B		Minimum 2500 ppm B	
Assembly Type	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$
BW15H1	3.80%	0.93273	4.10%	0.93540	4.40%	0.93380	4.70%	0.93644	5.00%	0.93468
BW15H2	3.70%	0.92923	4.00%	0.93281	4.30%	0.93250	4.60%	0.93389	4.90%	0.93451
BW15H3	3.70%	0.93169	4.00%	0.93345	4.30%	0.93311	4.60%	0.93475	4.90%	0.93564
BW15H4	3.80%	0.92945	4.20%	0.93582	4.50%	0.93322	4.80%	0.93247	5.00%	0.92658
BW17H1	3.80%	0.93545	4.10%	0.93648	4.40%	0.93695	4.60%	0.93200	4.90%	0.93284
CE14H1	4.50%	0.93588	4.80%	0.93066	5.00%	0.92489	5.00%	0.90699	5.00%	0.89106
CE16H1	4.40%	0.93241	4.80%	0.93602	5.00%	0.92723	5.00%	0.90831	5.00%	0.89213
WE14H1	4.80%	0.93574	5.00%	0.92232	5.00%	0.90377	5.00%	0.88564	5.00%	0.86589
WE15H1	3.90%	0.93411	4.20%	0.93343	4.50%	0.93351	4.80%	0.93262	5.00%	0.92694
WE15H2	4.00%	0.93138	4.40%	0.93683	4.70%	0.93626	5.00%	0.93357	5.00%	0.91454
WE17H1	3.90%	0.93532	4.20%	0.93495	4.50%	0.93712	4.80%	0.93706	5.00%	0.93241
WE17H2	4.10%	0.93359	4.40%	0.93279	4.80%	0.93707	5.00%	0.92966	5.00%	0.91118

Table 6.7.3-11 PWR System Generic Load Limits (0.036 ^{10}B g/cm^2 Absorber)

Assembly Type	# of Fuel Rods	# of Guide Tubes[a]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)	Max. Initial Enrichment (wt % ^{235}U)				
									Soluble Boron 1500 ppm	Soluble Boron 1750 ppm	Soluble Boron 2000 ppm	Soluble Boron 2250 pm	Soluble Boron 2500 ppm
BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858	3.70%	4.10%	4.40%	4.70%	5.00%
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988	3.70%	4.00%	4.30%	4.60%	4.90%
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006	3.70%	4.00%	4.30%	4.60%	4.90%
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690	3.80%	4.20%	4.50%	4.80%	5.00%
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799	3.70%	4.00%	4.30%	4.60%	4.90%
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167	4.50%	4.80%	5.00%	5.00%	5.00%
CE16H1	236	5	0.5063	0.382	0.025	0.325	150.0	0.4463	4.40%	4.80%	5.00%	5.00%	5.00%
WE14H1	179	17	0.556	0.40	0.0162	0.3674	145.2	0.4188	4.70%	5.00%	5.00%	5.00%	5.00%
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720	3.80%	4.20%	4.50%	4.80%	5.00%
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469	4.00%	4.40%	4.70%	5.00%	5.00%
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740	3.70%	4.10%	4.40%	4.70%	5.00%
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327	4.00%	4.30%	4.70%	5.00%	5.00%

Note: Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Combined number of guide and instrument tubes.

Table 6.7.3-12 PWR System Tube Location Study Summary

Configuration			Δk/σ from Baseline Square Tube @ 45°		
Tube	Tube Location	Grind	Average	Minimum	Maximum
Square	45°	Even	--		
Square	45°	Biased	0.6	-2.3	2.6
Square	Shift	Even	-1.3	-2.9	2.2
Square	Shift	Biased	0.3	-2.8	2.9
Rectangular	Shift	Even	N/A		
Rectangular	Shift	Biased	-5.7	-9.9	2.5

Table 6.7.3-13 PWR System Tube Location Study Detail – Baseline to Square Tube/Biased Grind/45° Alignment

Assembly Type	Minimum 1500 ppm B Change in Reactivity	Minimum 1750 ppm B Change in Reactivity	Minimum 2000 ppm B Change in Reactivity	Minimum 2250 ppm B Change in Reactivity	Minimum 2500 ppm B Change in Reactivity
	Δk/σ	Δk/σ	Δk/σ	Δk/σ	Δk/σ
BW15H1	0.4	-1.8	1.7	0.6	0.5
BW15H2	-0.6	-1.3	-2.3	-0.8	0.8
BW15H3	-0.1	1.1	0.5	-0.6	0.8
BW15H4	0.5	-0.1	1.7	2.1	-0.4
BW17H1	-0.2	0.7	-0.2	-1.4	1.9
CE14H1	-0.1	0.7	2.6	2.4	1.2
CE16H1	2.6	1.0	1.1	2.1	0.2
WE14H1	0.8	2.6	1.0	1.6	2.6
WE15H1	0.3	1.0	1.1	0.3	-0.1
WE15H2	-0.2	0.0	1.5	1.1	0.1
WE17H1	-0.7	-0.3	1.5	0.6	0.5
WE17H2	-0.1	1.3	0.1	-1.9	1.6

Table 6.7.3-14 PWR System Load Limits for Reduced Absorber

	Max. Initial Enrichment (wt % ^{235}U)									
	Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

- Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

6.7.4 BWR Model Details

The BWR system payload consists of 87 fuel assemblies that are placed into 87 of 89 openings formed by a combination of 45 fuel tubes, and 4 side and corner weldments. Two of the basket opening are located on the basket periphery below the vent and drain port opening and are not designed to contain fuel assemblies. All 89-fuel assembly openings are filled in the "87-Assembly" basket model.

Additional configurations are evaluated with assemblies removed from the basket. An 86 assembly configuration is evaluated with the center basket location without a fuel assembly. An "82-Assembly" configuration is evaluated with five assemblies removed in an x-pattern from the basket center. The alternate 82-assembly configuration moves the four empty basket locations out from the center of the basket. A sketch of the basket configuration is shown in Figure 6.1.1-1. The 86 and 82-assembly configurations removes a significant quantity of fissile material from the basket center in addition to providing flux traps for neutrons from the adjacent assemblies to thermalize and be absorbed by the absorber sheets. These effects combine to allow a significant enrichment increase over the 87-assembly configuration.

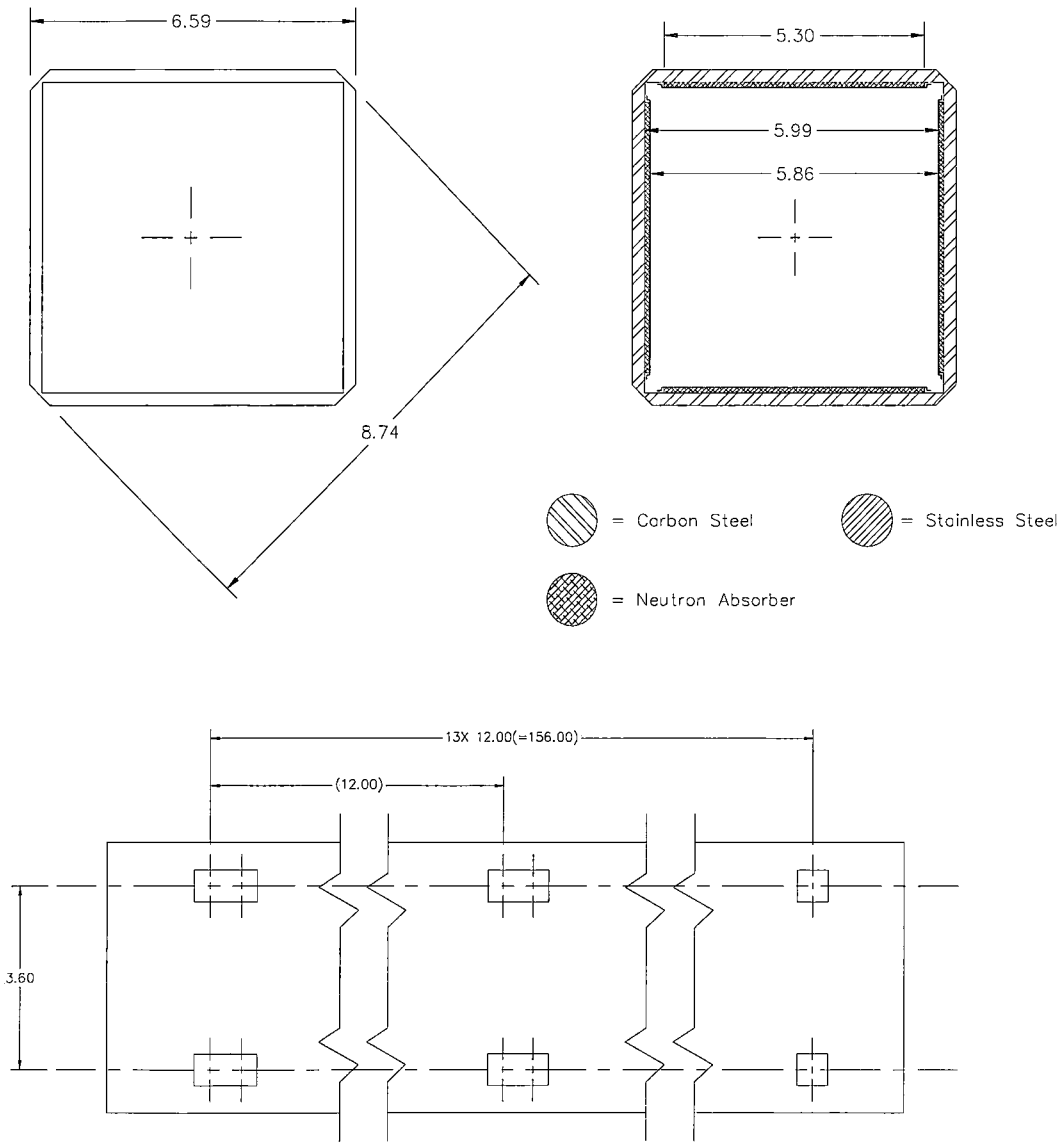
The BWR basket model is similar in structure to the PWR model documented in Section 6.7.1, with differences being limited to the addition of an optional zirconium-based alloy channel and the option to model sub-channeled type assemblies. Sub-channeled assemblies are comprised of four fuel rod sub-bundles. Dimensioned fuel tubes forming the base configuration of the basket are shown in Figure 6.7.4-1. The assembled BWR basket is shown in Figure 6.7.4-2.

All fuel tubes are initially modeled as containing four neutron absorber sheets with weld post locations along the tube face for the criticality evaluations associated with maximum reactivity payload and basket configuration and optimum moderation. Final system configuration increases the number of weld posts and allows the removal of the neutron absorber sheets or replacement by aluminum sheets at up to 24 basket peripheral locations for the 87-assembly basket and up to 16 locations for the 82-assembly basket. The reduction in the number of absorber sheets does not affect system reactivity, as demonstrated in Section 6.7.6.1. Similarly, an additional column of weld posts has no significant effect on system reactivity as shown in Section 6.7.6.1. Since the combination of a reduced number of absorber sheets and an increase in the number of weld posts has the potential for increasing k_{eff} slightly above the statistically significant level threshold, the maximum enrichments and k_{eff} in Section 6.7.6.2 are calculated using a model incorporating both design attributes.

Sample input files for the BWR transfer cask 87-assembly configuration and 82-assembly configuration are shown in Figure 6.7.4-3 and Figure 6.7.4-4, respectively. Only the transfer

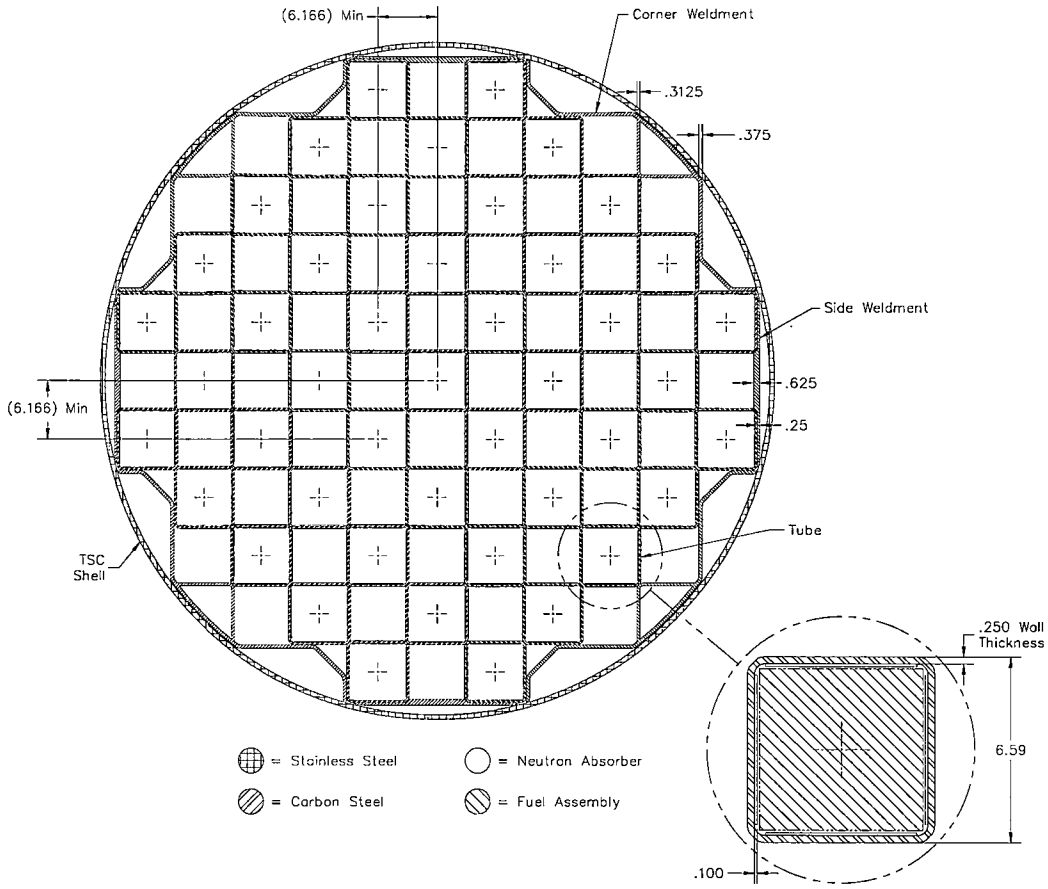
cask model is shown since PWR and BWR concrete cask models are identical with the exception of the TSC contents. The inputs provided represent the maximum reactivity configuration and include the minimum cell spacing, replacement of the optional peripheral absorbers by aluminum sheets, and the full number of weld posts illustrated in the licensing drawings.

Figure 6.7.4-1 BWR Fuel Tubes



Note: Dimensions in inches

Figure 6.7.4-2 BWR Basket Structure



Notes:

1. Dimensions in inches.
2. Assembly fuel pin array is explicitly modeled. Shown as homogenized area for illustration purposes only.
3. Represents square tube basket aligned at 45° with 8.72-inch minimum interface (diagonal flat-to-flat) width.

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
Transfer Cask Model - B10_96A
c
c  MAGNASTOR Canister Class 2
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c
c   Boron Content in Water - 0 ppm
c   Cavity Water Density 0.9982 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Model Revision 4.70
c
c Cells - Fuel Rod - B10_96A - BWR_10x10_5 WR
1 1 -1.0522E+01 -1   u=14 $ Fuel
2 13 -0.9982 -2 +1  u=14 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=14 $ Clad + End Plugs
4 3 -0.9982 +3   u=14 $ Outside Fuel Rod
c Array_10x10_96_5
7 3 -0.9982 -7 +8 -9 +10
      trcl=(0 0 17.1704)   lat=1 u=13 fill=-2:2 -2:2 0:0
      13 14 14 14 14
      14 14 14 14 14
      14 14 14 14 14
      14 14 14 14 14
      14 14 14 14 14
c Cells - Fuel Assembly Array Inserted Into Assembly - cell96_5Assy
11 3 -0.9982 -11  fill=13  *trcl=( 3.4540 3.4540 0.0000 )   u=12 $ Sub Array Q1
12 3 -0.9982 -11  fill=13
        *trcl=( -3.4540 3.4540 0.0000 270 360 90 180 270 90 90 90 0 )       u=12 $ Sub Array Q2
13 3 -0.9982 -11  fill=13
        *trcl=( -3.4540 -3.4540 0.0000 180 270 90 90 180 90 90 90 0 )       u=12 $ Sub Array Q3
14 3 -0.9982 -11  fill=13
        *trcl=( 3.4540 -3.4540 0.0000 90 180 90 0 90 90 90 90 0 )       u=12 $ Sub Array Q4
15 3 -0.9982 -12 #11 #12 #13 #14       u=12 $ Gap to Channel
16 2 -6.5600 -13 +12      u=12 $ Channel
17 4 -1.5373 -14  +11.6     u=12 $ Lower Nozzle
18 5 -2.1056 -14   +11.5    u=12 $ Upper Nozzle
19 3 -0.9982 +14       u=12 $ Remaining Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=11 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=11 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=11 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=11 $ Absorber Clad  +Y
105 6 -7.940 -105     u=11 $ Retainer -Y
106 6 -7.940 -106     u=11 $ Retainer+Y
107 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=11 $ Weld Post in Absorber -Y
108 3 -0.9982 -102 #101  #102  #107   u=11 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=11 $ Weld Post in Absorber +Y
110 3 -0.9982 -104 #103  #104  #109   u=11 $ Gap Weld Post to Absorber +Y
111 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=11 $ Absorber -X
112 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=11 $ Absorber Clad  -X
113 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=11 $ Absorber +X
114 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=11 $ Absorber Clad  +X
115 6 -7.940 -195     u=11 $ Retainer -X
116 6 -7.940 -196     u=11 $ Retainer+X
117 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=11 $ Weld Post in Absorber -X
118 3 -0.9982 -192 #111  #112  #117   u=11 $ Gap Weld Post to Absorber -X
119 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=11 $ Weld Post in Absorber
120 3 -0.9982 -194 #113  #114  #119   u=11 $ Gap Weld Post to Absorber +X
121 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=11 $ Space in Tube
122 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=11 $ Fuel Tube
123 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=11 $ Fuel Tube Weld Posts
124 3 -0.9982 -282 +281  #122  #123
             u=11 $ Space Around Weld Posts
125 3 -0.9982 +281 +282    u=11 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=10 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=10 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=10 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=10 $ Absorber Clad  +Y
130 6 -7.940 -105     u=10 $ Retainer -Y
131 6 -7.9400 -106     u=10 $ Retainer+Y
132 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=10 $ Weld Post in Absorber -Y
133 3 -0.9982 -102 #126  #127  #132   u=10 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=10 $ Weld Post in Absorber +Y
135 3 -0.9982 -104 #128  #129  #134   u=10 $ Gap Weld Post to Absorber +Y
136 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=10 $ Absorber -X
137 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=10 $ Absorber Clad  -X
138 7 -2.7020 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=10 $ Absorber +X
139 7 -2.7020 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=10 $ Absorber Clad  +X
140 6 -7.940 -195     u=10 $ Retainer -X
141 6 -7.9400 -196     u=10 $ Retainer+X
142 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=10 $ Weld Post in Plate-X
143 3 -0.9982 -192 #136  #137  #142   u=10 $ Gap Weld Post to Plate -X
144 6 -7.9400 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=10 $ Weld Post in Plate +X
145 3 -0.9982 -194 #138  #139  #144   u=10 $ Gap Weld Post to Plate +X
146 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=10 $ Space in Tube
147 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=10 $ Fuel Tube
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
148 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=10 $ Fuel Tube Weld Posts
149 3 -0.9982 -282 +281  #147  #148
             u=10 $ Space Around Weld Posts
150 3 -0.9982 +281 +282    u=10 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=9 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=9 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=9 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=9 $ Absorber Clad  +Y
155 6 -7.940 -105     u=9 $ Retainer -Y
156 6 -7.9400 -106     u=9 $ Retainer+Y
157 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=9 $ Weld Post in Absorber -Y
158 3 -0.9982 -102 #151  #152  #157   u=9 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=9 $ Weld Post in Absorber +Y
160 3 -0.9982 -104 #153  #154  #159   u=9 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=9 $ Absorber -X
162 7 -2.7020 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=9 $ Absorber Clad  -X
163 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=9 $ Absorber +X
164 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=9 $ Absorber Clad  +X
165 6 -7.9400 -195     u=9 $ Retainer -X
166 6 -7.940 -196     u=9 $ Retainer+X
167 6 -7.9400 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=9 $ Weld Post in Plate-X
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
168 3 -0.9982 -192 #161  #162  #167   u=9 $ Gap Weld Post to Plate -X
169 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=9 $ Weld Post in Plate +X
170 3 -0.9982 -194 #163  #164  #169   u=9 $ Gap Weld Post to Plate +X
171 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=9 $ Space in Tube
172 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=9 $ Fuel Tube
173 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=9 $ Fuel Tube Weld Posts
174 3 -0.9982 -282 +281  #172  #173
            u=9 $ Space Around Weld Posts
175 3 -0.9982 +281 +282    u=9 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=8 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=8 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=8 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=8 $ Absorber Clad  +Y
180 6 -7.9400 -105     u=8 $ Retainer -Y
181 6 -7.940 -106     u=8 $ Retainer+Y
182 6 -7.9400 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=8 $ Weld Post in Absorber -Y
183 3 -0.9982 -102 #176  #177  #182   u=8 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=8 $ Weld Post in Absorber +Y
185 3 -0.9982 -104 #178  #179  #184   u=8 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=8 $ Absorber -X
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
187 7 -2.7020 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=8 $ Absorber Clad  -X
188 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=8 $ Absorber +X
189 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=8 $ Absorber Clad  +X
190 6 -7.9400 -195     u=8 $ Retainer -X
191 6 -7.940 -196     u=8 $ Retainer+X
192 6 -7.9400 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=8 $ Weld Post in Plate-X
193 3 -0.9982 -192 #186  #187  #192   u=8 $ Gap Weld Post to Plate -X
194 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=8 $ Weld Post in Plate +X
195 3 -0.9982 -194 #188  #189  #194   u=8 $ Gap Weld Post to Plate +X
196 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=8 $ Space in Tube
197 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=8 $ Fuel Tube
198 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=8 $ Fuel Tube Weld Posts
199 3 -0.9982 -282 +281  #197  #198
            u=8 $ Space Around Weld Posts
200 3 -0.9982 +281 +282    u=8 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber Clad  -Y
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
          +130 +131 +132 +133 +134   u=7 $ Absorber Clad  +Y
205 6 -7.9400 -105     u=7 $ Retainer -Y
206 6 -7.940 -106     u=7 $ Retainer+Y
207 6 -7.9400 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=7 $ Weld Post in Absorber -Y
208 3 -0.9982 -102 #201  #202  #207   u=7 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=7 $ Weld Post in Absorber +Y
210 3 -0.9982 -104 #203  #204  #209   u=7 $ Gap Weld Post to Absorber +Y
211 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber -X
212 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber Clad  -X
213 7 -2.7020 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber +X
214 7 -2.7020 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber Clad  +X
215 6 -7.940 -195     u=7 $ Retainer -X
216 6 -7.9400 -196     u=7 $ Retainer+X
217 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=7 $ Weld Post in Plate-X
218 3 -0.9982 -192 #211  #212  #217   u=7 $ Gap Weld Post to Plate -X
219 6 -7.9400 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=7 $ Weld Post in Plate +X
220 3 -0.9982 -194 #213  #214  #219   u=7 $ Gap Weld Post to Plate +X
221 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=7 $ Space in Tube
222 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=7 $ Fuel Tube
223 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=7 $ Fuel Tube Weld Posts
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
224 3 -0.9982 -282 +281  #222  #223
            u=7 $ Space Around Weld Posts
225 3 -0.9982 +281 +282    u=7 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer (+Y Absorber & Retainer Removed)
226 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber -Y
227 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber Clad  -Y
228 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber +Y
229 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber Clad  +Y
230 6 -7.940 -105     u=6 $ Retainer -Y
231 6 -7.9400 -106     u=6 $ Retainer+Y
232 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)       u=6 $ Weld Post in Absorber -Y
233 3 -0.9982 -102 #226  #227  #232   u=6 $ Gap Weld Post to Absorber -Y
234 6 -7.9400 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)       u=6 $ Weld Post in Absorber +Y
235 3 -0.9982 -104 #228  #229  #234   u=6 $ Gap Weld Post to Absorber +Y
236 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber -X
237 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber Clad  -X
238 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber +X
239 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber Clad  +X
240 6 -7.940 -195     u=6 $ Retainer -X
241 6 -7.940 -196     u=6 $ Retainer+X
242 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)       u=6 $ Weld Post in Plate-X
243 3 -0.9982 -192 #236  #237  #242   u=6 $ Gap Weld Post to Plate -X
244 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)       u=6 $ Weld Post in Plate +X
245 3 -0.9982 -194 #238  #239  #244   u=6 $ Gap Weld Post to Plate +X
246 3 -0.9982 -281
       +102 +104 +105 +106
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
      +192 +194 +195 +196     u=6 $ Space in Tube
247 8 -7.821 -282 +281
      +135 +136 +137 +138 +139 +140 +141 +142 +143
      +144 +145 +146 +147 +148
      +149 +150 +151 +152 +153 +154 +155 +156 +157
      +158 +159 +160 +161 +162
      +225 +226 +227 +228 +229 +230 +231 +232 +233
      +234 +235 +236 +237 +238
      +239 +240 +241 +242 +243 +244 +245 +246 +247
      +248 +249 +250 +251 +252      u=6 $ Fuel Tube
248 6 -7.940 -282 +281
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190:
      -253:-254:-255:-256:-257:-258:-259:-260:-261:
      -262:-263:-264:-265:-266:
      -267:-268:-269:-270:-271:-272:-273:-274:-275:
      -276:-277:-278:-279:-280)      u=6 $ Fuel Tube Weld Posts
249 3 -0.9982 -282 +281  #247  #248
            u=6 $ Space Around Weld Posts
250 3 -0.9982 +281 +282    u=6 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer (-Y Absorber & Retainer Removed)
251 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120
         +121 +122 +123 +124 +125 +126 +127 +128 +129
         +130 +131 +132 +133 +134   u=5 $ Absorber -Y
252 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120
         +121 +122 +123 +124 +125 +126 +127 +128 +129
         +130 +131 +132 +133 +134   u=5 $ Absorber Clad  -Y
253 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120
         +121 +122 +123 +124 +125 +126 +127 +128 +129
         +130 +131 +132 +133 +134   u=5 $ Absorber +Y
254 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120
         +121 +122 +123 +124 +125 +126 +127 +128 +129
         +130 +131 +132 +133 +134   u=5 $ Absorber Clad  +Y
255 6 -7.9400 -105     u=5 $ Retainer -Y
256 6 -7.940 -106     u=5 $ Retainer+Y
257 6 -7.9400 -102
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190)      u=5 $ Weld Post in Absorber -Y
258 3 -0.9982 -102 #251  #252  #257   u=5 $ Gap Weld Post to Absorber -Y
259 6 -7.940 -104
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190)      u=5 $ Weld Post in Absorber +Y
260 3 -0.9982 -104 #253  #254  #259   u=5 $ Gap Weld Post to Absorber +Y
261 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=5 $ Absorber -X
262 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=5 $ Absorber Clad  -X
263 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=5 $ Absorber +X
264 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=5 $ Absorber Clad  +X
265 6 -7.940 -195     u=5 $ Retainer -X
266 6 -7.940 -196     u=5 $ Retainer+X
267 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=5 $ Weld Post in Plate-X
268 3 -0.9982 -192 #261  #262  #267   u=5 $ Gap Weld Post to Plate -X
269 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=5 $ Weld Post in Plate +X
270 3 -0.9982 -194 #263  #264  #269   u=5 $ Gap Weld Post to Plate +X
271 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=5 $ Space in Tube
272 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=5 $ Fuel Tube
273 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=5 $ Fuel Tube Weld Posts
274 3 -0.9982 -282 +281  #272  #273
            u=5 $ Space Around Weld Posts
275 3 -0.9982 +281 +282    u=5 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer (-X Absorber & Retainer Removed)
276 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber -Y
277 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber Clad  -Y
278 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber +Y
279 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber Clad  +Y
280 6 -7.940 -105     u=4 $ Retainer -Y
281 6 -7.940 -106     u=4 $ Retainer+Y
282 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=4 $ Weld Post in Absorber -Y
283 3 -0.9982 -102 #276  #277  #282   u=4 $ Gap Weld Post to Absorber -Y
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
284 6 -7.940 -104
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190)      u=4 $ Weld Post in Absorber +Y
285 3 -0.9982 -104 #278  #279  #284   u=4 $ Gap Weld Post to Absorber +Y
286 7 -2.7020 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=4 $ Absorber -X
287 7 -2.7020 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=4 $ Absorber Clad  -X
288 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=4 $ Absorber +X
289 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
         +206 +207 +208 +209 +210
         +211 +212 +213 +214 +215 +216 +217 +218 +219
         +220 +221 +222 +223 +224   u=4 $ Absorber Clad  +X
290 6 -7.9400 -195     u=4 $ Retainer -X
291 6 -7.940 -196     u=4 $ Retainer+X
292 6 -7.9400 -192
      (-253:-254:-255:-256:-257:-258:-259:-260:-261:
      -267:-268:-269:-270:-271:-272:-273:-274:-275:
      -276:-277:-278:-279:-280:
      -262:-263:-264:-265:-266)      u=4 $ Weld Post in Plate-X
293 3 -0.9982 -192 #286  #287  #292   u=4 $ Gap Weld Post to Plate -X
294 6 -7.940 -194
      (-253:-254:-255:-256:-257:-258:-259:-260:-261:
      -267:-268:-269:-270:-271:-272:-273:-274:-275:
      -276:-277:-278:-279:-280:
      -262:-263:-264:-265:-266)      u=4 $ Weld Post in Plate +X
295 3 -0.9982 -194 #288  #289  #294   u=4 $ Gap Weld Post to Plate +X
296 3 -0.9982 -281
      +102 +104 +105 +106
      +192 +194 +195 +196     u=4 $ Space in Tube
297 8 -7.821 -282 +281
      +135 +136 +137 +138 +139 +140 +141 +142 +143
      +144 +145 +146 +147 +148
      +149 +150 +151 +152 +153 +154 +155 +156 +157
      +158 +159 +160 +161 +162
      +225 +226 +227 +228 +229 +230 +231 +232 +233
      +234 +235 +236 +237 +238
      +239 +240 +241 +242 +243 +244 +245 +246 +247
      +248 +249 +250 +251 +252      u=4 $ Fuel Tube
298 6 -7.940 -282 +281
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190:
      -253:-254:-255:-256:-257:-258:-259:-260:-261:
      -262:-263:-264:-265:-266:
      -267:-268:-269:-270:-271:-272:-273:-274:-275:
      -276:-277:-278:-279:-280)      u=4 $ Fuel Tube Weld Posts
299 3 -0.9982 -282 +281  #297  #298
            u=4 $ Space Around Weld Posts
300 3 -0.9982 +281 +282    u=4 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer (+X Absorber & Retainer Removed)
301 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
         +116 +117 +118 +119 +120
         +121 +122 +123 +124 +125 +126 +127 +128 +129
         +130 +131 +132 +133 +134   u=3 $ Absorber -Y
302 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber Clad  -Y
303 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber +Y
304 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber Clad  +Y
305 6 -7.940 -105     u=3 $ Retainer -Y
306 6 -7.940 -106     u=3 $ Retainer+Y
307 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=3 $ Weld Post in Absorber -Y
308 3 -0.9982 -102 #301  #302  #307   u=3 $ Gap Weld Post to Absorber -Y
309 6 -7.940 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=3 $ Weld Post in Absorber +Y
310 3 -0.9982 -104 #303  #304  #309   u=3 $ Gap Weld Post to Absorber +Y
311 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber -X
312 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber Clad  -X
313 7 -2.7020 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber +X
314 7 -2.7020 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber Clad  +X
315 6 -7.940 -195     u=3 $ Retainer -X
316 6 -7.9400 -196     u=3 $ Retainer+X
317 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=3 $ Weld Post in Plate-X
318 3 -0.9982 -192 #311  #312  #317   u=3 $ Gap Weld Post to Plate -X
319 6 -7.9400 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=3 $ Weld Post in Plate +X
320 3 -0.9982 -194 #313  #314  #319   u=3 $ Gap Weld Post to Plate +X
321 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=3 $ Space in Tube
322 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
      +248 +249 +250 +251 +252      u=3 $ Fuel Tube
323 6 -7.940 -282 +281
      (-163:-164:-165:-166:-167:-168:-169:-170:-171:
      -172:-173:-174:-175:-176:
      -177:-178:-179:-180:-181:-182:-183:-184:-185:
      -186:-187:-188:-189:-190:
      -253:-254:-255:-256:-257:-258:-259:-260:-261:
      -262:-263:-264:-265:-266:
      -267:-268:-269:-270:-271:-272:-273:-274:-275:
      -276:-277:-278:-279:-280)      u=3 $ Fuel Tube Weld Posts
324 3 -0.9982 -282 +281  #322  #323
            u=3 $ Space Around Weld Posts
325 3 -0.9982 +281 +282    u=3 $ Exterior Space
C Cells - Basket
401 3 -0.9982 -401 -402 fill=9 *trcl=( -15.6617 78.3083 0.0000 )    u=2 $ Tube Loc 1
402 like 401 but  fill=10 *trcl=( 15.6617 78.3083 0.0000 )    u=2 $ Tube Loc 2
403 like 401 but  fill=6 *trcl=( -31.3233 62.6467 0.0000 )    u=2 $ Tube Loc 3
404 like 401 but  fill=11 *trcl=( 0.0000 62.6467 0.0000 )    u=2 $ Tube Loc 4
405 like 401 but  fill=6 *trcl=( 31.3233 62.6467 0.0000 )    u=2 $ Tube Loc 5
406 like 401 but  fill=11 *trcl=( -46.9850 46.9850 0.0000 )    u=2 $ Tube Loc 6
407 like 401 but  fill=11 *trcl=( -15.6617 46.9850 0.0000 )    u=2 $ Tube Loc 7
408 like 401 but  fill=11 *trcl=( 15.6617 46.9850 0.0000 )    u=2 $ Tube Loc 8
409 like 401 but  fill=11 *trcl=( 46.9850 46.9850 0.0000 )    u=2 $ Tube Loc 9
410 like 401 but  fill=4 *trcl=( -62.6467 31.3233 0.0000 )    u=2 $ Tube Loc 10
411 like 401 but  fill=11 *trcl=( -31.3233 31.3233 0.0000 )    u=2 $ Tube Loc 11
412 like 401 but  fill=11 *trcl=( 0.0000 31.3233 0.0000 )    u=2 $ Tube Loc 12
413 like 401 but  fill=11 *trcl=( 31.3233 31.3233 0.0000 )    u=2 $ Tube Loc 13
414 like 401 but  fill=3 *trcl=( 62.6467 31.3233 0.0000 )    u=2 $ Tube Loc 14
415 like 401 but  fill=9 *trcl=( -78.3083 15.6617 0.0000 )    u=2 $ Tube Loc 15
416 like 401 but  fill=11 *trcl=( -46.9850 15.6617 0.0000 )    u=2 $ Tube Loc 16
417 like 401 but  fill=11 *trcl=( -15.6617 15.6617 0.0000 )    u=2 $ Tube Loc 17
418 like 401 but  fill=11 *trcl=( 15.6617 15.6617 0.0000 )    u=2 $ Tube Loc 18
419 like 401 but  fill=11 *trcl=( 46.9850 15.6617 0.0000 )    u=2 $ Tube Loc 19
420 like 401 but  fill=10 *trcl=( 78.3083 15.6617 0.0000 )    u=2 $ Tube Loc 20
421 like 401 but  fill=11 *trcl=( -62.6467 0.0000 0.0000 )    u=2 $ Tube Loc 21
422 like 401 but  fill=11 *trcl=( -31.3233 0.0000 0.0000 )    u=2 $ Tube Loc 22
423 like 401 but  fill=11 *trcl=( 0.0000 0.0000 0.0000 )    u=2 $ Tube Loc 23
424 like 401 but  fill=11 *trcl=( 31.3233 0.0000 0.0000 )    u=2 $ Tube Loc 24
425 like 401 but  fill=11 *trcl=( 62.6467 0.0000 0.0000 )    u=2 $ Tube Loc 25
426 like 401 but  fill=8 *trcl=( -78.3083 -15.6617 0.0000 )    u=2 $ Tube Loc 26
427 like 401 but  fill=11 *trcl=( -46.9850 -15.6617 0.0000 )    u=2 $ Tube Loc 27
428 like 401 but  fill=11 *trcl=( -15.6617 -15.6617 0.0000 )    u=2 $ Tube Loc 28
429 like 401 but  fill=11 *trcl=( 15.6617 -15.6617 0.0000 )    u=2 $ Tube Loc 29
430 like 401 but  fill=11 *trcl=( 46.9850 -15.6617 0.0000 )    u=2 $ Tube Loc 30
431 like 401 but  fill=7 *trcl=( 78.3083 -15.6617 0.0000 )    u=2 $ Tube Loc 31
432 like 401 but  fill=4 *trcl=( -62.6467 -31.3233 0.0000 )    u=2 $ Tube Loc 32
433 like 401 but  fill=11 *trcl=( -31.3233 -31.3233 0.0000 )    u=2 $ Tube Loc 33
434 like 401 but  fill=11 *trcl=( 0.0000 -31.3233 0.0000 )    u=2 $ Tube Loc 34
435 like 401 but  fill=11 *trcl=( 31.3233 -31.3233 0.0000 )    u=2 $ Tube Loc 35
436 like 401 but  fill=3 *trcl=( 62.6467 -31.3233 0.0000 )    u=2 $ Tube Loc 36
437 like 401 but  fill=11 *trcl=( -46.9850 -46.9850 0.0000 )    u=2 $ Tube Loc 37
438 like 401 but  fill=11 *trcl=( -15.6617 -46.9850 0.0000 )    u=2 $ Tube Loc 38
439 like 401 but  fill=11 *trcl=( 15.6617 -46.9850 0.0000 )    u=2 $ Tube Loc 39
440 like 401 but  fill=11 *trcl=( 46.9850 -46.9850 0.0000 )    u=2 $ Tube Loc 40
441 like 401 but  fill=5 *trcl=( -31.3233 -62.6467 0.0000 )    u=2 $ Tube Loc 41
442 like 401 but  fill=11 *trcl=( 0.0000 -62.6467 0.0000 )    u=2 $ Tube Loc 42
443 like 401 but  fill=5 *trcl=( 31.3233 -62.6467 0.0000 )    u=2 $ Tube Loc 43
444 like 401 but  fill=8 *trcl=( -15.6617 -78.3083 0.0000 )    u=2 $ Tube Loc 44
445 like 401 but  fill=7 *trcl=( 15.6617 -78.3083 0.0000 )    u=2 $ Tube Loc 45
446 8 -7.821 -404 +405 #401  #402  #444  #445   u=2 $ Side Weldment Y Center
447 8 -7.821 -408 +409 #415  #426  #420  #431   u=2 $ Side Weldment X Center
448 8 -7.821 -406 +407 +404     u=2 $ Side Weldment Y Mount
449 8 -7.821 -410 +411 +408     u=2 $ Side Weldment X Mount
450 8 -7.821 -413 +412 -414 +416 +418 +420 +422 u=2 $ Corner Weldment Part 1
451 8 -7.821 (-420 +419 +412) : (-422 +421 +412)       u=2 $ Corner Weldment Part 2
452 8 -7.821 -416 +415 +418 +412 #406 #409 #437 #440    u=2 $ Corner Weldment Part 3
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
453 8 -7.821 -418 +417 +415 +412 #406 #409 #437 #440    u=2 $ Corner Weldment Part 4
454 3 -0.9982 -403
      #404 #407 #408 #411 #412 #413 #416 #417 #418 #419
      #421 #422 #423 #424 #425 #427 #428 #429 #430 #433
      #434 #435 #438 #439 #442          u=2 $ Interior Open Space
455 3 -0.9982 +403
      #401 #402 #403 #405 #406 #409 #410 #414 #415 #420
      #426 #431 #432 #436 #437 #440 #441 #443 #444 #445
      #446 #447 #448 #449 #450 #451 #452 #453          u=2 $ Remaining Open Space
c Cell Cards - Canister
501 3 -0.9982 -14 fill=12 *trcl=( -15.3418 77.9885 0.0000 )    u=1 $ Assy loc 1
502 like 501 but     *trcl=( 15.3418 77.9885 0.0000 )    u=1 $ Assy loc 2
503 like 501 but     *trcl=( -31.0035 62.3268 0.0000 )    u=1 $ Assy loc 3
504 like 501 but     *trcl=( 0.0000 62.3268 0.0000 )    u=1 $ Assy loc 4
505 like 501 but     *trcl=( 31.0035 62.3268 0.0000 )    u=1 $ Assy loc 5
506 like 501 but     *trcl=( -46.6652 46.6652 0.0000 )    u=1 $ Assy loc 6
507 like 501 but     *trcl=( -15.3418 46.6652 0.0000 )    u=1 $ Assy loc 7
508 like 501 but     *trcl=( 15.3418 46.6652 0.0000 )    u=1 $ Assy loc 8
509 like 501 but     *trcl=( 46.6652 46.6652 0.0000 )    u=1 $ Assy loc 9
510 like 501 but     *trcl=( -62.3268 31.0035 0.0000 )    u=1 $ Assy loc 10
511 like 501 but     *trcl=( -31.0035 31.0035 0.0000 )    u=1 $ Assy loc 11
512 like 501 but     *trcl=( 0.0000 31.0035 0.0000 )    u=1 $ Assy loc 12
513 like 501 but     *trcl=( 31.0035 31.0035 0.0000 )    u=1 $ Assy loc 13
514 like 501 but     *trcl=( 62.3268 31.0035 0.0000 )    u=1 $ Assy loc 14
515 like 501 but     *trcl=( -77.9885 15.3418 0.0000 )    u=1 $ Assy loc 15
516 like 501 but     *trcl=( -46.6652 15.3418 0.0000 )    u=1 $ Assy loc 16
517 like 501 but     *trcl=( -15.3418 15.3418 0.0000 )    u=1 $ Assy loc 17
518 like 501 but     *trcl=( 15.3418 15.3418 0.0000 )    u=1 $ Assy loc 18
519 like 501 but     *trcl=( 46.6652 15.3418 0.0000 )    u=1 $ Assy loc 19
520 like 501 but     *trcl=( 77.9885 15.3418 0.0000 )    u=1 $ Assy loc 20
521 like 501 but     *trcl=( -62.3268 0.0000 0.0000 )    u=1 $ Assy loc 21
522 like 501 but     *trcl=( -31.0035 0.0000 0.0000 )    u=1 $ Assy loc 22
523 like 501 but     *trcl=( 0.0000 0.0000 0.0000 )    u=1 $ Assy loc 23
524 like 501 but     *trcl=( 31.0035 0.0000 0.0000 )    u=1 $ Assy loc 24
525 like 501 but     *trcl=( 62.3268 0.0000 0.0000 )    u=1 $ Assy loc 25
526 like 501 but     *trcl=( -77.9885 -15.3418 0.0000 )    u=1 $ Assy loc 26
527 like 501 but     *trcl=( -46.6652 -15.3418 0.0000 )    u=1 $ Assy loc 27
528 like 501 but     *trcl=( -15.3418 -15.3418 0.0000 )    u=1 $ Assy loc 28
529 like 501 but     *trcl=( 15.3418 -15.3418 0.0000 )    u=1 $ Assy loc 29
530 like 501 but     *trcl=( 46.6652 -15.3418 0.0000 )    u=1 $ Assy loc 30
531 like 501 but     *trcl=( 77.9885 -15.3418 0.0000 )    u=1 $ Assy loc 31
532 like 501 but     *trcl=( -62.3268 -31.0035 0.0000 )    u=1 $ Assy loc 32
533 like 501 but     *trcl=( -31.0035 -31.0035 0.0000 )    u=1 $ Assy loc 33
534 like 501 but     *trcl=( 0.0000 -31.0035 0.0000 )    u=1 $ Assy loc 34
535 like 501 but     *trcl=( 31.0035 -31.0035 0.0000 )    u=1 $ Assy loc 35
536 like 501 but     *trcl=( 62.3268 -31.0035 0.0000 )    u=1 $ Assy loc 36
537 like 501 but     *trcl=( -46.6652 -46.6652 0.0000 )    u=1 $ Assy loc 37
538 like 501 but     *trcl=( -15.3418 -46.6652 0.0000 )    u=1 $ Assy loc 38
539 like 501 but     *trcl=( 15.3418 -46.6652 0.0000 )    u=1 $ Assy loc 39
540 like 501 but     *trcl=( 46.6652 -46.6652 0.0000 )    u=1 $ Assy loc 40
541 like 501 but     *trcl=( -31.0035 -62.3268 0.0000 )    u=1 $ Assy loc 41
542 like 501 but     *trcl=( 0.0000 -62.3268 0.0000 )    u=1 $ Assy loc 42
543 like 501 but     *trcl=( 31.0035 -62.3268 0.0000 )    u=1 $ Assy loc 43
544 like 501 but     *trcl=( -15.3418 -77.9885 0.0000 )    u=1 $ Assy loc 44
545 like 501 but     *trcl=( 15.3418 -77.9885 0.0000 )    u=1 $ Assy loc 45
546 like 501 but     *trcl=( 0.0000 77.9987 0.0000 )    u=1 $ Assy loc 46
547 like 501 but     *trcl=( -46.6754 62.3371 0.0000 )    u=1 $ Assy loc 47
548 like 501 but     *trcl=( -15.3521 62.3371 0.0000 )    u=1 $ Assy loc 48
549 like 501 but     *trcl=( 15.3521 62.3371 0.0000 )    u=1 $ Assy loc 49
550 like 501 but     *trcl=( 46.6754 62.3371 0.0000 )    u=1 $ Assy loc 50
551 like 501 but     *trcl=( -62.3371 46.6754 0.0000 )    u=1 $ Assy loc 51
552 like 501 but     *trcl=( -31.0137 46.6754 0.0000 )    u=1 $ Assy loc 52
553 like 501 but     *trcl=( 0.0000 46.6754 0.0000 )    u=1 $ Assy loc 53
554 like 501 but     *trcl=( 31.0137 46.6754 0.0000 )    u=1 $ Assy loc 54
555 like 501 but     *trcl=( 62.3371 46.6754 0.0000 )    u=1 $ Assy loc 55
556 like 501 but     *trcl=( -46.6754 31.0137 0.0000 )    u=1 $ Assy loc 56
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
557 like 501 but     *trcl=( -15.3521 31.0137 0.0000 )    u=1 $ Assy loc 57
558 like 501 but     *trcl=( 15.3521 31.0137 0.0000 )    u=1 $ Assy loc 58
559 like 501 but     *trcl=( 46.6754 31.0137 0.0000 )    u=1 $ Assy loc 59
560 like 501 but     *trcl=( -62.3371 15.3521 0.0000 )    u=1 $ Assy loc 60
561 like 501 but     *trcl=( -31.0137 15.3521 0.0000 )    u=1 $ Assy loc 61
562 like 501 but     *trcl=( 0.0000 15.3521 0.0000 )    u=1 $ Assy loc 62
563 like 501 but     *trcl=( 31.0137 15.3521 0.0000 )    u=1 $ Assy loc 63
564 like 501 but     *trcl=( 62.3371 15.3521 0.0000 )    u=1 $ Assy loc 64
565 like 501 but     *trcl=( -77.9987 0.0000 0.0000 )    u=1 $ Assy loc 65
566 like 501 but     *trcl=( -46.6754 0.0000 0.0000 )    u=1 $ Assy loc 66
567 like 501 but     *trcl=( -15.3521 0.0000 0.0000 )    u=1 $ Assy loc 67
568 like 501 but     *trcl=( 15.3521 0.0000 0.0000 )    u=1 $ Assy loc 68
569 like 501 but     *trcl=( 46.6754 0.0000 0.0000 )    u=1 $ Assy loc 69
570 like 501 but     *trcl=( 77.9987 0.0000 0.0000 )    u=1 $ Assy loc 70
571 like 501 but     *trcl=( -62.3371 -15.3521 0.0000 )    u=1 $ Assy loc 71
572 like 501 but     *trcl=( -31.0137 -15.3521 0.0000 )    u=1 $ Assy loc 72
573 like 501 but     *trcl=( 0.0000 -15.3521 0.0000 )    u=1 $ Assy loc 73
574 like 501 but     *trcl=( 31.0137 -15.3521 0.0000 )    u=1 $ Assy loc 74
575 like 501 but     *trcl=( 62.3371 -15.3521 0.0000 )    u=1 $ Assy loc 75
576 like 501 but     *trcl=( -46.6754 -31.0137 0.0000 )    u=1 $ Assy loc 76
577 like 501 but     *trcl=( -15.3521 -31.0137 0.0000 )    u=1 $ Assy loc 77
578 like 501 but     *trcl=( 15.3521 -31.0137 0.0000 )    u=1 $ Assy loc 78
579 like 501 but     *trcl=( 46.6754 -31.0137 0.0000 )    u=1 $ Assy loc 79
580 like 501 but     *trcl=( -62.3371 -46.6754 0.0000 )    u=1 $ Assy loc 80
581 like 501 but     *trcl=( -31.0137 -46.6754 0.0000 )    u=1 $ Assy loc 81
582 like 501 but     *trcl=( 0.0000 -46.6754 0.0000 )    u=1 $ Assy loc 82
583 like 501 but     *trcl=( 31.0137 -46.6754 0.0000 )    u=1 $ Assy loc 83
584 like 501 but     *trcl=( 62.3371 -46.6754 0.0000 )    u=1 $ Assy loc 84
585 like 501 but     *trcl=( -46.6754 -62.3371 0.0000 )    u=1 $ Assy loc 85
586 like 501 but     *trcl=( -15.3521 -62.3371 0.0000 )    u=1 $ Assy loc 86
587 like 501 but     *trcl=( 15.3521 -62.3371 0.0000 )    u=1 $ Assy loc 87
588 like 501 but     *trcl=( 46.6754 -62.3371 0.0000 )    u=1 $ Assy loc 88
589 like 501 but     *trcl=( 0.0000 -77.9987 0.0000 )    u=1 $ Assy loc 89
590 3 -0.9982 -501 +502
       #501 #502 #503 #504 #505 #506 #507 #508 #509 #510
       #511 #512 #513 #514 #515 #516 #517 #518 #519 #520
       #521 #522 #523 #524 #525
       #546 #547 #548 #549 #550
       #551 #552 #553 #554 #555 #556 #557 #558 #559 #560
       #561 #562 #563 #564 #565 #566 #567 #568 #569 #570
             fill=2 u=1 $ Cavity
591 3 -0.9982 -501 -502
       #526 #527 #528 #529 #530
       #531 #532 #533 #534 #535 #536 #537 #538 #539 #540
       #541 #542 #543 #544 #545
       #571 #572 #573 #574 #575 #576 #577 #578 #579 #580
       #581 #582 #583 #584 #585 #586 #587 #588 #589
             fill=2 u=1 $ Cavity
592 6 -7.940 -503 +501     u=1 $ Canister Shell / Lid / Bottom
593 13 -0.0001 +503      u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
601 13 -0.0001 -601 -602  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
602 8 -7.821 -601 +602 -606     $ Bottom plate
603 8 -7.821 -603 +602 +606 -607    $ Inner shell
604 9 -11.344 -604 +603 +606 -607    $ Lead shell
605 10 -1.632 -605 +604 +606 -607    $ NS-4-FR
606 8 -7.821 -601 +605 +606 -607    $ Outer shell
607 8 -7.821 -601 +602 +607     $ Top plate
608 8 -7.821 -608 +609  -614    $ Door rail
609 8 -7.821 -608 -610  -614    $ Door rail
610 8 -7.821 -613 -611 +612 -614    $ Door steel
611 13 -0.0001 -614 +601 #608 #609 #610      $ Exterior space to Reflector
612 0         +614       $ Exterior space

c Surfaces - Fuel Rod - B10_96A - BWR_10x10_5 WR
1 RCC 0.0000 0.0000 1.5875 0.0000 0.0000 381.0000 0.4095 $ Fuel pellet stack
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
2 RCC 0.0000 0.0000 1.5875 0.0000 0.0000 405.3332 0.4184 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 407.8006 0.4801 $ Clad + End-Caps
c Surfaces - Pitch - B10_96A - BWR_10x10_5 WR
7 PX 0.6198       $ Lattice Cell Boundaries
8 PX -0.6198
9 PY 0.6198
10 PY -0.6198
c Surfaces - Fuel Assembly Array Inserted Into Assembly - B10_96A - BWR_10x10_5 WR
11 RPP -3.0987 3.0987 -3.0987 3.0987 17.1704 428.4980  $ Array
12 RPP -6.7031 6.7031 -6.7031 6.7031 17.1704 428.4980  $ Channel Inner
13 RPP -7.0079 7.0079 -7.0079 7.0079 17.1704 428.4980  $ Channel Outer
14 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 447.5480  $ Assembly Outer Dims
c Surface Cards - Tube, Absorber and Retainer
101 RPP -6.7056 6.7056 -7.5946 -7.4041 8.8900 427.5074 $ Absorber -Y
102 RPP -6.7056 6.7056 -7.6327 -7.3660 8.8900 427.5074 $ Absorber Clad  -Y
103 RPP -6.7056 6.7056 7.4041 7.5946 8.8900 427.5074 $ Absorber +Y
104 RPP -6.7056 6.7056 7.3660 7.6327 8.8900 427.5074 $ Absorber Clad  +Y
105 RPP -6.8326 6.8326 -7.3660 -7.3279 7.6200 429.4124 $ Retainer -Y
106 RPP -6.8326 6.8326 7.3279 7.3660 7.6200 429.4124 $ Retainer  +Y
107 RPP 3.7783 5.3658 -8.3439 8.3439 18.8024 21.9901 $ Weld Post Slot Y Absorber
108 RPP 3.7783 5.3658 -8.3439 8.3439 49.2824 52.4701 $ Weld Post Slot Y Absorber
109 RPP 3.7783 5.3658 -8.3439 8.3439 79.7624 82.9501 $ Weld Post Slot Y Absorber
110 RPP 3.7783 5.3658 -8.3439 8.3439 110.2424 113.4301 $ Weld Post Slot Y Absorber
111 RPP 3.7783 5.3658 -8.3439 8.3439 140.7224 143.9101 $ Weld Post Slot Y Absorber
112 RPP 3.7783 5.3658 -8.3439 8.3439 171.2024 174.3901 $ Weld Post Slot Y Absorber
113 RPP 3.7783 5.3658 -8.3439 8.3439 201.6824 204.8701 $ Weld Post Slot Y Absorber
114 RPP 3.7783 5.3658 -8.3439 8.3439 232.1624 235.3501 $ Weld Post Slot Y Absorber
115 RPP 3.7783 5.3658 -8.3439 8.3439 262.6424 265.8301 $ Weld Post Slot Y Absorber
116 RPP 3.7783 5.3658 -8.3439 8.3439 293.1224 296.3101 $ Weld Post Slot Y Absorber
117 RPP 3.7783 5.3658 -8.3439 8.3439 323.6024 326.7901 $ Weld Post Slot Y Absorber
118 RPP 3.7783 5.3658 -8.3439 8.3439 354.0824 357.2701 $ Weld Post Slot Y Absorber
119 RPP 3.7783 5.3658 -8.3439 8.3439 384.5624 387.7501 $ Weld Post Slot Y Absorber
120 RPP 3.7783 5.3658 -8.3439 8.3439 415.0424 418.2301 $ Weld Post Slot Y Absorber
121 RPP -5.3658 -3.7783 -8.3439 8.3439 18.8024 21.9901 $ Weld Post Slot Y Absorber
122 RPP -5.3658 -3.7783 -8.3439 8.3439 49.2824 52.4701 $ Weld Post Slot Y Absorber
123 RPP -5.3658 -3.7783 -8.3439 8.3439 79.7624 82.9501 $ Weld Post Slot Y Absorber
124 RPP -5.3658 -3.7783 -8.3439 8.3439 110.2424 113.4301 $ Weld Post Slot Y Absorber
125 RPP -5.3658 -3.7783 -8.3439 8.3439 140.7224 143.9101 $ Weld Post Slot Y Absorber
126 RPP -5.3658 -3.7783 -8.3439 8.3439 171.2024 174.3901 $ Weld Post Slot Y Absorber
127 RPP -5.3658 -3.7783 -8.3439 8.3439 201.6824 204.8701 $ Weld Post Slot Y Absorber
128 RPP -5.3658 -3.7783 -8.3439 8.3439 232.1624 235.3501 $ Weld Post Slot Y Absorber
129 RPP -5.3658 -3.7783 -8.3439 8.3439 262.6424 265.8301 $ Weld Post Slot Y Absorber
130 RPP -5.3658 -3.7783 -8.3439 8.3439 293.1224 296.3101 $ Weld Post Slot Y Absorber
131 RPP -5.3658 -3.7783 -8.3439 8.3439 323.6024 326.7901 $ Weld Post Slot Y Absorber
132 RPP -5.3658 -3.7783 -8.3439 8.3439 354.0824 357.2701 $ Weld Post Slot Y Absorber
133 RPP -5.3658 -3.7783 -8.3439 8.3439 384.5624 387.7501 $ Weld Post Slot Y Absorber
134 RPP -5.3658 -3.7783 -8.3439 8.3439 415.0424 418.2301 $ Weld Post Slot Y Absorber
135 C/Y 4.5720 20.3962 0.4191    $ Weld Post Hole Y
136 C/Y 4.5720 50.8762 0.4191    $ Weld Post Hole Y
137 C/Y 4.5720 81.3562 0.4191    $ Weld Post Hole Y
138 C/Y 4.5720 111.8362 0.4191    $ Weld Post Hole Y
139 C/Y 4.5720 142.3162 0.4191    $ Weld Post Hole Y
140 C/Y 4.5720 172.7962 0.4191    $ Weld Post Hole Y
141 C/Y 4.5720 203.2762 0.4191    $ Weld Post Hole Y
142 C/Y 4.5720 233.7562 0.4191    $ Weld Post Hole Y
143 C/Y 4.5720 264.2362 0.4191    $ Weld Post Hole Y
144 C/Y 4.5720 294.7162 0.4191    $ Weld Post Hole Y
145 C/Y 4.5720 325.1962 0.4191    $ Weld Post Hole Y
146 C/Y 4.5720 355.6762 0.4191    $ Weld Post Hole Y
147 C/Y 4.5720 386.1562 0.4191    $ Weld Post Hole Y
148 C/Y 4.5720 416.6362 0.4191    $ Weld Post Hole Y
149 C/Y -4.5720 20.3962 0.4191    $ Weld Post Hole Y
150 C/Y -4.5720 50.8762 0.4191    $ Weld Post Hole Y
151 C/Y -4.5720 81.3562 0.4191    $ Weld Post Hole Y
152 C/Y -4.5720 111.8362 0.4191    $ Weld Post Hole Y
153 C/Y -4.5720 142.3162 0.4191    $ Weld Post Hole Y
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
154 C/Y -4.5720 172.7962 0.4191    $ Weld Post Hole Y
155 C/Y -4.5720 203.2762 0.4191    $ Weld Post Hole Y
156 C/Y -4.5720 233.7562 0.4191    $ Weld Post Hole Y
157 C/Y -4.5720 264.2362 0.4191    $ Weld Post Hole Y
158 C/Y -4.5720 294.7162 0.4191    $ Weld Post Hole Y
159 C/Y -4.5720 325.1962 0.4191    $ Weld Post Hole Y
160 C/Y -4.5720 355.6762 0.4191    $ Weld Post Hole Y
161 C/Y -4.5720 386.1562 0.4191    $ Weld Post Hole Y
162 C/Y -4.5720 416.6362 0.4191    $ Weld Post Hole Y
163 C/Y 4.5720 20.3962 0.3175    $ Weld Post Y
164 C/Y 4.5720 50.8762 0.3175    $ Weld Post Y
165 C/Y 4.5720 81.3562 0.3175    $ Weld Post Y
166 C/Y 4.5720 111.8362 0.3175    $ Weld Post Y
167 C/Y 4.5720 142.3162 0.3175    $ Weld Post Y
168 C/Y 4.5720 172.7962 0.3175    $ Weld Post Y
169 C/Y 4.5720 203.2762 0.3175    $ Weld Post Y
170 C/Y 4.5720 233.7562 0.3175    $ Weld Post Y
171 C/Y 4.5720 264.2362 0.3175    $ Weld Post Y
172 C/Y 4.5720 294.7162 0.3175    $ Weld Post Y
173 C/Y 4.5720 325.1962 0.3175    $ Weld Post Y
174 C/Y 4.5720 355.6762 0.3175    $ Weld Post Y
175 C/Y 4.5720 386.1562 0.3175    $ Weld Post Y
176 C/Y 4.5720 416.6362 0.3175    $ Weld Post Y
177 C/Y -4.5720 20.3962 0.3175    $ Weld Post Y
178 C/Y -4.5720 50.8762 0.3175    $ Weld Post Y
179 C/Y -4.5720 81.3562 0.3175    $ Weld Post Y
180 C/Y -4.5720 111.8362 0.3175    $ Weld Post Y
181 C/Y -4.5720 142.3162 0.3175    $ Weld Post Y
182 C/Y -4.5720 172.7962 0.3175    $ Weld Post Y
183 C/Y -4.5720 203.2762 0.3175    $ Weld Post Y
184 C/Y -4.5720 233.7562 0.3175    $ Weld Post Y
185 C/Y -4.5720 264.2362 0.3175    $ Weld Post Y
186 C/Y -4.5720 294.7162 0.3175    $ Weld Post Y
187 C/Y -4.5720 325.1962 0.3175    $ Weld Post Y
188 C/Y -4.5720 355.6762 0.3175    $ Weld Post Y
189 C/Y -4.5720 386.1562 0.3175    $ Weld Post Y
190 C/Y -4.5720 416.6362 0.3175    $ Weld Post Y
191 RPP -7.5946 -7.4041 -6.7056 6.7056 8.8900 427.5074 $ Absorber -X
192 RPP -7.6327 -7.3660 -6.7056 6.7056 8.8900 427.5074 $ Absorber Clad  -X
193 RPP 7.4041 7.5946 -6.7056 6.7056 8.8900 427.5074 $ Absorber +X
194 RPP 7.3660 7.6327 -6.7056 6.7056 8.8900 427.5074 $ Absorber Clad  +X
195 RPP -7.3660 -7.3279 -6.8326 6.8326 7.6200 429.4124 $ Retainer -X
196 RPP 7.3279 7.3660 -6.8326 6.8326 7.6200 429.4124 $ Retainer  +X
197 RPP -8.3439 8.3439 3.7783 5.3658 18.8024 21.9901 $ Weld Post Slot X Absorber
198 RPP -8.3439 8.3439 3.7783 5.3658 49.2824 52.4701 $ Weld Post Slot X Absorber
199 RPP -8.3439 8.3439 3.7783 5.3658 79.7624 82.9501 $ Weld Post Slot X Absorber
200 RPP -8.3439 8.3439 3.7783 5.3658 110.2424 113.4301 $ Weld Post Slot X Absorber
201 RPP -8.3439 8.3439 3.7783 5.3658 140.7224 143.9101 $ Weld Post Slot X Absorber
202 RPP -8.3439 8.3439 3.7783 5.3658 171.2024 174.3901 $ Weld Post Slot X Absorber
203 RPP -8.3439 8.3439 3.7783 5.3658 201.6824 204.8701 $ Weld Post Slot X Absorber
204 RPP -8.3439 8.3439 3.7783 5.3658 232.1624 235.3501 $ Weld Post Slot X Absorber
205 RPP -8.3439 8.3439 3.7783 5.3658 262.6424 265.8301 $ Weld Post Slot X Absorber
206 RPP -8.3439 8.3439 3.7783 5.3658 293.1224 296.3101 $ Weld Post Slot X Absorber
207 RPP -8.3439 8.3439 3.7783 5.3658 323.6024 326.7901 $ Weld Post Slot X Absorber
208 RPP -8.3439 8.3439 3.7783 5.3658 354.0824 357.2701 $ Weld Post Slot X Absorber
209 RPP -8.3439 8.3439 3.7783 5.3658 384.5624 387.7501 $ Weld Post Slot X Absorber
210 RPP -8.3439 8.3439 3.7783 5.3658 415.0424 418.2301 $ Weld Post Slot X Absorber
211 RPP -8.3439 8.3439 -5.3658 -3.7783 18.8024 21.9901 $ Weld Post Slot X Absorber
212 RPP -8.3439 8.3439 -5.3658 -3.7783 49.2824 52.4701 $ Weld Post Slot X Absorber
213 RPP -8.3439 8.3439 -5.3658 -3.7783 79.7624 82.9501 $ Weld Post Slot X Absorber
214 RPP -8.3439 8.3439 -5.3658 -3.7783 110.2424 113.4301 $ Weld Post Slot X Absorber
215 RPP -8.3439 8.3439 -5.3658 -3.7783 140.7224 143.9101 $ Weld Post Slot X Absorber
216 RPP -8.3439 8.3439 -5.3658 -3.7783 171.2024 174.3901 $ Weld Post Slot X Absorber
217 RPP -8.3439 8.3439 -5.3658 -3.7783 201.6824 204.8701 $ Weld Post Slot X Absorber
218 RPP -8.3439 8.3439 -5.3658 -3.7783 232.1624 235.3501 $ Weld Post Slot X Absorber
219 RPP -8.3439 8.3439 -5.3658 -3.7783 262.6424 265.8301 $ Weld Post Slot X Absorber
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
220 RPP -8.3439 8.3439 -5.3658 -3.7783 293.1224 296.3101 $ Weld Post Slot X Absorber
221 RPP -8.3439 8.3439 -5.3658 -3.7783 323.6024 326.7901 $ Weld Post Slot X Absorber
222 RPP -8.3439 8.3439 -5.3658 -3.7783 354.0824 357.2701 $ Weld Post Slot X Absorber
223 RPP -8.3439 8.3439 -5.3658 -3.7783 384.5624 387.7501 $ Weld Post Slot X Absorber
224 RPP -8.3439 8.3439 -5.3658 -3.7783 415.0424 418.2301 $ Weld Post Slot X Absorber
225 C/X 4.5720 20.3962 0.4191    $ Weld Post Hole X
226 C/X 4.5720 50.8762 0.4191    $ Weld Post Hole X
227 C/X 4.5720 81.3562 0.4191    $ Weld Post Hole X
228 C/X 4.5720 111.8362 0.4191    $ Weld Post Hole X
229 C/X 4.5720 142.3162 0.4191    $ Weld Post Hole X
230 C/X 4.5720 172.7962 0.4191    $ Weld Post Hole X
231 C/X 4.5720 203.2762 0.4191    $ Weld Post Hole X
232 C/X 4.5720 233.7562 0.4191    $ Weld Post Hole X
233 C/X 4.5720 264.2362 0.4191    $ Weld Post Hole X
234 C/X 4.5720 294.7162 0.4191    $ Weld Post Hole X
235 C/X 4.5720 325.1962 0.4191    $ Weld Post Hole X
236 C/X 4.5720 355.6762 0.4191    $ Weld Post Hole X
237 C/X 4.5720 386.1562 0.4191    $ Weld Post Hole X
238 C/X 4.5720 416.6362 0.4191    $ Weld Post Hole X
239 C/X -4.5720 20.3962 0.4191    $ Weld Post Hole X
240 C/X -4.5720 50.8762 0.4191    $ Weld Post Hole X
241 C/X -4.5720 81.3562 0.4191    $ Weld Post Hole X
242 C/X -4.5720 111.8362 0.4191    $ Weld Post Hole X
243 C/X -4.5720 142.3162 0.4191    $ Weld Post Hole X
244 C/X -4.5720 172.7962 0.4191    $ Weld Post Hole X
245 C/X -4.5720 203.2762 0.4191    $ Weld Post Hole X
246 C/X -4.5720 233.7562 0.4191    $ Weld Post Hole X
247 C/X -4.5720 264.2362 0.4191    $ Weld Post Hole X
248 C/X -4.5720 294.7162 0.4191    $ Weld Post Hole X
249 C/X -4.5720 325.1962 0.4191    $ Weld Post Hole X
250 C/X -4.5720 355.6762 0.4191    $ Weld Post Hole X
251 C/X -4.5720 386.1562 0.4191    $ Weld Post Hole X
252 C/X -4.5720 416.6362 0.4191    $ Weld Post Hole X
253 C/X 4.5720 20.3962 0.3175    $ Weld Post X
254 C/X 4.5720 50.8762 0.3175    $ Weld Post X
255 C/X 4.5720 81.3562 0.3175    $ Weld Post X
256 C/X 4.5720 111.8362 0.3175    $ Weld Post X
257 C/X 4.5720 142.3162 0.3175    $ Weld Post X
258 C/X 4.5720 172.7962 0.3175    $ Weld Post X
259 C/X 4.5720 203.2762 0.3175    $ Weld Post X
260 C/X 4.5720 233.7562 0.3175    $ Weld Post X
261 C/X 4.5720 264.2362 0.3175    $ Weld Post X
262 C/X 4.5720 294.7162 0.3175    $ Weld Post X
263 C/X 4.5720 325.1962 0.3175    $ Weld Post X
264 C/X 4.5720 355.6762 0.3175    $ Weld Post X
265 C/X 4.5720 386.1562 0.3175    $ Weld Post X
266 C/X 4.5720 416.6362 0.3175    $ Weld Post X
267 C/X -4.5720 20.3962 0.3175    $ Weld Post X
268 C/X -4.5720 50.8762 0.3175    $ Weld Post X
269 C/X -4.5720 81.3562 0.3175    $ Weld Post X
270 C/X -4.5720 111.8362 0.3175    $ Weld Post X
271 C/X -4.5720 142.3162 0.3175    $ Weld Post X
272 C/X -4.5720 172.7962 0.3175    $ Weld Post X
273 C/X -4.5720 203.2762 0.3175    $ Weld Post X
274 C/X -4.5720 233.7562 0.3175    $ Weld Post X
275 C/X -4.5720 264.2362 0.3175    $ Weld Post X
276 C/X -4.5720 294.7162 0.3175    $ Weld Post X
277 C/X -4.5720 325.1962 0.3175    $ Weld Post X
278 C/X -4.5720 355.6762 0.3175    $ Weld Post X
279 C/X -4.5720 386.1562 0.3175    $ Weld Post X
280 C/X -4.5720 416.6362 0.3175    $ Weld Post X
281 RPP -7.6327 7.6327 -7.6327 7.6327 0.0000 458.4700 $  Space inside tube - cavity extent
282 RPP -8.3439 8.3439 -8.3439 8.3439 7.6200 429.4124 $  Fuel tube
C Surfaces - Basket
401  RPP -8.3439 8.3439 -8.3439 8.3439 0.0000 458.4700   $ Tube Enclosing Body - Cavity Height
402 1 RPP -11.0744 11.0744 -11.0744 11.0744 0.0000 458.4700   $ Tube Corner Cuts
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
403 1 RPP -55.37235 55.37235 -55.37235 55.37235 0.0000 458.4700   $ Array Interior Limit
404  RPP -8.3693 8.3693 -87.2872 87.2872 0.0000 455.9300   $ Outer Surface Side Weld. Middle
405  RPP -8.3693 8.3693 -85.6997 85.6997 0.0000 455.9300   $ Inner Surface Side Weld. Middle
406  RPP -22.2250 22.2250 -87.2872 87.2872 7.6200 429.4124   $ Outer Surface Side Weld. Side
Mount
407  RPP -22.2250 22.2250 -86.6522 86.6522 7.6200 429.4124   $ Inner Surface Side Weld. Side
Mount
408  RPP -87.2872 87.2872 -8.3693 8.3693 0.0000 455.9300   $ Outer Surface Side Weld. Middle
409  RPP -85.6997 85.6997 -8.3693 8.3693 0.0000 455.9300   $ Inner Surface Side Weld. Middle
410  RPP -87.2872 87.2872 -22.2250 22.2250 7.6200 429.4124   $ Outer Surface Side Weld. Side
Mount
411  RPP -86.6522 86.6522 -22.2250 22.2250 7.6200 429.4124   $ Inner Surface Side Weld. Side
Mount
412 1 RPP -71.9600 71.9600 -71.9600 71.9600 7.6200 448.3100   $ Inner Surface Corner Weld.
413 1 RPP -72.9125 72.9125 -72.9125 72.9125 7.6200 448.3100   $ Outer Surface Corner Weld.
414  RPP -86.3728 86.3728 -86.3728 86.3728 7.6200 448.3100   $ Outer Cut Surface Corner Weld.
415  RPP -54.3129 54.3129 -70.9906 70.9906 7.6200 448.3100   $ Inner Surface Corner Weld.
416  RPP -55.1066 55.1066 -71.9431 71.9431 7.6200 448.3100   $ Outer Surface Corner Weld.
417  RPP -70.9906 70.9906 -54.3129 54.3129 7.6200 448.3100   $ Inner Surface Corner Weld.
418  RPP -71.9431 71.9431 -55.1066 55.1066 7.6200 448.3100   $ Outer Surface Corner Weld.
419  RPP -24.0056 24.0056 -86.3728 86.3728 7.6200 448.3100   $ Inner Surface Corner Weld.
420  RPP -24.9581 24.9581 -86.3728 86.3728 7.6200 448.3100   $ Outer Surface Corner Weld.
421  RPP -86.3728 86.3728 -24.0056 24.0056 7.6200 448.3100   $ Inner Surface Corner Weld.
422  RPP -86.3728 86.3728 -24.9581 24.9581 7.6200 448.3100   $ Outer Surface Corner Weld.
c Surface Cards - Canister
501 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 458.4700  90.1700 $ Canister cavity
502 PY -7.6327
503 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 487.0450  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
601 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
602 CZ 92.7100        $ Cask cavity radius
603 CZ 94.6150        $ Inner shell OR
604 CZ 102.7430        $ Lead shell OR
605 CZ 108.5850        $ Outer shell IR
606 PZ 30.4800        $ Top of bottom plate
607 PZ 453.3900        $ Bottom of top plate
608 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
609 PY 97.0026        $ Inside rail surface
610 PY -97.0026        $ Inside rail surface
611 PY 96.52        $ Door surface
612 PY -96.52        $ Door surface
613 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*614 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
c Fuel Pellet Material  3.70%  Weight UO2 [amu]  269.9385
m1    92235.66c -3.261E-02 92238.66c -8.488E-01  8016.62c -1.185E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.119E-01  8016.62c -8.881E-01
mt3  lwtr.01t
c Lower Nozzle Material
m4
       1001.62c -6.702E-02  8016.62c -5.319E-01
      24050.62c -3.185E-03 26054.62c -1.575E-02 28058.62c -2.561E-02
      24052.62c -6.379E-02 26056.62c -2.562E-01 28060.62c -1.020E-02
      24053.62c -7.372E-03 26057.62c -6.026E-03 28061.62c -4.510E-04
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
      24054.62c -1.866E-03 26058.62c -8.098E-04 28062.62c -1.460E-03
                                                28064.62c -3.860E-04
      25055.62c -8.023E-03
mt4  lwtr.01t
c Upper Nozzle Material
m5
       1001.62c -4.459E-02  8016.62c -3.539E-01
      24050.62c -4.776E-03 26054.62c -2.362E-02 28058.62c -3.840E-02
      24052.62c -9.567E-02 26056.62c -3.842E-01 28060.62c -1.530E-02
      24053.62c -1.106E-02 26057.62c -9.036E-03 28061.62c -6.763E-04
      24054.62c -2.798E-03 26058.62c -1.214E-03 28062.62c -2.189E-03
                                                28064.62c -5.789E-04
      25055.62c -1.203E-02
mt5  lwtr.01t
c SS304
m6    24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                28064.62c -9.623E-04
      25055.62c -2.000E-02
c Aluminum
m7    13027.62c -1.000E+00
c Carbon Steel
m8    26054.62c -5.594E-02  6000.66c -1.000E-02
      26056.62c -9.098E-01
      26057.62c -2.140E-02
      26058.62c -2.876E-03
c Lead
m9    82206.66c -2.534E-01
      82207.66c -2.207E-01
      82208.66c -5.259E-01
c NS-F-FR
m10    5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
       5011.66c -3.772E-03  7015.66c -7.852E-05
      13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11   26054.62c -7.911E-04 14000.60c -3.370E-01
      26056.62c -1.287E-02
      26057.62c -3.026E-04
      26058.62c -4.067E-05
       1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
       8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12    5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
       5011.66c -2.799E-01
c Water Exterior
m13    1001.62c 2.0
       8016.62c 1.0
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
c
c Cell Importances
c
mode n
imp:n 1 397r 0
c
c
c Criticality Controls
c
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= 601 : D2 : D5 : 7 : -1
      ERG= D1
      POS= 0.0000 0.00 1.5875
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          1        d
      501 1
      502 1
      503 1
      504 1
      505 1
      506 1
      507 1
      508 1
      509 1
      510 1
      511 1
      512 1
      513 1
      514 1
      515 1
      516 1
      517 1
      518 1
      519 1
      520 1
      521 1
      522 1
      523 1
      524 1
      525 1
      526 1
      527 1
      528 1
      529 1
      530 1
      531 1
      532 1
      533 1
      534 1
      535 1
      536 1
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
      537 1
      538 1
      539 1
      540 1
      541 1
      542 1
      543 1
      544 1
      545 1
      546 1
      547 1
      548 1
      549 1
      550 1
      551 1
      552 1
      553 1
      554 1
      555 1
      556 1
      557 1
      558 1
      559 1
      560 1
      561 1
      562 1
      563 1
      564 1
      565 1
      566 1
      567 1
      568 1
      569 1
      570 1
      571 1
      572 1
      573 1
      574 1
      575 1
      576 1
      577 1
      578 1
      579 1
      580 1
      581 1
      582 1
      583 1
      584 1
      585 1
      586 1
      587 1
      588 1
      589 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4095 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      381 1.0
c Assembly Source Distribution
#    SI5        SP5
          1        d
      11 1
      12 1
```

Figure 6.7.4-3 MCNP Transfer Cask Model – BWR 87-Assembly Basket

```
      13 1
      14 1
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
Transfer Cask Model - B10_96A
c
c  MAGNASTOR Canister Class 2
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c
c   Boron Content in Water - 0 ppm
c   Cavity Water Density 0.9982 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Model Revision 4.70
c
c Cells - Fuel Rod - B10_96A - BWR_10x10_5 WR
1 1 -1.0522E+01 -1   u=10 $ Fuel
2 13 -0.9982 -2 +1  u=10 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=10 $ Clad + End Plugs
4 3 -0.9982 +3   u=10 $ Outside Fuel Rod
c Array_10x10_96_5
7 3 -0.9982 -7 +8 -9 +10
      trcl=(0 0 17.1704)   lat=1 u=9 fill=-2:2 -2:2 0:0
      9 10 10 10 10
      10 10 10 9 10
      10 10 10 10 10
      10 9 10 9 10
      10 10 10 10 10
c Cells - Fuel Assembly Array Inserted Into Assembly - cell96_5Assy
11 3 -0.9982 -11  fill=9  *trcl=( 3.4540 3.4540 0.0000 )   u=8 $ Sub Array Q1
12 3 -0.9982 -11  fill=9
        *trcl=( -3.4540 3.4540 0.0000 270 360 90 180 270 90 90 90 0 )       u=8 $ Sub Array Q2
13 3 -0.9982 -11  fill=9
        *trcl=( -3.4540 -3.4540 0.0000 180 270 90 90 180 90 90 90 0 )       u=8 $ Sub Array Q3
14 3 -0.9982 -11  fill=9
        *trcl=( 3.4540 -3.4540 0.0000 90 180 90 0 90 90 90 90 0 )       u=8 $ Sub Array Q4
15 3 -0.9982 -12 #11 #12 #13 #14       u=8 $ Gap to Channel
16 2 -6.5600 -13 +12      u=8 $ Channel
17 4 -1.5373 -14  +11.6     u=8 $ Lower Nozzle
18 5 -2.1056 -14   +11.5    u=8 $ Upper Nozzle
19 3 -0.9982 +14       u=8 $ Remaining Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=7 $ Absorber Clad  +Y
105 6 -7.940 -105     u=7 $ Retainer -Y
106 6 -7.940 -106     u=7 $ Retainer+Y
107 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=7 $ Weld Post in Absorber -Y
108 3 -0.9982 -102 #101  #102  #107   u=7 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=7 $ Weld Post in Absorber +Y
110 3 -0.9982 -104 #103  #104  #109   u=7 $ Gap Weld Post to Absorber +Y
111 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber -X
112 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber Clad  -X
113 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber +X
114 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=7 $ Absorber Clad  +X
115 6 -7.940 -195     u=7 $ Retainer -X
116 6 -7.940 -196     u=7 $ Retainer+X
117 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=7 $ Weld Post in Absorber -X
118 3 -0.9982 -192 #111  #112  #117   u=7 $ Gap Weld Post to Absorber -X
119 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=7 $ Weld Post in Absorber
120 3 -0.9982 -194 #113  #114  #119   u=7 $ Gap Weld Post to Absorber +X
121 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=7 $ Space in Tube
122 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=7 $ Fuel Tube
123 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=7 $ Fuel Tube Weld Posts
124 3 -0.9982 -282 +281  #122  #123
             u=7 $ Space Around Weld Posts
125 3 -0.9982 +281 +282    u=7 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=6 $ Absorber Clad  +Y
130 6 -7.940 -105     u=6 $ Retainer -Y
131 6 -7.9400 -106     u=6 $ Retainer+Y
132 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=6 $ Weld Post in Absorber -Y
133 3 -0.9982 -102 #126  #127  #132   u=6 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=6 $ Weld Post in Absorber +Y
135 3 -0.9982 -104 #128  #129  #134   u=6 $ Gap Weld Post to Absorber +Y
136 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber -X
137 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber Clad  -X
138 7 -2.7020 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber +X
139 7 -2.7020 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=6 $ Absorber Clad  +X
140 6 -7.940 -195     u=6 $ Retainer -X
141 6 -7.9400 -196     u=6 $ Retainer+X
142 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=6 $ Weld Post in Plate-X
143 3 -0.9982 -192 #136  #137  #142   u=6 $ Gap Weld Post to Plate -X
144 6 -7.9400 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=6 $ Weld Post in Plate +X
145 3 -0.9982 -194 #138  #139  #144   u=6 $ Gap Weld Post to Plate +X
146 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=6 $ Space in Tube
147 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=6 $ Fuel Tube
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
148 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=6 $ Fuel Tube Weld Posts
149 3 -0.9982 -282 +281  #147  #148
             u=6 $ Space Around Weld Posts
150 3 -0.9982 +281 +282    u=6 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=5 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=5 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=5 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=5 $ Absorber Clad  +Y
155 6 -7.940 -105     u=5 $ Retainer -Y
156 6 -7.9400 -106     u=5 $ Retainer+Y
157 6 -7.940 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=5 $ Weld Post in Absorber -Y
158 3 -0.9982 -102 #151  #152  #157   u=5 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=5 $ Weld Post in Absorber +Y
160 3 -0.9982 -104 #153  #154  #159   u=5 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=5 $ Absorber -X
162 7 -2.7020 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=5 $ Absorber Clad  -X
163 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=5 $ Absorber +X
164 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=5 $ Absorber Clad  +X
165 6 -7.9400 -195     u=5 $ Retainer -X
166 6 -7.940 -196     u=5 $ Retainer+X
167 6 -7.9400 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=5 $ Weld Post in Plate-X
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
168 3 -0.9982 -192 #161  #162  #167   u=5 $ Gap Weld Post to Plate -X
169 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=5 $ Weld Post in Plate +X
170 3 -0.9982 -194 #163  #164  #169   u=5 $ Gap Weld Post to Plate +X
171 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=5 $ Space in Tube
172 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=5 $ Fuel Tube
173 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=5 $ Fuel Tube Weld Posts
174 3 -0.9982 -282 +281  #172  #173
            u=5 $ Space Around Weld Posts
175 3 -0.9982 +281 +282    u=5 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=4 $ Absorber Clad  +Y
180 6 -7.9400 -105     u=4 $ Retainer -Y
181 6 -7.940 -106     u=4 $ Retainer+Y
182 6 -7.9400 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=4 $ Weld Post in Absorber -Y
183 3 -0.9982 -102 #176  #177  #182   u=4 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=4 $ Weld Post in Absorber +Y
185 3 -0.9982 -104 #178  #179  #184   u=4 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=4 $ Absorber -X
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
187 7 -2.7020 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=4 $ Absorber Clad  -X
188 12 -2.358 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=4 $ Absorber +X
189 7 -2.702 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=4 $ Absorber Clad  +X
190 6 -7.9400 -195     u=4 $ Retainer -X
191 6 -7.940 -196     u=4 $ Retainer+X
192 6 -7.9400 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=4 $ Weld Post in Plate-X
193 3 -0.9982 -192 #186  #187  #192   u=4 $ Gap Weld Post to Plate -X
194 6 -7.940 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=4 $ Weld Post in Plate +X
195 3 -0.9982 -194 #188  #189  #194   u=4 $ Gap Weld Post to Plate +X
196 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=4 $ Space in Tube
197 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=4 $ Fuel Tube
198 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=4 $ Fuel Tube Weld Posts
199 3 -0.9982 -282 +281  #197  #198
            u=4 $ Space Around Weld Posts
200 3 -0.9982 +281 +282    u=4 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber Clad  -Y
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
          +130 +131 +132 +133 +134   u=3 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120
          +121 +122 +123 +124 +125 +126 +127 +128 +129
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
          +130 +131 +132 +133 +134   u=3 $ Absorber Clad  +Y
205 6 -7.9400 -105     u=3 $ Retainer -Y
206 6 -7.940 -106     u=3 $ Retainer+Y
207 6 -7.9400 -102
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=3 $ Weld Post in Absorber -Y
208 3 -0.9982 -102 #201  #202  #207   u=3 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190)      u=3 $ Weld Post in Absorber +Y
210 3 -0.9982 -104 #203  #204  #209   u=3 $ Gap Weld Post to Absorber +Y
211 12 -2.358 -191  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber -X
212 7 -2.702 -192 +191 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber Clad  -X
213 7 -2.7020 -193  +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber +X
214 7 -2.7020 -194 +193 +197 +198 +199 +200 +201 +202 +203 +204 +205
          +206 +207 +208 +209 +210
          +211 +212 +213 +214 +215 +216 +217 +218 +219
          +220 +221 +222 +223 +224   u=3 $ Absorber Clad  +X
215 6 -7.940 -195     u=3 $ Retainer -X
216 6 -7.9400 -196     u=3 $ Retainer+X
217 6 -7.940 -192
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=3 $ Weld Post in Plate-X
218 3 -0.9982 -192 #211  #212  #217   u=3 $ Gap Weld Post to Plate -X
219 6 -7.9400 -194
       (-253:-254:-255:-256:-257:-258:-259:-260:-261:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280:
       -262:-263:-264:-265:-266)      u=3 $ Weld Post in Plate +X
220 3 -0.9982 -194 #213  #214  #219   u=3 $ Gap Weld Post to Plate +X
221 3 -0.9982 -281
       +102 +104 +105 +106
       +192 +194 +195 +196     u=3 $ Space in Tube
222 8 -7.821 -282 +281
       +135 +136 +137 +138 +139 +140 +141 +142 +143
       +144 +145 +146 +147 +148
       +149 +150 +151 +152 +153 +154 +155 +156 +157
       +158 +159 +160 +161 +162
       +225 +226 +227 +228 +229 +230 +231 +232 +233
       +234 +235 +236 +237 +238
       +239 +240 +241 +242 +243 +244 +245 +246 +247
       +248 +249 +250 +251 +252      u=3 $ Fuel Tube
223 6 -7.940 -282 +281
       (-163:-164:-165:-166:-167:-168:-169:-170:-171:
       -172:-173:-174:-175:-176:
       -177:-178:-179:-180:-181:-182:-183:-184:-185:
       -186:-187:-188:-189:-190:
       -253:-254:-255:-256:-257:-258:-259:-260:-261:
       -262:-263:-264:-265:-266:
       -267:-268:-269:-270:-271:-272:-273:-274:-275:
       -276:-277:-278:-279:-280)      u=3 $ Fuel Tube Weld Posts
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
224 3 -0.9982 -282 +281  #222  #223
            u=3 $ Space Around Weld Posts
225 3 -0.9982 +281 +282    u=3 $ Exterior Space
C Cells - Basket
401 3 -0.9982 -401 -402 fill=5 *trcl=( -15.6617 78.3083 0.0000 )    u=2 $ Tube Loc 1
402 like 401 but  fill=6 *trcl=( 15.6617 78.3083 0.0000 )    u=2 $ Tube Loc 2
403 like 401 but  fill=7 *trcl=( -31.3233 62.6467 0.0000 )    u=2 $ Tube Loc 3
404 like 401 but  fill=7 *trcl=( 0.0000 62.6467 0.0000 )    u=2 $ Tube Loc 4
405 like 401 but  fill=7 *trcl=( 31.3233 62.6467 0.0000 )    u=2 $ Tube Loc 5
406 like 401 but  fill=7 *trcl=( -46.9850 46.9850 0.0000 )    u=2 $ Tube Loc 6
407 like 401 but  fill=7 *trcl=( -15.6617 46.9850 0.0000 )    u=2 $ Tube Loc 7
408 like 401 but  fill=7 *trcl=( 15.6617 46.9850 0.0000 )    u=2 $ Tube Loc 8
409 like 401 but  fill=7 *trcl=( 46.9850 46.9850 0.0000 )    u=2 $ Tube Loc 9
410 like 401 but  fill=7 *trcl=( -62.6467 31.3233 0.0000 )    u=2 $ Tube Loc 10
411 like 401 but  fill=7 *trcl=( -31.3233 31.3233 0.0000 )    u=2 $ Tube Loc 11
412 like 401 but  fill=7 *trcl=( 0.0000 31.3233 0.0000 )    u=2 $ Tube Loc 12
413 like 401 but  fill=7 *trcl=( 31.3233 31.3233 0.0000 )    u=2 $ Tube Loc 13
414 like 401 but  fill=7 *trcl=( 62.6467 31.3233 0.0000 )    u=2 $ Tube Loc 14
415 like 401 but  fill=5 *trcl=( -78.3083 15.6617 0.0000 )    u=2 $ Tube Loc 15
416 like 401 but  fill=7 *trcl=( -46.9850 15.6617 0.0000 )    u=2 $ Tube Loc 16
417 like 401 but  fill=7 *trcl=( -15.6617 15.6617 0.0000 )    u=2 $ Tube Loc 17
418 like 401 but  fill=7 *trcl=( 15.6617 15.6617 0.0000 )    u=2 $ Tube Loc 18
419 like 401 but  fill=7 *trcl=( 46.9850 15.6617 0.0000 )    u=2 $ Tube Loc 19
420 like 401 but  fill=6 *trcl=( 78.3083 15.6617 0.0000 )    u=2 $ Tube Loc 20
421 like 401 but  fill=7 *trcl=( -62.6467 0.0000 0.0000 )    u=2 $ Tube Loc 21
422 like 401 but  fill=7 *trcl=( -31.3233 0.0000 0.0000 )    u=2 $ Tube Loc 22
423 like 401 but  fill=7 *trcl=( 0.0000 0.0000 0.0000 )    u=2 $ Tube Loc 23
424 like 401 but  fill=7 *trcl=( 31.3233 0.0000 0.0000 )    u=2 $ Tube Loc 24
425 like 401 but  fill=7 *trcl=( 62.6467 0.0000 0.0000 )    u=2 $ Tube Loc 25
426 like 401 but  fill=4 *trcl=( -78.3083 -15.6617 0.0000 )    u=2 $ Tube Loc 26
427 like 401 but  fill=7 *trcl=( -46.9850 -15.6617 0.0000 )    u=2 $ Tube Loc 27
428 like 401 but  fill=7 *trcl=( -15.6617 -15.6617 0.0000 )    u=2 $ Tube Loc 28
429 like 401 but  fill=7 *trcl=( 15.6617 -15.6617 0.0000 )    u=2 $ Tube Loc 29
430 like 401 but  fill=7 *trcl=( 46.9850 -15.6617 0.0000 )    u=2 $ Tube Loc 30
431 like 401 but  fill=3 *trcl=( 78.3083 -15.6617 0.0000 )    u=2 $ Tube Loc 31
432 like 401 but  fill=7 *trcl=( -62.6467 -31.3233 0.0000 )    u=2 $ Tube Loc 32
433 like 401 but  fill=7 *trcl=( -31.3233 -31.3233 0.0000 )    u=2 $ Tube Loc 33
434 like 401 but  fill=7 *trcl=( 0.0000 -31.3233 0.0000 )    u=2 $ Tube Loc 34
435 like 401 but  fill=7 *trcl=( 31.3233 -31.3233 0.0000 )    u=2 $ Tube Loc 35
436 like 401 but  fill=7 *trcl=( 62.6467 -31.3233 0.0000 )    u=2 $ Tube Loc 36
437 like 401 but  fill=7 *trcl=( -46.9850 -46.9850 0.0000 )    u=2 $ Tube Loc 37
438 like 401 but  fill=7 *trcl=( -15.6617 -46.9850 0.0000 )    u=2 $ Tube Loc 38
439 like 401 but  fill=7 *trcl=( 15.6617 -46.9850 0.0000 )    u=2 $ Tube Loc 39
440 like 401 but  fill=7 *trcl=( 46.9850 -46.9850 0.0000 )    u=2 $ Tube Loc 40
441 like 401 but  fill=7 *trcl=( -31.3233 -62.6467 0.0000 )    u=2 $ Tube Loc 41
442 like 401 but  fill=7 *trcl=( 0.0000 -62.6467 0.0000 )    u=2 $ Tube Loc 42
443 like 401 but  fill=7 *trcl=( 31.3233 -62.6467 0.0000 )    u=2 $ Tube Loc 43
444 like 401 but  fill=4 *trcl=( -15.6617 -78.3083 0.0000 )    u=2 $ Tube Loc 44
445 like 401 but  fill=3 *trcl=( 15.6617 -78.3083 0.0000 )    u=2 $ Tube Loc 45
446 8 -7.821 -404 +405 #401  #402  #444  #445   u=2 $ Side Weldment Y Center
447 8 -7.821 -408 +409 #415  #426  #420  #431   u=2 $ Side Weldment X Center
448 8 -7.821 -406 +407 +404     u=2 $ Side Weldment Y Mount
449 8 -7.821 -410 +411 +408     u=2 $ Side Weldment X Mount
450 8 -7.821 -413 +412 -414 +416 +418 +420 +422 u=2 $ Corner Weldment Part 1
451 8 -7.821 (-420 +419 +412) : (-422 +421 +412)       u=2 $ Corner Weldment Part 2
452 8 -7.821 -416 +415 +418 +412 #406 #409 #437 #440    u=2 $ Corner Weldment Part 3
453 8 -7.821 -418 +417 +415 +412 #406 #409 #437 #440    u=2 $ Corner Weldment Part 4
454 3 -0.9982 -403
      #404 #407 #408 #411 #412 #413 #416 #417 #418 #419
      #421 #422 #423 #424 #425 #427 #428 #429 #430 #433
      #434 #435 #438 #439 #442          u=2 $ Interior Open Space
455 3 -0.9982 +403
      #401 #402 #403 #405 #406 #409 #410 #414 #415 #420
      #426 #431 #432 #436 #437 #440 #441 #443 #444 #445
      #446 #447 #448 #449 #450 #451 #452 #453          u=2 $ Remaining Open Space
c Cell Cards - Canister
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
501 3 -0.9982 -14 fill=8 *trcl=( -15.3418 77.9885 0.0000 )    u=1 $ Assy loc 1
502 like 501 but     *trcl=( 15.3418 77.9885 0.0000 )    u=1 $ Assy loc 2
503 like 501 but     *trcl=( -31.0035 62.3268 0.0000 )    u=1 $ Assy loc 3
504 like 501 but     *trcl=( 0.0000 62.3268 0.0000 )    u=1 $ Assy loc 4
505 like 501 but     *trcl=( 31.0035 62.3268 0.0000 )    u=1 $ Assy loc 5
506 like 501 but     *trcl=( -46.6652 46.6652 0.0000 )    u=1 $ Assy loc 6
507 like 501 but     *trcl=( -15.3418 46.6652 0.0000 )    u=1 $ Assy loc 7
508 like 501 but     *trcl=( 15.3418 46.6652 0.0000 )    u=1 $ Assy loc 8
509 like 501 but     *trcl=( 46.6652 46.6652 0.0000 )    u=1 $ Assy loc 9
510 like 501 but     *trcl=( -62.3268 31.0035 0.0000 )    u=1 $ Assy loc 10
511 like 501 but     *trcl=( -31.0035 31.0035 0.0000 )    u=1 $ Assy loc 11
512 like 501 but     *trcl=( 0.0000 31.0035 0.0000 )    u=1 $ Assy loc 12
513 like 501 but     *trcl=( 31.0035 31.0035 0.0000 )    u=1 $ Assy loc 13
514 like 501 but     *trcl=( 62.3268 31.0035 0.0000 )    u=1 $ Assy loc 14
515 like 501 but     *trcl=( -77.9885 15.3418 0.0000 )    u=1 $ Assy loc 15
516 like 501 but     *trcl=( -46.6652 15.3418 0.0000 )    u=1 $ Assy loc 16
517 like 501 but     *trcl=( 46.6652 15.3418 0.0000 )    u=1 $ Assy loc 19
518 like 501 but     *trcl=( 77.9885 15.3418 0.0000 )    u=1 $ Assy loc 20
519 like 501 but     *trcl=( -62.3268 0.0000 0.0000 )    u=1 $ Assy loc 21
520 like 501 but     *trcl=( -31.0035 0.0000 0.0000 )    u=1 $ Assy loc 22
521 like 501 but     *trcl=( 31.0035 0.0000 0.0000 )    u=1 $ Assy loc 24
522 like 501 but     *trcl=( 62.3268 0.0000 0.0000 )    u=1 $ Assy loc 25
523 like 501 but     *trcl=( -77.9885 -15.3418 0.0000 )    u=1 $ Assy loc 26
524 like 501 but     *trcl=( -46.6652 -15.3418 0.0000 )    u=1 $ Assy loc 27
525 like 501 but     *trcl=( 46.6652 -15.3418 0.0000 )    u=1 $ Assy loc 30
526 like 501 but     *trcl=( 77.9885 -15.3418 0.0000 )    u=1 $ Assy loc 31
527 like 501 but     *trcl=( -62.3268 -31.0035 0.0000 )    u=1 $ Assy loc 32
528 like 501 but     *trcl=( -31.0035 -31.0035 0.0000 )    u=1 $ Assy loc 33
529 like 501 but     *trcl=( 0.0000 -31.0035 0.0000 )    u=1 $ Assy loc 34
530 like 501 but     *trcl=( 31.0035 -31.0035 0.0000 )    u=1 $ Assy loc 35
531 like 501 but     *trcl=( 62.3268 -31.0035 0.0000 )    u=1 $ Assy loc 36
532 like 501 but     *trcl=( -46.6652 -46.6652 0.0000 )    u=1 $ Assy loc 37
533 like 501 but     *trcl=( -15.3418 -46.6652 0.0000 )    u=1 $ Assy loc 38
534 like 501 but     *trcl=( 15.3418 -46.6652 0.0000 )    u=1 $ Assy loc 39
535 like 501 but     *trcl=( 46.6652 -46.6652 0.0000 )    u=1 $ Assy loc 40
536 like 501 but     *trcl=( -31.0035 -62.3268 0.0000 )    u=1 $ Assy loc 41
537 like 501 but     *trcl=( 0.0000 -62.3268 0.0000 )    u=1 $ Assy loc 42
538 like 501 but     *trcl=( 31.0035 -62.3268 0.0000 )    u=1 $ Assy loc 43
539 like 501 but     *trcl=( -15.3418 -77.9885 0.0000 )    u=1 $ Assy loc 44
540 like 501 but     *trcl=( 15.3418 -77.9885 0.0000 )    u=1 $ Assy loc 45
541 like 501 but     *trcl=( 0.0000 77.9987 0.0000 )    u=1 $ Assy loc 46
542 like 501 but     *trcl=( -46.6754 62.3371 0.0000 )    u=1 $ Assy loc 47
543 like 501 but     *trcl=( -15.3521 62.3371 0.0000 )    u=1 $ Assy loc 48
544 like 501 but     *trcl=( 15.3521 62.3371 0.0000 )    u=1 $ Assy loc 49
545 like 501 but     *trcl=( 46.6754 62.3371 0.0000 )    u=1 $ Assy loc 50
546 like 501 but     *trcl=( -62.3371 46.6754 0.0000 )    u=1 $ Assy loc 51
547 like 501 but     *trcl=( -31.0137 46.6754 0.0000 )    u=1 $ Assy loc 52
548 like 501 but     *trcl=( 0.0000 46.6754 0.0000 )    u=1 $ Assy loc 53
549 like 501 but     *trcl=( 31.0137 46.6754 0.0000 )    u=1 $ Assy loc 54
550 like 501 but     *trcl=( 62.3371 46.6754 0.0000 )    u=1 $ Assy loc 55
551 like 501 but     *trcl=( -46.6754 31.0137 0.0000 )    u=1 $ Assy loc 56
552 like 501 but     *trcl=( -15.3521 31.0137 0.0000 )    u=1 $ Assy loc 57
553 like 501 but     *trcl=( 15.3521 31.0137 0.0000 )    u=1 $ Assy loc 58
554 like 501 but     *trcl=( 46.6754 31.0137 0.0000 )    u=1 $ Assy loc 59
555 like 501 but     *trcl=( -62.3371 15.3521 0.0000 )    u=1 $ Assy loc 60
556 like 501 but     *trcl=( -31.0137 15.3521 0.0000 )    u=1 $ Assy loc 61
557 like 501 but     *trcl=( 0.0000 15.3521 0.0000 )    u=1 $ Assy loc 62
558 like 501 but     *trcl=( 31.0137 15.3521 0.0000 )    u=1 $ Assy loc 63
559 like 501 but     *trcl=( 62.3371 15.3521 0.0000 )    u=1 $ Assy loc 64
560 like 501 but     *trcl=( -77.9987 0.0000 0.0000 )    u=1 $ Assy loc 65
561 like 501 but     *trcl=( -46.6754 0.0000 0.0000 )    u=1 $ Assy loc 66
562 like 501 but     *trcl=( -15.3521 0.0000 0.0000 )    u=1 $ Assy loc 67
563 like 501 but     *trcl=( 15.3521 0.0000 0.0000 )    u=1 $ Assy loc 68
564 like 501 but     *trcl=( 46.6754 0.0000 0.0000 )    u=1 $ Assy loc 69
565 like 501 but     *trcl=( 77.9987 0.0000 0.0000 )    u=1 $ Assy loc 70
566 like 501 but     *trcl=( -62.3371 -15.3521 0.0000 )    u=1 $ Assy loc 71
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
567 like 501 but     *trcl=( -31.0137 -15.3521 0.0000 )    u=1 $ Assy loc 72
568 like 501 but     *trcl=( 0.0000 -15.3521 0.0000 )    u=1 $ Assy loc 73
569 like 501 but     *trcl=( 31.0137 -15.3521 0.0000 )    u=1 $ Assy loc 74
570 like 501 but     *trcl=( 62.3371 -15.3521 0.0000 )    u=1 $ Assy loc 75
571 like 501 but     *trcl=( -46.6754 -31.0137 0.0000 )    u=1 $ Assy loc 76
572 like 501 but     *trcl=( -15.3521 -31.0137 0.0000 )    u=1 $ Assy loc 77
573 like 501 but     *trcl=( 15.3521 -31.0137 0.0000 )    u=1 $ Assy loc 78
574 like 501 but     *trcl=( 46.6754 -31.0137 0.0000 )    u=1 $ Assy loc 79
575 like 501 but     *trcl=( -62.3371 -46.6754 0.0000 )    u=1 $ Assy loc 80
576 like 501 but     *trcl=( -31.0137 -46.6754 0.0000 )    u=1 $ Assy loc 81
577 like 501 but     *trcl=( 0.0000 -46.6754 0.0000 )    u=1 $ Assy loc 82
578 like 501 but     *trcl=( 31.0137 -46.6754 0.0000 )    u=1 $ Assy loc 83
579 like 501 but     *trcl=( 62.3371 -46.6754 0.0000 )    u=1 $ Assy loc 84
580 like 501 but     *trcl=( -46.6754 -62.3371 0.0000 )    u=1 $ Assy loc 85
581 like 501 but     *trcl=( -15.3521 -62.3371 0.0000 )    u=1 $ Assy loc 86
582 like 501 but     *trcl=( 15.3521 -62.3371 0.0000 )    u=1 $ Assy loc 87
583 like 501 but     *trcl=( 46.6754 -62.3371 0.0000 )    u=1 $ Assy loc 88
584 like 501 but     *trcl=( 0.0000 -77.9987 0.0000 )    u=1 $ Assy loc 89
585 3 -0.9982 -501 +502
       #501 #502 #503 #504 #505 #506 #507 #508 #509 #510
       #511 #512 #513 #514 #515 #516 #517 #518
       #519 #520 #521 #522
       #541 #542 #543 #544 #545
       #546 #547 #548 #549 #550 #551 #552 #553 #554 #555
       #556 #557 #558 #559 #560 #561 #562 #563 #564 #565
             fill=2 u=1 $ Cavity
586 3 -0.9982 -501 -502
       #523 #524 #525
       #526 #527 #528 #529 #530 #531 #532 #533 #534 #535
       #536 #537 #538 #539 #540
       #566 #567 #568 #569 #570 #571 #572 #573 #574 #575
       #576 #577 #578 #579 #580 #581 #582 #583 #584
             fill=2 u=1 $ Cavity
587 6 -7.940 -503 +501     u=1 $ Canister Shell / Lid / Bottom
588 13 -0.0001 +503      u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
601 13 -0.0001 -601 -602  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
602 8 -7.821 -601 +602 -606     $ Bottom plate
603 8 -7.821 -603 +602 +606 -607    $ Inner shell
604 9 -11.344 -604 +603 +606 -607    $ Lead shell
605 10 -1.632 -605 +604 +606 -607    $ NS-4-FR
606 8 -7.821 -601 +605 +606 -607    $ Outer shell
607 8 -7.821 -601 +602 +607     $ Top plate
608 8 -7.821 -608 +609  -614    $ Door rail
609 8 -7.821 -608 -610  -614    $ Door rail
610 8 -7.821 -613 -611 +612 -614    $ Door steel
611 13 -0.0001 -614 +601 +608 +609 +610      $ Exterior space to Reflector
612 0         +614       $ Exterior space

c Surfaces - Fuel Rod - B10_96A - BWR_10x10_5 WR
1 RCC 0.0000 0.0000 1.5875 0.0000 0.0000 381.0000 0.4095 $ Fuel pellet stack
2 RCC 0.0000 0.0000 1.5875 0.0000 0.0000 405.3332 0.4184 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 407.8006 0.4801 $ Clad + End-Caps
c Surfaces - Pitch - B10_96A - BWR_10x10_5 WR
7 PX 0.6198       $ Lattice Cell Boundaries
8 PX -0.6198
9 PY 0.6198
10 PY -0.6198
c Surfaces - Fuel Assembly Array Inserted Into Assembly - B10_96A - BWR_10x10_5 WR
11 RPP -3.0987 3.0987 -3.0987 3.0987 17.1704 428.4980  $ Array
12 RPP -6.7031 6.7031 -6.7031 6.7031 17.1704 428.4980  $ Channel Inner
13 RPP -7.0079 7.0079 -7.0079 7.0079 17.1704 428.4980  $ Channel Outer
14 RPP -7.0079 7.0079 -7.0079 7.0079 0.0000 447.5480  $ Assembly Outer Dims
c Surface Cards - Tube, Absorber and Retainer
101 RPP -6.7056 6.7056 -7.5946 -7.4041 8.8900 427.5074 $ Absorber -Y
102 RPP -6.7056 6.7056 -7.6327 -7.3660 8.8900 427.5074 $ Absorber Clad  -Y
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
103 RPP -6.7056 6.7056 7.4041 7.5946 8.8900 427.5074 $ Absorber +Y
104 RPP -6.7056 6.7056 7.3660 7.6327 8.8900 427.5074 $ Absorber Clad  +Y
105 RPP -6.8326 6.8326 -7.3660 -7.3279 7.6200 429.4124 $ Retainer -Y
106 RPP -6.8326 6.8326 7.3279 7.3660 7.6200 429.4124 $ Retainer  +Y
107 RPP 3.7783 5.3658 -8.3439 8.3439 18.8024 21.9901 $ Weld Post Slot Y Absorber
108 RPP 3.7783 5.3658 -8.3439 8.3439 49.2824 52.4701 $ Weld Post Slot Y Absorber
109 RPP 3.7783 5.3658 -8.3439 8.3439 79.7624 82.9501 $ Weld Post Slot Y Absorber
110 RPP 3.7783 5.3658 -8.3439 8.3439 110.2424 113.4301 $ Weld Post Slot Y Absorber
111 RPP 3.7783 5.3658 -8.3439 8.3439 140.7224 143.9101 $ Weld Post Slot Y Absorber
112 RPP 3.7783 5.3658 -8.3439 8.3439 171.2024 174.3901 $ Weld Post Slot Y Absorber
113 RPP 3.7783 5.3658 -8.3439 8.3439 201.6824 204.8701 $ Weld Post Slot Y Absorber
114 RPP 3.7783 5.3658 -8.3439 8.3439 232.1624 235.3501 $ Weld Post Slot Y Absorber
115 RPP 3.7783 5.3658 -8.3439 8.3439 262.6424 265.8301 $ Weld Post Slot Y Absorber
116 RPP 3.7783 5.3658 -8.3439 8.3439 293.1224 296.3101 $ Weld Post Slot Y Absorber
117 RPP 3.7783 5.3658 -8.3439 8.3439 323.6024 326.7901 $ Weld Post Slot Y Absorber
118 RPP 3.7783 5.3658 -8.3439 8.3439 354.0824 357.2701 $ Weld Post Slot Y Absorber
119 RPP 3.7783 5.3658 -8.3439 8.3439 384.5624 387.7501 $ Weld Post Slot Y Absorber
120 RPP 3.7783 5.3658 -8.3439 8.3439 415.0424 418.2301 $ Weld Post Slot Y Absorber
121 RPP -5.3658 -3.7783 -8.3439 8.3439 18.8024 21.9901 $ Weld Post Slot Y Absorber
122 RPP -5.3658 -3.7783 -8.3439 8.3439 49.2824 52.4701 $ Weld Post Slot Y Absorber
123 RPP -5.3658 -3.7783 -8.3439 8.3439 79.7624 82.9501 $ Weld Post Slot Y Absorber
124 RPP -5.3658 -3.7783 -8.3439 8.3439 110.2424 113.4301 $ Weld Post Slot Y Absorber
125 RPP -5.3658 -3.7783 -8.3439 8.3439 140.7224 143.9101 $ Weld Post Slot Y Absorber
126 RPP -5.3658 -3.7783 -8.3439 8.3439 171.2024 174.3901 $ Weld Post Slot Y Absorber
127 RPP -5.3658 -3.7783 -8.3439 8.3439 201.6824 204.8701 $ Weld Post Slot Y Absorber
128 RPP -5.3658 -3.7783 -8.3439 8.3439 232.1624 235.3501 $ Weld Post Slot Y Absorber
129 RPP -5.3658 -3.7783 -8.3439 8.3439 262.6424 265.8301 $ Weld Post Slot Y Absorber
130 RPP -5.3658 -3.7783 -8.3439 8.3439 293.1224 296.3101 $ Weld Post Slot Y Absorber
131 RPP -5.3658 -3.7783 -8.3439 8.3439 323.6024 326.7901 $ Weld Post Slot Y Absorber
132 RPP -5.3658 -3.7783 -8.3439 8.3439 354.0824 357.2701 $ Weld Post Slot Y Absorber
133 RPP -5.3658 -3.7783 -8.3439 8.3439 384.5624 387.7501 $ Weld Post Slot Y Absorber
134 RPP -5.3658 -3.7783 -8.3439 8.3439 415.0424 418.2301 $ Weld Post Slot Y Absorber
135 C/Y 4.5720 20.3962 0.4191    $ Weld Post Hole Y
136 C/Y 4.5720 50.8762 0.4191    $ Weld Post Hole Y
137 C/Y 4.5720 81.3562 0.4191    $ Weld Post Hole Y
138 C/Y 4.5720 111.8362 0.4191    $ Weld Post Hole Y
139 C/Y 4.5720 142.3162 0.4191    $ Weld Post Hole Y
140 C/Y 4.5720 172.7962 0.4191    $ Weld Post Hole Y
141 C/Y 4.5720 203.2762 0.4191    $ Weld Post Hole Y
142 C/Y 4.5720 233.7562 0.4191    $ Weld Post Hole Y
143 C/Y 4.5720 264.2362 0.4191    $ Weld Post Hole Y
144 C/Y 4.5720 294.7162 0.4191    $ Weld Post Hole Y
145 C/Y 4.5720 325.1962 0.4191    $ Weld Post Hole Y
146 C/Y 4.5720 355.6762 0.4191    $ Weld Post Hole Y
147 C/Y 4.5720 386.1562 0.4191    $ Weld Post Hole Y
148 C/Y 4.5720 416.6362 0.4191    $ Weld Post Hole Y
149 C/Y -4.5720 20.3962 0.4191    $ Weld Post Hole Y
150 C/Y -4.5720 50.8762 0.4191    $ Weld Post Hole Y
151 C/Y -4.5720 81.3562 0.4191    $ Weld Post Hole Y
152 C/Y -4.5720 111.8362 0.4191    $ Weld Post Hole Y
153 C/Y -4.5720 142.3162 0.4191    $ Weld Post Hole Y
154 C/Y -4.5720 172.7962 0.4191    $ Weld Post Hole Y
155 C/Y -4.5720 203.2762 0.4191    $ Weld Post Hole Y
156 C/Y -4.5720 233.7562 0.4191    $ Weld Post Hole Y
157 C/Y -4.5720 264.2362 0.4191    $ Weld Post Hole Y
158 C/Y -4.5720 294.7162 0.4191    $ Weld Post Hole Y
159 C/Y -4.5720 325.1962 0.4191    $ Weld Post Hole Y
160 C/Y -4.5720 355.6762 0.4191    $ Weld Post Hole Y
161 C/Y -4.5720 386.1562 0.4191    $ Weld Post Hole Y
162 C/Y -4.5720 416.6362 0.4191    $ Weld Post Hole Y
163 C/Y 4.5720 20.3962 0.3175    $ Weld Post Y
164 C/Y 4.5720 50.8762 0.3175    $ Weld Post Y
165 C/Y 4.5720 81.3562 0.3175    $ Weld Post Y
166 C/Y 4.5720 111.8362 0.3175    $ Weld Post Y
167 C/Y 4.5720 142.3162 0.3175    $ Weld Post Y
168 C/Y 4.5720 172.7962 0.3175    $ Weld Post Y
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
169 C/Y 4.5720 203.2762 0.3175    $ Weld Post Y
170 C/Y 4.5720 233.7562 0.3175    $ Weld Post Y
171 C/Y 4.5720 264.2362 0.3175    $ Weld Post Y
172 C/Y 4.5720 294.7162 0.3175    $ Weld Post Y
173 C/Y 4.5720 325.1962 0.3175    $ Weld Post Y
174 C/Y 4.5720 355.6762 0.3175    $ Weld Post Y
175 C/Y 4.5720 386.1562 0.3175    $ Weld Post Y
176 C/Y 4.5720 416.6362 0.3175    $ Weld Post Y
177 C/Y -4.5720 20.3962 0.3175    $ Weld Post Y
178 C/Y -4.5720 50.8762 0.3175    $ Weld Post Y
179 C/Y -4.5720 81.3562 0.3175    $ Weld Post Y
180 C/Y -4.5720 111.8362 0.3175    $ Weld Post Y
181 C/Y -4.5720 142.3162 0.3175    $ Weld Post Y
182 C/Y -4.5720 172.7962 0.3175    $ Weld Post Y
183 C/Y -4.5720 203.2762 0.3175    $ Weld Post Y
184 C/Y -4.5720 233.7562 0.3175    $ Weld Post Y
185 C/Y -4.5720 264.2362 0.3175    $ Weld Post Y
186 C/Y -4.5720 294.7162 0.3175    $ Weld Post Y
187 C/Y -4.5720 325.1962 0.3175    $ Weld Post Y
188 C/Y -4.5720 355.6762 0.3175    $ Weld Post Y
189 C/Y -4.5720 386.1562 0.3175    $ Weld Post Y
190 C/Y -4.5720 416.6362 0.3175    $ Weld Post Y
191 RPP -7.5946 -7.4041 -6.7056 6.7056 8.8900 427.5074 $ Absorber -X
192 RPP -7.6327 -7.3660 -6.7056 6.7056 8.8900 427.5074 $ Absorber Clad  -X
193 RPP 7.4041 7.5946 -6.7056 6.7056 8.8900 427.5074 $ Absorber +X
194 RPP 7.3660 7.6327 -6.7056 6.7056 8.8900 427.5074 $ Absorber Clad  +X
195 RPP -7.3660 -7.3279 -6.8326 6.8326 7.6200 429.4124 $ Retainer -X
196 RPP 7.3279 7.3660 -6.8326 6.8326 7.6200 429.4124 $ Retainer  +X
197 RPP -8.3439 8.3439 3.7783 5.3658 18.8024 21.9901 $ Weld Post Slot X Absorber
198 RPP -8.3439 8.3439 3.7783 5.3658 49.2824 52.4701 $ Weld Post Slot X Absorber
199 RPP -8.3439 8.3439 3.7783 5.3658 79.7624 82.9501 $ Weld Post Slot X Absorber
200 RPP -8.3439 8.3439 3.7783 5.3658 110.2424 113.4301 $ Weld Post Slot X Absorber
201 RPP -8.3439 8.3439 3.7783 5.3658 140.7224 143.9101 $ Weld Post Slot X Absorber
202 RPP -8.3439 8.3439 3.7783 5.3658 171.2024 174.3901 $ Weld Post Slot X Absorber
203 RPP -8.3439 8.3439 3.7783 5.3658 201.6824 204.8701 $ Weld Post Slot X Absorber
204 RPP -8.3439 8.3439 3.7783 5.3658 232.1624 235.3501 $ Weld Post Slot X Absorber
205 RPP -8.3439 8.3439 3.7783 5.3658 262.6424 265.8301 $ Weld Post Slot X Absorber
206 RPP -8.3439 8.3439 3.7783 5.3658 293.1224 296.3101 $ Weld Post Slot X Absorber
207 RPP -8.3439 8.3439 3.7783 5.3658 323.6024 326.7901 $ Weld Post Slot X Absorber
208 RPP -8.3439 8.3439 3.7783 5.3658 354.0824 357.2701 $ Weld Post Slot X Absorber
209 RPP -8.3439 8.3439 3.7783 5.3658 384.5624 387.7501 $ Weld Post Slot X Absorber
210 RPP -8.3439 8.3439 3.7783 5.3658 415.0424 418.2301 $ Weld Post Slot X Absorber
211 RPP -8.3439 8.3439 -5.3658 -3.7783 18.8024 21.9901 $ Weld Post Slot X Absorber
212 RPP -8.3439 8.3439 -5.3658 -3.7783 49.2824 52.4701 $ Weld Post Slot X Absorber
213 RPP -8.3439 8.3439 -5.3658 -3.7783 79.7624 82.9501 $ Weld Post Slot X Absorber
214 RPP -8.3439 8.3439 -5.3658 -3.7783 110.2424 113.4301 $ Weld Post Slot X Absorber
215 RPP -8.3439 8.3439 -5.3658 -3.7783 140.7224 143.9101 $ Weld Post Slot X Absorber
216 RPP -8.3439 8.3439 -5.3658 -3.7783 171.2024 174.3901 $ Weld Post Slot X Absorber
217 RPP -8.3439 8.3439 -5.3658 -3.7783 201.6824 204.8701 $ Weld Post Slot X Absorber
218 RPP -8.3439 8.3439 -5.3658 -3.7783 232.1624 235.3501 $ Weld Post Slot X Absorber
219 RPP -8.3439 8.3439 -5.3658 -3.7783 262.6424 265.8301 $ Weld Post Slot X Absorber
220 RPP -8.3439 8.3439 -5.3658 -3.7783 293.1224 296.3101 $ Weld Post Slot X Absorber
221 RPP -8.3439 8.3439 -5.3658 -3.7783 323.6024 326.7901 $ Weld Post Slot X Absorber
222 RPP -8.3439 8.3439 -5.3658 -3.7783 354.0824 357.2701 $ Weld Post Slot X Absorber
223 RPP -8.3439 8.3439 -5.3658 -3.7783 384.5624 387.7501 $ Weld Post Slot X Absorber
224 RPP -8.3439 8.3439 -5.3658 -3.7783 415.0424 418.2301 $ Weld Post Slot X Absorber
225 C/X 4.5720 20.3962 0.4191    $ Weld Post Hole X
226 C/X 4.5720 50.8762 0.4191    $ Weld Post Hole X
227 C/X 4.5720 81.3562 0.4191    $ Weld Post Hole X
228 C/X 4.5720 111.8362 0.4191    $ Weld Post Hole X
229 C/X 4.5720 142.3162 0.4191    $ Weld Post Hole X
230 C/X 4.5720 172.7962 0.4191    $ Weld Post Hole X
231 C/X 4.5720 203.2762 0.4191    $ Weld Post Hole X
232 C/X 4.5720 233.7562 0.4191    $ Weld Post Hole X
233 C/X 4.5720 264.2362 0.4191    $ Weld Post Hole X
234 C/X 4.5720 294.7162 0.4191    $ Weld Post Hole X
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
235 C/X 4.5720 325.1962 0.4191    $ Weld Post Hole X
236 C/X 4.5720 355.6762 0.4191    $ Weld Post Hole X
237 C/X 4.5720 386.1562 0.4191    $ Weld Post Hole X
238 C/X 4.5720 416.6362 0.4191    $ Weld Post Hole X
239 C/X -4.5720 20.3962 0.4191    $ Weld Post Hole X
240 C/X -4.5720 50.8762 0.4191    $ Weld Post Hole X
241 C/X -4.5720 81.3562 0.4191    $ Weld Post Hole X
242 C/X -4.5720 111.8362 0.4191    $ Weld Post Hole X
243 C/X -4.5720 142.3162 0.4191    $ Weld Post Hole X
244 C/X -4.5720 172.7962 0.4191    $ Weld Post Hole X
245 C/X -4.5720 203.2762 0.4191    $ Weld Post Hole X
246 C/X -4.5720 233.7562 0.4191    $ Weld Post Hole X
247 C/X -4.5720 264.2362 0.4191    $ Weld Post Hole X
248 C/X -4.5720 294.7162 0.4191    $ Weld Post Hole X
249 C/X -4.5720 325.1962 0.4191    $ Weld Post Hole X
250 C/X -4.5720 355.6762 0.4191    $ Weld Post Hole X
251 C/X -4.5720 386.1562 0.4191    $ Weld Post Hole X
252 C/X -4.5720 416.6362 0.4191    $ Weld Post Hole X
253 C/X 4.5720 20.3962 0.3175    $ Weld Post X
254 C/X 4.5720 50.8762 0.3175    $ Weld Post X
255 C/X 4.5720 81.3562 0.3175    $ Weld Post X
256 C/X 4.5720 111.8362 0.3175    $ Weld Post X
257 C/X 4.5720 142.3162 0.3175    $ Weld Post X
258 C/X 4.5720 172.7962 0.3175    $ Weld Post X
259 C/X 4.5720 203.2762 0.3175    $ Weld Post X
260 C/X 4.5720 233.7562 0.3175    $ Weld Post X
261 C/X 4.5720 264.2362 0.3175    $ Weld Post X
262 C/X 4.5720 294.7162 0.3175    $ Weld Post X
263 C/X 4.5720 325.1962 0.3175    $ Weld Post X
264 C/X 4.5720 355.6762 0.3175    $ Weld Post X
265 C/X 4.5720 386.1562 0.3175    $ Weld Post X
266 C/X 4.5720 416.6362 0.3175    $ Weld Post X
267 C/X -4.5720 20.3962 0.3175    $ Weld Post X
268 C/X -4.5720 50.8762 0.3175    $ Weld Post X
269 C/X -4.5720 81.3562 0.3175    $ Weld Post X
270 C/X -4.5720 111.8362 0.3175    $ Weld Post X
271 C/X -4.5720 142.3162 0.3175    $ Weld Post X
272 C/X -4.5720 172.7962 0.3175    $ Weld Post X
273 C/X -4.5720 203.2762 0.3175    $ Weld Post X
274 C/X -4.5720 233.7562 0.3175    $ Weld Post X
275 C/X -4.5720 264.2362 0.3175    $ Weld Post X
276 C/X -4.5720 294.7162 0.3175    $ Weld Post X
277 C/X -4.5720 325.1962 0.3175    $ Weld Post X
278 C/X -4.5720 355.6762 0.3175    $ Weld Post X
279 C/X -4.5720 386.1562 0.3175    $ Weld Post X
280 C/X -4.5720 416.6362 0.3175    $ Weld Post X
281 RPP -7.6327 7.6327 -7.6327 7.6327 0.0000 458.4700 $  Space inside tube - cavity extent
282 RPP -8.3439 8.3439 -8.3439 8.3439 7.6200 429.4124 $  Fuel tube
C Surfaces - Basket
401  RPP -8.3439 8.3439 -8.3439 8.3439 0.0000 458.4700   $ Tube Enclosing Body - Cavity Height
402 1 RPP -11.0744 11.0744 -11.0744 11.0744 0.0000 458.4700   $ Tube Corner Cuts
403 1 RPP -55.37235 55.37235 -55.37235 55.37235 0.0000 458.4700   $ Array Interior Limit
404  RPP -8.3693 8.3693 -87.2872 87.2872 0.0000 455.9300   $ Outer Surface Side Weld. Middle
405  RPP -8.3693 8.3693 -85.6997 85.6997 0.0000 455.9300   $ Inner Surface Side Weld. Middle
406  RPP -22.2250 22.2250 -87.2872 87.2872 7.6200 429.4124   $ Outer Surface Side Weld. Side
Mount
407  RPP -22.2250 22.2250 -86.6522 86.6522 7.6200 429.4124   $ Inner Surface Side Weld. Side
Mount
408  RPP -87.2872 87.2872 -8.3693 8.3693 0.0000 455.9300   $ Outer Surface Side Weld. Middle
409  RPP -85.6997 85.6997 -8.3693 8.3693 0.0000 455.9300   $ Inner Surface Side Weld. Middle
410  RPP -87.2872 87.2872 -22.2250 22.2250 7.6200 429.4124   $ Outer Surface Side Weld. Side
Mount
411  RPP -86.6522 86.6522 -22.2250 22.2250 7.6200 429.4124   $ Inner Surface Side Weld. Side
Mount
412 1 RPP -71.9600 71.9600 -71.9600 71.9600 7.6200 448.3100   $ Inner Surface Corner Weld.
413 1 RPP -72.9125 72.9125 -72.9125 72.9125 7.6200 448.3100   $ Outer Surface Corner Weld.
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
414  RPP -86.3728 86.3728 -86.3728 86.3728 7.6200 448.3100   $ Outer Cut Surface Corner Weld.
415  RPP -54.3129 54.3129 -70.9906 70.9906 7.6200 448.3100   $ Inner Surface Corner Weld.
416  RPP -55.1066 55.1066 -71.9431 71.9431 7.6200 448.3100   $ Outer Surface Corner Weld.
417  RPP -70.9906 70.9906 -54.3129 54.3129 7.6200 448.3100   $ Inner Surface Corner Weld.
418  RPP -71.9431 71.9431 -55.1066 55.1066 7.6200 448.3100   $ Outer Surface Corner Weld.
419  RPP -24.0056 24.0056 -86.3728 86.3728 7.6200 448.3100   $ Inner Surface Corner Weld.
420  RPP -24.9581 24.9581 -86.3728 86.3728 7.6200 448.3100   $ Outer Surface Corner Weld.
421  RPP -86.3728 86.3728 -24.0056 24.0056 7.6200 448.3100   $ Inner Surface Corner Weld.
422  RPP -86.3728 86.3728 -24.9581 24.9581 7.6200 448.3100   $ Outer Surface Corner Weld.
c Surface Cards - Canister
501 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 458.4700  90.1700 $ Canister cavity
502 PY -7.6327
503 RCC 0.0000 0.0000 -6.9850 0.0000 0.0000 487.0450  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
601 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
602 CZ 92.7100        $ Cask cavity radius
603 CZ 94.6150        $ Inner shell OR
604 CZ 102.7430        $ Lead shell OR
605 CZ 108.5850        $ Outer shell IR
606 PZ 30.4800        $ Top of bottom plate
607 PZ 453.3900        $ Bottom of top plate
608 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
609 PY 97.0026        $ Inside rail surface
610 PY -97.0026        $ Inside rail surface
611 PY 96.52        $ Door surface
612 PY -96.52        $ Door surface
613 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*614 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
c Fuel Pellet Material  4.30%  Weight UO2 [amu]  269.9205
m1    92235.66c -3.790E-02 92238.66c -8.435E-01  8016.62c -1.185E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.119E-01  8016.62c -8.881E-01
mt3  lwtr.01t
c Lower Nozzle Material
m4
       1001.62c -6.702E-02  8016.62c -5.319E-01
      24050.62c -3.185E-03 26054.62c -1.575E-02 28058.62c -2.561E-02
      24052.62c -6.379E-02 26056.62c -2.562E-01 28060.62c -1.020E-02
      24053.62c -7.372E-03 26057.62c -6.026E-03 28061.62c -4.510E-04
      24054.62c -1.866E-03 26058.62c -8.098E-04 28062.62c -1.460E-03
                                                28064.62c -3.860E-04
      25055.62c -8.023E-03
mt4  lwtr.01t
c Upper Nozzle Material
m5
       1001.62c -4.459E-02  8016.62c -3.539E-01
      24050.62c -4.776E-03 26054.62c -2.362E-02 28058.62c -3.840E-02
      24052.62c -9.567E-02 26056.62c -3.842E-01 28060.62c -1.530E-02
      24053.62c -1.106E-02 26057.62c -9.036E-03 28061.62c -6.763E-04
      24054.62c -2.798E-03 26058.62c -1.214E-03 28062.62c -2.189E-03
                                                28064.62c -5.789E-04
      25055.62c -1.203E-02
mt5  lwtr.01t
c SS304
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
m6     24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
       24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
       24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
       24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                 28064.62c -9.623E-04
       25055.62c -2.000E-02
c Aluminum
m7     13027.62c -1.000E+00
c Carbon Steel
m8     26054.62c -5.594E-02  6000.66c -1.000E-02
       26056.62c -9.098E-01
       26057.62c -2.140E-02
       26058.62c -2.876E-03
c Lead
m9     82206.66c -2.534E-01
       82207.66c -2.207E-01
       82208.66c -5.259E-01
c NS-F-FR
m10     5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
        5011.66c -3.772E-03  7015.66c -7.852E-05
       13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11    26054.62c -7.911E-04 14000.60c -3.370E-01
       26056.62c -1.287E-02
       26057.62c -3.026E-04
       26058.62c -4.067E-05
        1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
        8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12     5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
        5011.66c -2.799E-01
c Water Exterior
m13     1001.62c 2.0
        8016.62c 1.0
mt13   lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14    92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15    28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
       28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
       28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
       28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
       28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
        5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
        5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16     5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17     8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
       13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18     5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
        5011.66c -1.611E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
c
c Cell Importances
c
mode n
imp:n 1 292r 0
c
c
c Criticality Controls
c
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= 601 : D2 : D5 : 7 : -1
      ERG= D1
      POS= 0.0000 0.00 1.5875
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          l        d
      501 1
      502 1
      503 1
      504 1
      505 1
      506 1
      507 1
      508 1
      509 1
      510 1
      511 1
      512 1
      513 1
      514 1
      515 1
      516 1
      517 1
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      519 1
      520 1
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      522 1
      523 1
      524 1
      525 1
      526 1
      527 1
      528 1
      529 1
      530 1
      531 1
      532 1
      533 1
      534 1
      535 1
      536 1
      537 1
      538 1
      539 1
      540 1
      541 1
      542 1
      543 1
      544 1
      545 1
      546 1
      547 1
      548 1
      549 1
      550 1
      551 1
```

Figure 6.7.4-4 MCNP Transfer Cask Model – BWR 82-Assembly Basket

```
      552 1
      553 1
      554 1
      555 1
      556 1
      557 1
      558 1
      559 1
      560 1
      561 1
      562 1
      563 1
      564 1
      565 1
      566 1
      567 1
      568 1
      569 1
      570 1
      571 1
      572 1
      573 1
      574 1
      575 1
      576 1
      577 1
      578 1
      579 1
      580 1
      581 1
      582 1
      583 1
      584 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4095 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      381 1.0
c Assembly Source Distribution
#    SI5        SP5
          1        d
      11 1
      12 1
      13 1
      14 1
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

6.7.5 BWR Fuel Characterization

Fuel definitions listed in Section 6.4 are the result of grouping the large range of commercial fuel types by core type, number of fuel rods, and key criticality characteristics. These characteristics are primarily associated with the assembly moderator ratio and fuel mass and include pellet diameter, active fuel length, fuel rod diameter and clad thickness, and water rod configuration. Another variable for BWR assemblies is the presence, and thickness, of the channel.

Characterization studies are based on the 87-assembly basket configuration. For assemblies exceeding the USL at the enrichment specified in the studies either the 86-assembly basket, the 82-assembly basket configurations or reduced maximum enrichments are required. Enrichment limits for the basket configurations are provided in Section 6.7.6.

Lattice Configuration and Channel Studies

BWR fuel assemblies are typically undermoderated in the basket structure (H/U ratio below optimum levels). Therefore, initial criticality analysis extracts from each assembly type the following characteristics.

- Minimum fuel rod outer diameter
- Minimum clad thickness (only relevant to flooded pellet-to-clad gap scenarios)
- Minimum water rod outer diameter and thickness
- Maximum rod pitch (assemblies are grouped by core type and, therefore, typically have single nominal pitch)

Based on the maximum H/U set of characteristics, the reactivity of each assembly is determined under various conditions. Evaluated is a dry and flooded pellet-to-clad gap. Since relative reactivity for the assembly design and flood conditions are evaluated, the models are based on nominal basket characteristics with the assemblies centered in the tube and developed cell. Comparisons are performed at a 4 wt.% enrichment level.

Results of the analysis at various clad-to-gap conditions are shown in Table 6.7.5-1. Flooding the pellet-to-clad gap raised system reactivity across the majority of fuel types, indicating that the fuel assemblies are significantly undermoderated in the basket. No statistically significant reactivity decrease occurs as a result of flooding the gap for any of the fuel types. The channel thickness study documented in Table 6.7.5-2 demonstrates that modeling the maximum channel thickness is conservative and that it is permissible to load assemblies without channel.

The evaluation presented previously assumed that the assemblies are undermoderated and that choosing the corresponding set of parameters maximizes system reactivity. This assumption is supported by the pellet-to-clad gap flood evaluation, which clearly demonstrates that providing

additional moderator to the lattice increases reactivity. This assumption is further validated by evaluating a subset of the fuel assembly types for a variation in the lattice parameters. As typical assemblies loaded into the cask are expected to be intact (no leak), the pellet-to-clad gap is specified to be dry for these analyses. Fuel assemblies are evaluated in a nominal configuration basket with fuel assemblies centered in the tube. As this evaluation is concerned with relative reactivity differences due to lattice parameter changes, the results of this analysis may be applied to the maximum reactivity basket configuration. Each assembly hybrid is evaluated over its range of nominal lattice parameters.

Rather than evaluating individual parameter effects separately, the fuel characteristics analysis is divided into distinct regions.

Fuel rod lattice unit cell
- H/U ratio controlled by rod pitch, rod diameter, and clad thickness

Water rod unit cell (note that not all BWR assemblies contain water rods)
- H/U controlled by water rod diameter and thickness

Pellet diameter (NUREG-6716 [9] indicates the possibility of a minimum pellet diameter increasing system reactivity)

Monte Carlo evaluation results of the nominal assembly parameter ranges provided limited useful information, as the majority of reactivity changes were not resolvable within a two or three sigma uncertainty band. Statistically significant results were obtained from an additional calculation set applying increased variances to each of the parameters. The results of the increased variance evaluation for 4.0 wt.% enriched cases are shown in Table 6.7.5-3. As shown, the cases containing maximum H/U ratio in the fuel rod lattice location, maximum H/U in the water rod location (minimum water rod diameter and thickness), and maximum pellet diameter produce a maximum reactivity configuration system. The result set also demonstrates that water rod dimensions are not a crucial to system criticality control. Critical assemblies characteristics are listed below.

Number of fuel rods

Minimum fuel rod outer diameter

Minimum clad thickness

Maximum rod pitch

Maximum active fuel length (not evaluated but based on neutron leakage maximum active fuel length results in a bounding payload definition)

Homogeneous versus Heterogeneous Assembly Enrichment Evaluation

BWR fuel assemblies are typically loaded with a heterogeneous enrichment scheme of multiple fuel pin enrichments in one assembly. For the criticality analysis presented previously, an initial peak planar-average enrichment is used. The initial peak planar-average enrichment is the

maximum planar-average enrichment at any height along the axis of the fuel assembly. This section demonstrates that the use of a planar-average enrichment provides a conservative k_{eff} compared to the heterogeneous fuel assembly. Sample fuel assembly loading patterns are evaluated using both homogeneous and heterogeneous enrichment schemes and the resulting k_{eff} are compared. No gadolinium poisons are included in any of the models.

Fuel assembly types studied are the GE 8×8 60 and 62 fuel rod and GE 9×9 74 fuel rod assembly types. Each of the fuel assemblies is evaluated at a planar-average homogeneous enrichment and the actual documented enrichment pattern. Results of the analysis, listed in Table 6.7.5-4, show that for all cases, the heterogeneous enrichment produces a lower k_{eff} than the homogeneous planar average (in this case assembly average) enrichment case. This demonstrates that applying the maximum planar-average enrichment provides a conservative estimate of the cask k_{eff}. The maximum pin enrichments in each of the assemblies evaluated are included in Table 6.7.5-4.

Table 6.7.5-1 System Reactivity Response to BWR Fuel Type and Pellet-to-Clad Condition

Assembly Type	Dry Gap k_{eff}	Wet Gap k_{eff}	Dry Gap to Wet Gap $\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.92232	4.2
B7_49A	0.92470	0.93034	5.4
B7_49B	0.92610	0.93136	4.8
B8_59A	0.91930	0.92592	6.2
B8_60A	0.92497	0.93054	5.2
B8_60B	0.92589	0.93186	5.5
B8_61B	0.92650	0.93161	4.9
B8_62A	0.93055	0.93352	2.7
B8_63A	0.92687	0.93557	8.0
B8_64A	0.92594	0.93140	5.0
B8_64B	0.94157	0.94661	4.8
B9_72A	0.93299	0.93695	3.7
B9_74A	0.94392	0.94364	-0.3
B9_76A	0.95063	0.94997	-0.6
B9_79A	0.94155	0.94264	1.0
B9_80A	0.92757	0.93214	4.3
B10_91A	0.92961	0.93362	3.8
B10_92A	0.92366	0.92975	5.6
B10_96A	0.93807	0.94274	4.6
B10_100A	0.93827	0.94478	6.1

Table 6.7.5-2 System Reactivity Response to BWR Fuel Type and Channel Thickness

Assembly Type	120 mil Channel k_{eff}	80 mil Channel k_{eff}	No Channel k_{eff}	120 mil to No Channel $\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.91549	0.91525	-2.2
B7_49A	0.92470	0.92250	0.92091	-3.6
B7_49B	0.92610	0.92429	0.92316	-2.8
B8_59A	0.91930	0.91846	0.91865	-0.6
B8_60A	0.92497	0.92290	0.92020	-4.3
B8_60B	0.92589	0.92519	0.92307	-2.7
B8_61B	0.92650	0.92572	0.92190	-4.3
B8_62A	0.93055	0.92618	0.92355	-6.4
B8_63A	0.92687	0.92697	0.92528	-1.5
B8_64A	0.92594	0.92314	0.92202	-3.6
B8_64B	0.94157	0.93918	0.93761	-3.6
B9_72A	0.93299	0.92914	0.92862	-4.2
B9_74A	0.94392	0.94160	0.93910	-4.5
B9_76A	0.95063	0.94770	0.94725	-3.2
B9_79A	0.94155	0.93869	0.93711	-4.2
B9_80A	0.92757	0.92482	0.92120	-5.8
B10_91A	0.92961	0.92519	0.92590	-3.5
B10_92A	0.92366	0.92230	0.92224	-1.3
B10_96A	0.93807	0.93718	0.93597	-2.1
B10_100A	0.93827	0.93701	0.93622	-1.9

Table 6.7.5-3 BWR Lattice Parameter Reactivity Study (Increased Variance)

	2	1	3	4	5	6	7	8
Fuel Pin Cell H/U	Max	Max	Max	Max	Min	Min	Min	Min
Pellet Dia.	Max	Max	Min	Min	Max	Max	Min	Min
WR Thick & Dia.	Min	Max	Max	Min	Max	Min	Max	Min
B7_49A	0.92730	0.92730	0.92056	0.92056	0.91586	0.91586	0.90754	0.90754
B8_62A	0.93236	0.93074	0.92250	0.92221	0.92329	0.92487	0.91509	0.91531
B8_64B	0.94490	0.94490	0.94492	0.94492	0.94077	0.94077	0.94024	0.94024
B9_76A	0.95166	0.95339	0.93279	0.93515	0.92594	0.92475	0.90617	0.90821
B9_79A	0.94460	0.94312	0.92833	0.92976	0.91394	0.91460	0.89807	0.90005
B10_92A	0.92811	0.92719	0.92661	0.92590	0.92079	0.92305	0.92089	0.91909
B10_96A	0.94037	0.94037	0.94109	0.94109	0.93618	0.93618	0.93490	0.93490
		Case 2 To Case 1	Case 2 To Case 3	Case 2 to Case 4	Case 2 to Case 5	Case 2 to Case 6	Case 2 to Case 7	Case 2 To Case 8
		$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$	$\Delta k_{eff}/\sigma$
B7_49A		--	-6.2	-6.2	-10.9	-10.9	-18.9	-18.9
B8_62A		-1.4	-8.8	-8.8	-8.0	-6.6	-15.6	-15.4
B8_64B		--	0.0	0.0	-3.8	-3.8	-4.3	-4.3
B9_76A		1.7	-18.2	-18.2	-24.1	-25.2	-43.5	-41.5
B9_79A		-1.5	-15.4	-15.4	-29.7	-29.1	-45.7	-43.8
B10_92A		-0.9	-1.4	-1.4	-6.8	-4.7	-6.7	-8.4
B10_96A		--	0.7	0.7	-4.2	-4.2	-5.5	-5.5

Table 6.7.5-4 BWR Heterogeneous vs. Homogeneous Enrichment Analysis Results

Assembly Type	Avg. Enrichment (wt ^{235}U)	Max. Pellet Enrichment (wt % ^{235}U)	Pattern	k_{eff}	$\Delta k_{eff}/\sigma$
B8_60B	3.40	3.40	Homog.	0.88886	--
B8_60B	3.40	3.95	Variable	0.88371	-4.8
B8_60B	4.00	4.00	Homog.	0.92589	--
B8_60B	4.00	4.64	Variable	0.92017	-5.4
B8_60B	4.20	4.20	Homog.	0.93765	--
B8_60B	4.20	4.87	Variable	0.93229	-5.1
B8_62A	2.80	2.80	Homog.	0.84529	--
B8_62A	2.80	3.80	Variable	0.83869	-6.3
B8_62A	3.50	3.50	Homog.	0.89956	--
B8_62A	3.50	4.71	Variable	0.88756	-11.8
B8_62A	4.00	4.00	Homog.	0.93055	--
B8_62A	4.00	5.38	Variable	0.91787	-11.3
B9_74A	3.50	3.50	Homog.	0.91161	--
B9_74A	3.50	4.20	Variable	0.90810	-3.3
B9_74A	4.10	4.10	Homog.	0.94574	--
B9_74A	4.10	4.90	Variable	0.94391	-1.8
B9_74A	4.20	4.20	Homog.	0.95367	--
B9_74A	4.20	5.04	Variable	0.95139	-2.2

6.7.6 BWR Undamaged Fuel Criticality Evaluation

6.7.6.1 Optimum System Configuration

Enrichment limits are based on a maximum reactivity configuration system. To determine the maximum reactivity system, the following system perturbations are evaluated:

TSC interior moderator elevation variations (partial flooding)
Moderator density changes from void to full density (inside and outside the TSC)
Basket fabrication tolerance
Component shift scenarios

All system perturbation analyses are based on fuel assemblies at the maximum lattice moderator (H/U) ratio. Justification for this fuel assembly configuration is provided in Section 6.7.5. Only transfer cask cases are used in these evaluations since the transfer cask is the only cask body in which TSC flooding occurs. In the dry concrete cask, the TSC has a low reactivity, $k_{eff} < 0.5$.

All elevations in this section are based on full-length rods in all assemblies. Partial length rods are addressed in the loading tables. Optimum system configuration studies are based on the 87-assembly basket configuration and a 4.0 wt % ^{235}U initial enrichment, unless otherwise stated. Certain assembly types and configurations exceed the USL at the 4.0 wt % ^{235}U in the 87-assembly basket configuration. These assemblies require the use of either the 86-assembly basket, the 82-assembly basket configurations, or reduced maximum enrichments.

Initial reactivity analysis is based on a basket and neutron absorber configuration with the following characteristics:

a.) Neutron absorbers on all four sides of each tube.

b.) A single column of weld posts connecting neutron absorber to tube.

c.) A neutron absorber thickness tolerance of ±0.005 inch.

d.) A neutron absorber width tolerance of ±0.02 inch.

e.) Neutron absorber sheet effective areal density of 0.027 ^{10}B g/cm^2.

Differences in reactivity due to system configuration and tolerance changes from these characteristics are evaluated in the subsection titled "Neutron Absorber Modifications."

Changes in neutron absorber areal density are addressed in Section 6.7.6.2.

Partial Flooding

Partial flood cases drain the TSC to the top of the active fuel region. The partial flood reactivity cases investigate reactivity difference between a water reflector over the active fuel region and reflection from the steel lid. The results of the partial flooding study, documented in Table 6.7.6-1, demonstrate that BWR system reactivity is independent of TSC moderator elevations.

Moderator Density Variations

Moderator density variation cases are based on a cask array model generated by surrounding a single cask body with a cylindrical reflecting enclosure. The reflecting body is spaced 20 cm from the cask body to allow exterior moderator density conditions to affect the results. Reactivities calculated for various moderator densities are graphically illustrated in Figure 6.7.6-1 and Figure 6.7.6-2 for the 87-assembly and 82-assembly basket configurations, respectively. Moderator density curves are based on the B9_79A assembly hybrid at an initial enrichment of 4.0 wt % ^{235}U and a flooded pellet-to-clad gap. Reactivity increases in the system as TSC interior moderator density rises. Exterior moderator conditions have no significant effect on system reactivity for a flooded TSC. The k_{eff} of the dry TSC is less than 0.5 under all exterior conditions.

Fabrication Tolerances and Component Shift

Fabrication tolerances and shift effects are evaluated using representative fuel types from the major core configurations. Nominal fuel assembly characteristics are employed in the tolerance and shifting evaluations.

Fabrication Tolerance

The basket is composed of a set of fuel tubes, pinned together in the tube corners, and located in the TSC cavity with side and corner weldments. Tube location in the basket is controlled by the diagonal dimension across the exterior face of the fuel tube corners. This value is a key dimension for tube array and developed cell size. The tube diagonal is referred to as tube "interface width" in the analysis discussions. Similar to the PWR model, neutron absorber and tube tolerances are evaluated. Neutron absorber thickness studies are based on the minimum ^{10}B areal density allowed for the design. As such, variations in absorber thickness require adjustments in the sheet composition. The results of the tolerance evaluation for centered fuel assemblies and basket components are included in Table 6.7.6-2. As indicated in the table, little statistically significant information ($>3\sigma$) is available from this study. None of the fabrication-related tolerances, with the exception of maximum tube wall thickness, produce significant reactivity increases when taken independently.

Further evaluations of the component tolerances, including combinations of tolerances, are performed in conjunction with the shifted component configuration.

Component Shift

In addition to the component tolerances, a reactivity study on component shifts is required. Based on the pinned tube arrangement, the only radial shift to be evaluated is the shift of the fuel assembly within the tubes. The tubes are restrained in the corner by pins, minimizing tube shift potential. Evaluations on tube shift are included within the Phase 3 Design Modifications subsection (pages 6.7.6-5 through 6.7.6-7). The results of shift evaluations are shown in Table 6.7.6-2, indicating that shifting the fuel assembly towards the basket center clearly increases system reactivity.

Combined Shift and Tolerance Study

This section evaluates the effect of combining various basket tolerances with the maximum reactivity shift configuration (radial in). The results for this evaluation are shown in Table 6.7.6-3. Similar to the results of the independent basket tolerance evaluation, only fuel tube thickness affects system reactivity to a statistically significant level.

While no statistically significant reactivity difference is found between the cases with and without tolerances applied, the maximum reactivity configuration chosen for the evaluations of all fuel hybrids is as follows.

Minimum tube width and interface width
Maximum tube thickness
Minimum absorber width and maximum thickness
Fuel assemblies shifted to basket center

This configuration produced reactivities within a 3σ uncertainty band of the maximum reported value for all fuel types evaluated, and provides for the minimum separation between adjacent assemblies. The minimum separation reduces the amount of moderation and the corresponding effectiveness of the absorber sheet, which depend on the ^{10}B neutron capture cross-section in the thermal energy range.

Shift and tolerance evaluations were based on a full, 87-assembly, basket loading. While fabrication tolerance impacts relate to tube and developed cell unit behavior, a limited set of evaluations is performed to verify that the radial shifting in a fuel assembly pattern remains bounding for the 82-assembly basket configuration. The results of this evaluation are shown in Table 6.7.6-4 and demonstrate that the radial shifting in a fuel assembly pattern is limiting.

Neutron Absorber Modifications

Phase I Design Modifications

Design options permit the replacement or removal of up to 24 neutron absorber sheets in the 87-assembly and 86-assembly basket peripheral fuel tubes or up to 16 neutron absorber sheets in the 82-assembly baskets. Locations for the optional absorber sheets are shown in Figure 6.7.6-3 and Figure 6.7.6-4, respectively. Replacement sheets for the neutron absorber in the peripheral basket locations are composed of unborated aluminum. Using the most reactive basket and fuel assembly shifting specified in Section 6.7.6.1, each BWR fuel type specified in Section 6.7.5 was analyzed at 4.0 wt % ^{235}U for the 87-assembly basket and 4.5 wt % ^{235}U for the 82-assembly basket. As shown in Table 6.7.6-5 and Table 6.7.6-6, no statistically significant reactivity changes are associated with the absorber sheet removal or replacement in the model. Results were calculated using unborated water in the pellet-to-clad gap. Results for the 87-assembly basket may exceed the USL at 4.0 wt% ^{235}U. For assemblies exceeding the USL, a lower enrichment or the use of either the 86 or 82-assembly basket configuration is required.

Design enhancements introduced after completion of the primary criticality evaluations replaced the single column of weld posts down the tube face centerline with a two-column weld post configuration. The weld post columns are located 1.8 in from the tube centerline. As demonstrated in Table 6.7.6-7, the increased number of weld posts does not significantly change system reactivity. Results were calculated using unborated water in the pellet-to-clad gap.

As the combined reactivity effect of a reduced number of absorber sheets and an increased number of weld posts may exceed the statistically significant threshold ($> 3\sigma$) or potentially result in a $k_{eff} + 2\sigma > USL$ if added as a Δk, the maximum allowed enrichments are calculated with a model containing the reduced number of absorber sheets and the increased number of weld posts.

Phase 2 Design Modifications

Neutron absorbers may be manufactured at an increased tolerance band. Rather than the ±0.005-inch thickness and ±0.02-inch width tolerance evaluated in the previous calculations, a thickness tolerance of ±0.006 inch and a width tolerance of ±0.08 inch may be applied. Changes in the absorber thickness tolerance do not result in changes in the areal density of the ^{10}B absorber material as it is defined at its minimum value regardless of absorber thickness. The focus of the revised analysis is maximum tolerance sheet thickness and minimum width, as the maximum thickness change displaces moderator between fuel and absorber (i.e., potentially decreases absorber efficiency) and the minimum width removes absorber from the system.

To evaluate the design change, each maximum reactivity fuel type/enrichment combination in Section 6.7.6.2 is evaluated at the increased tolerance band. Results for this analysis at the updated maximum tolerance thickness and minimum width cases are shown in Table 6.7.6-10.

The maximum change in reactivity due to the updated absorber tolerances for the BWR cases was 1.81σ. The overall average change in reactivity was 0.58σ. No case exceeded the USL. The change in the absorber tolerance had an insignificant effect on the reactivity of the BWR system.

Phase 3 Design Modifications

BWR tube drawing dimensions were modified to list the outer width as a reference dimension with the tube corner chamfer specifying a minimum and maximum quantity of material to be removed. This specification limits tube minimum and maximum outer width when applied to the fixed tube interface width. The tube interface width is retained as a toleranced dimension (8.72-inch minimum/8.76-inch maximum). The drawing changes provide additional flexibility on the tube width, while ensuring criticality control is retained. Modifications of the tube dimensions and pin and slot configuration have a secondary effect of allowing increased relative shift of the tube centers. To demonstrate that this design modification does not result in significant reactivity changes, additional criticality evaluations are performed.

Variations in system configuration are evaluated that shift from the baseline model that relied on square tubes located at a 45° angle (i.e., even grind tube flats are touching at their midpoints). The 45° aligned model with relative square tubes is expected to be the as-built configuration of the final basket assembly as the basket: (a) is assembled horizontally producing tube-to-tube contact, with a drawing limitation on the gap allowed between tubes (maximum continuous gap of 0.02 inch over 24-inch interval); and (b) includes installation of side and corner weldments and placement of the basket into the cylindrical TSC, which would not be feasible for a significantly out-of-alignment tube array. As the basket is composed of individual fuel tubes connected by pin-slot connectors and tubes are attached to the weldment by mounting bosses, each with manufacturing tolerances and gaps, localized variations in tube spacing are allowed by the basket drawings. An additional set of analyses is performed to confirm that the interface width is the primary criticality control dimension and that changes in reactivity associated with (a) the potential tube shift away from a 45° alignment and (b) system tolerances associated with the tube and tube-to-weldment interface are either not statistically resolvable or reduce reactivity. In these analyses, maximum shifts in tube relative location are applied to the entire basket rather than to a localized basket area to magnify any potential reactivity effects. Applying the changes to the basket globally results in a configuration that could not be built since corner and side

weldments had to be modified beyond drawing allowables to produce a model fitting into the TSC shell.

System variables were modified to produce the maximum shift from the baseline analysis dimensions. Tube minimum interface, or diagonal face-to-face distance of 8.72 inches, is maintained during the shift/tolerance studies. Maximum perturbation from the baseline may either be a reduced orthogonal dimension (x and/or y) or a reduction in tube diagonal center-to-center spacing. Tube shift reduces the developed cell size by reducing one orthogonal dimension while increasing the other. Figure 6.7.6-5 through Figure 6.7.6-10 contain sketches for the bounding shift/tolerance configurations. There are three even grind and three biased configurations considered in this evaluation. The grind produces the flat at the tube corner and is expected to be uniform during tube fabrication, but drawings allow for a minimum 0.006-inch grind with a maximum 0.04-inch grind. The starting point for the analysis is the baseline square tube aligned at 45° with the even grind shown in Figure 6.7.6-5. This represents the configuration on which maximum allowed enrichments are calculated. Figure 6.7.6-6 modified this configuration to evaluate the impact of a biased grind while retaining the 45° alignment. Next, both even and biased grind configurations were evaluated to determine the maximum shift that could occur between square tubes. The resulting dimension sets are shown in Figure 6.7.6-7 and Figure 6.7.6-8 indicating that the biased grind condition produces the minimum tube center-to-center diagonal spacing, while the even grind condition produces the minimum orthogonal dimension. Note that without regard to the overall basket structure constraints, the developed cell opening is reduced in these scenarios. A sample graphic representation of the MCNP geometry for the shifted tube is shown in Figure 6.7.6-11 to illustrate the potential tube movement. The third set of analyses builds on the shifted tube model while considering the possibility of tubes having a rectangular rather than square cross-section. Sketches of the tube position under the rectangular tube assumption are included in Figure 6.7.6-9 and Figure 6.7.6-10. As the rectangular biased grind dimensions bound the even grind dimensions in both minimum orthogonal and center-to-center diagonal distance, only the biased grind configuration is evaluated.

To address the range of fuel types allowed in the 82-assembly and the 87-assembly system, each of the configurations specified in Section 6.7.6.2 was evaluated for potential reactivity change. Reactivity effects in terms of $\Delta k/\sigma$ are listed in Table 6.7.6-11 for each of the scenarios demonstrating either no statistically resolvable change in reactivity or a decrease in system reactivity occurs. A breakdown of the analysis results by fuel type for each basket consideration at a 0.027 gm/cm^2 effective absorber is shown in Table 6.7.6-12.

Based on the studies described in the previous section, the interface (tube grind flat-to-flat) width controls the critical tube spacing and, therefore, assembly spacing and system reactivity.

6.7.6.2 Allowable Loading Definitions and Maximum System Reactivities

Based on the most reactive basket configuration, each of the fuel assembly types is evaluated at various enrichment levels to determine the maximum enrichment at which $k_{eff} + 2\sigma$ remains below the USL. Physical limitation on the assemblies allowed for loading are listed in Table 6.7.6-9. The maximum allowed planar average initial ebnrichments are listed in Table 6.7.6-8 for assemblies with and without partial length rods, wehre applicable, for a 0.027 ^{10}B g/cm^2 absorber basket configuration. Table 6.7.6-13 summarizes the enrichment limits for 87-assembly, 86-assembly, 82-assembly, and alternate 82-assembly basket configurations at neutron absorber sheet effective areal densities of 0.027, 0.0225, and 0.020 ^{10}B g/cm^2. The 86-assembly and alternate 82-assembly configurations are only applicable to the 0.027 ^{10}B/cm^2 absorber. In all evaluations, the pellet-to-clad gap is flooded.

Maximum system reactivities are summarized as follows. Analysis results represent maximum reactivity basket and fuel geometry. There are no design basis off-normal or accident transfer cask conditions affecting system reactivity. Therefore, only normal condition results are presented. An accident condition for the concrete cask represents a flooding of the concrete cask to canister annulus. Concrete cask results are based on the maximum fuel mass assembly at the highest allowed enrichment (4.5 wt % ^{235}U).

Condition	Pellet to Clad Gap Condition	Maximum Multiplication Factors ($k_{eff} + 2\sigma$)	
		Transfer Cask	Concrete Cask
Normal	Dry	0.92900	0.43685
Normal	Wet	0.93679	N/A
Accident / Off-Normal	Dry	N/A	0.42991

Note that there is no statistical difference between normal and accident condition cases, which differ only by the flooding of the pellet-to-clad gap under the "accident condition."

Figure 6.7.6-1 87-Assembly Basket BWR Water Density Variations

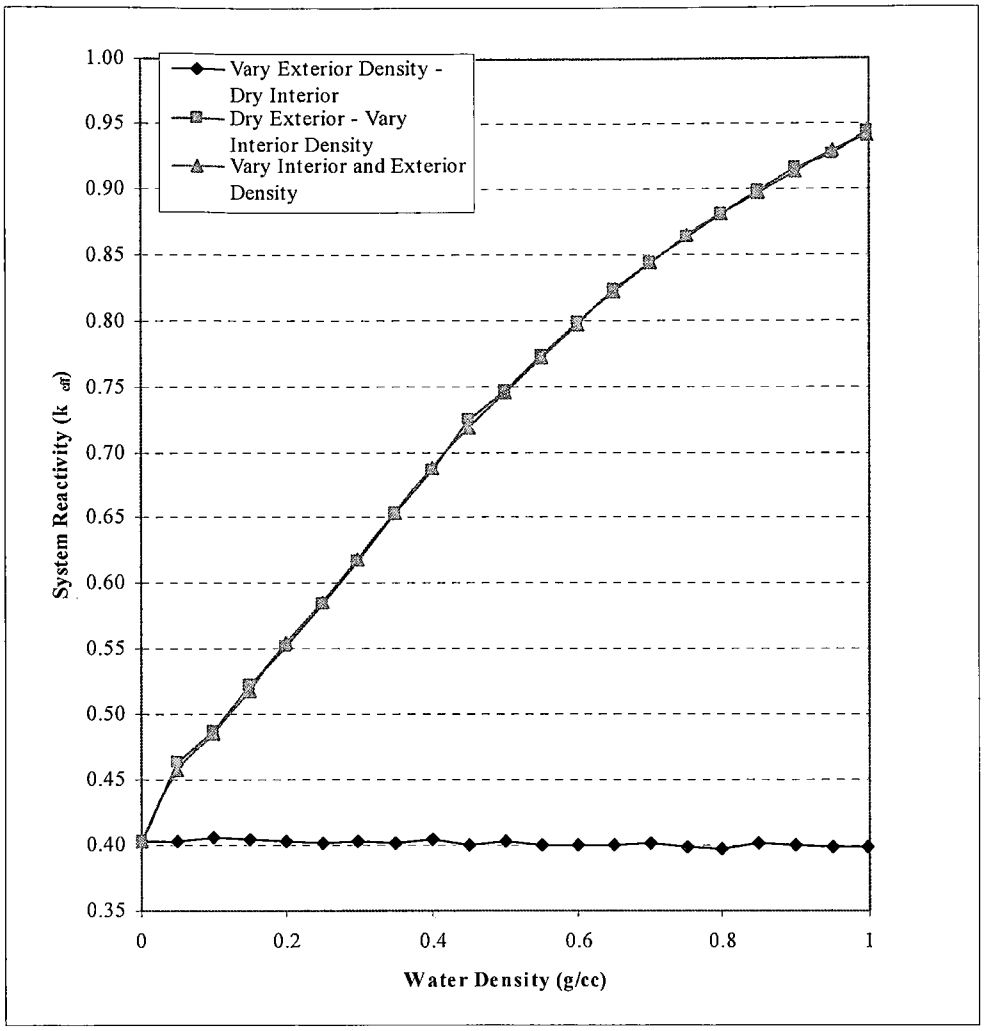


Figure 6.7.6-2 82-Assembly Basket BWR Water Density Variations

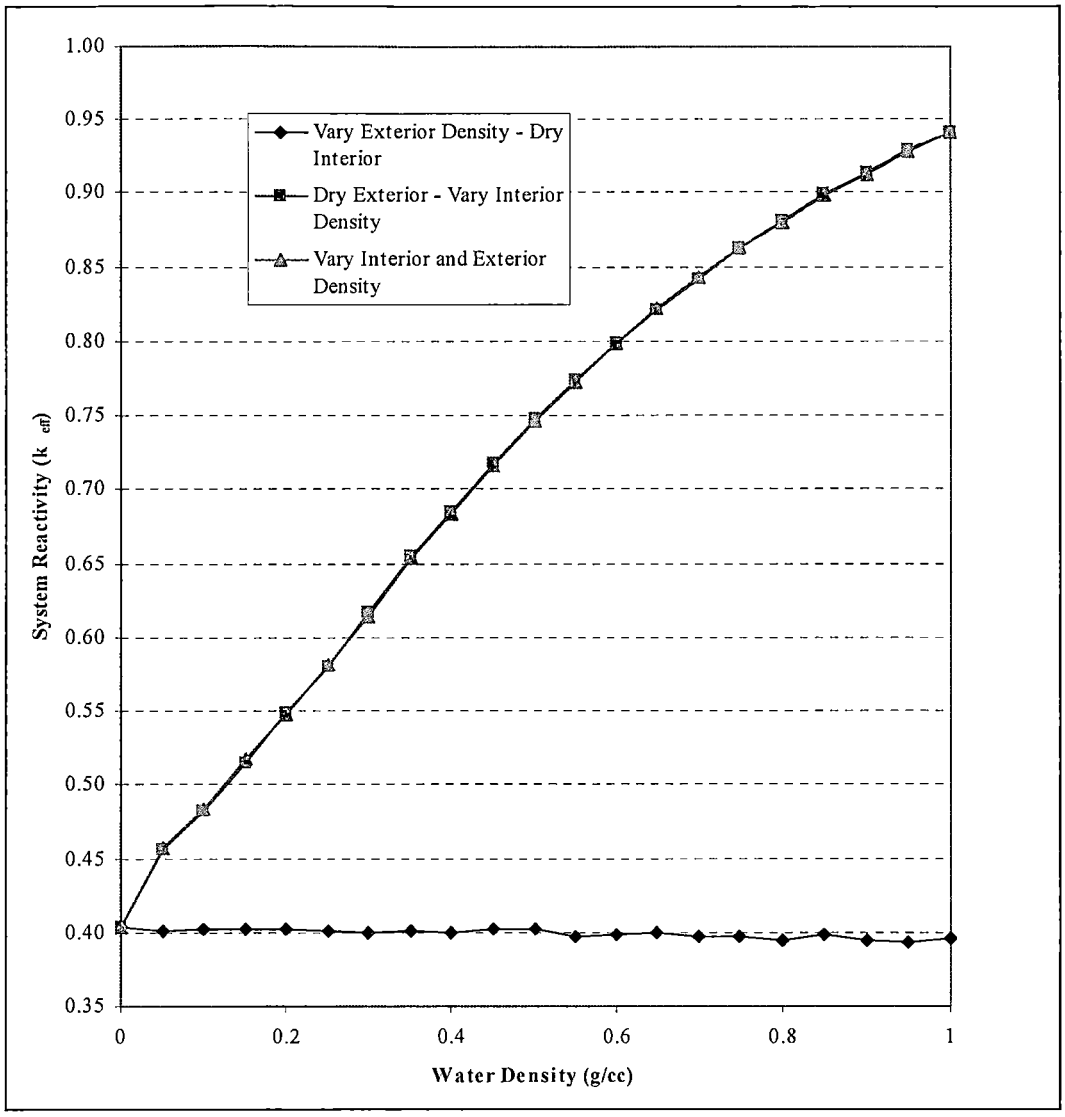
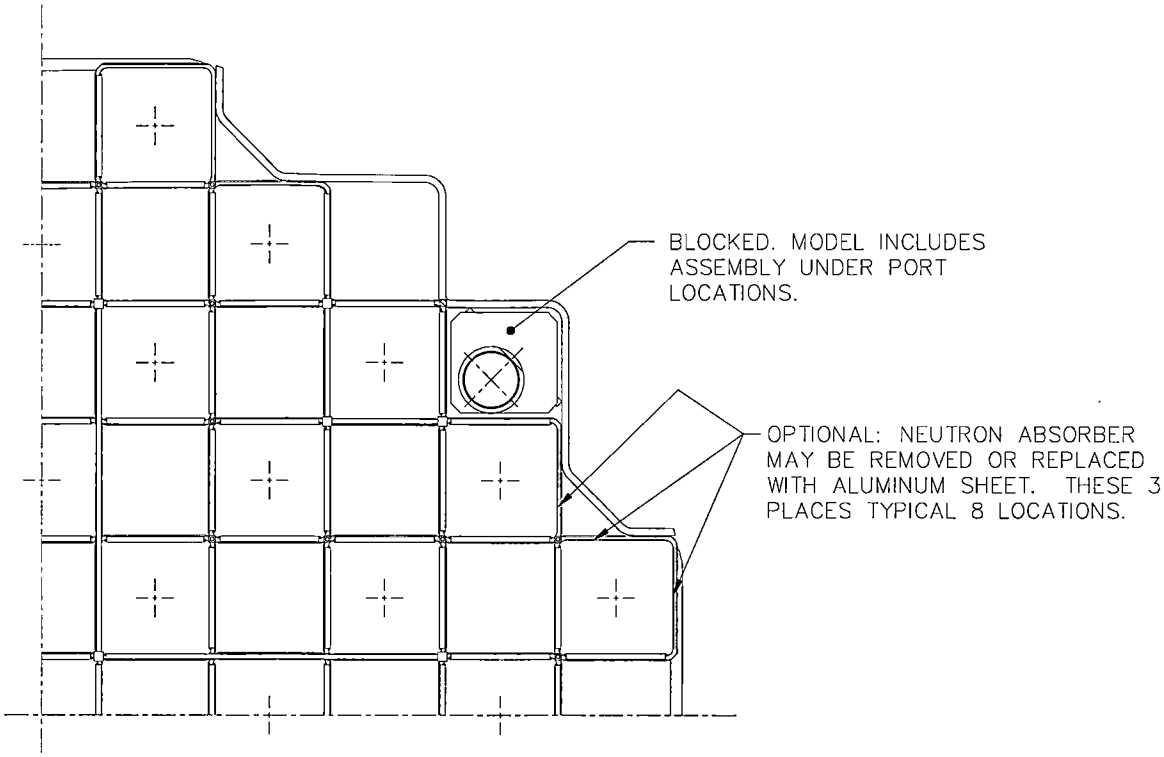
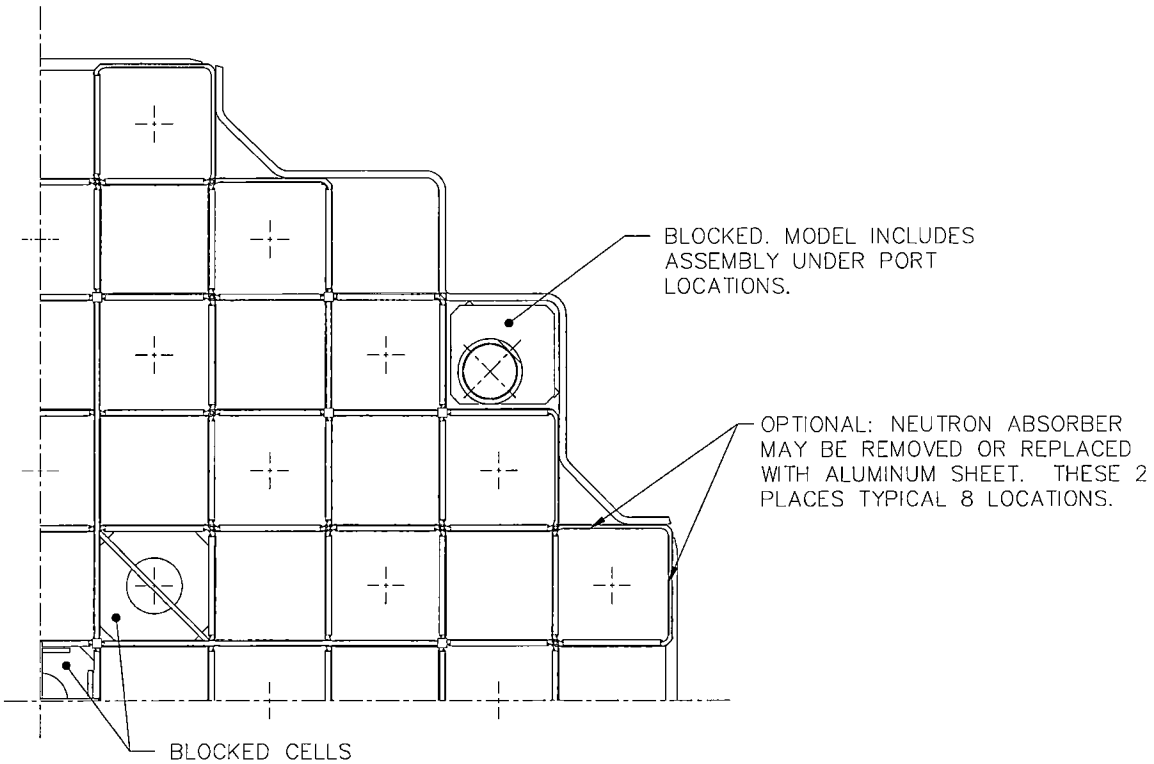


Figure 6.7.6-3 BWR 87-Assembly Basket Optional Neutron Absorber Sheet Locations[a]



[a] Quarter basket model is shown for clarity. Symmetric locations are affected in all four basket quadrants.

Figure 6.7.6-4 BWR 82-Assembly Basket Optional Neutron Absorber Sheet Locations[a]



[a] Quarter basket model is shown for clarity. Symmetric locations are affected in all four basket quadrants.

Figure 6.7.6-5 BWR Minimum Tube Spacing – Baseline Configuration – Square Tube – Even Grind – 45° Aligned

Figure 6.7.6-6 BWR Minimum Tube Spacing – Square Tube – Biased Grind – 45° Aligned

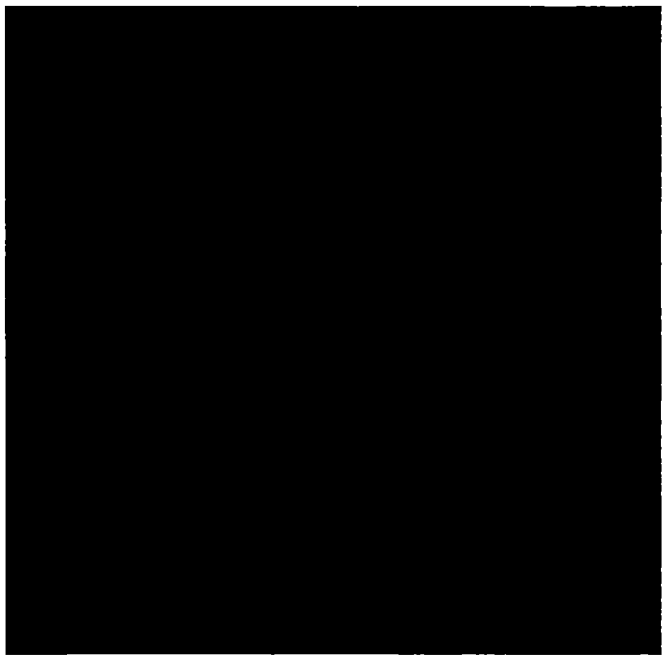


Figure 6.7.6-7 BWR Minimum Tube Spacing – Square Tube – Even Grind – Shifted

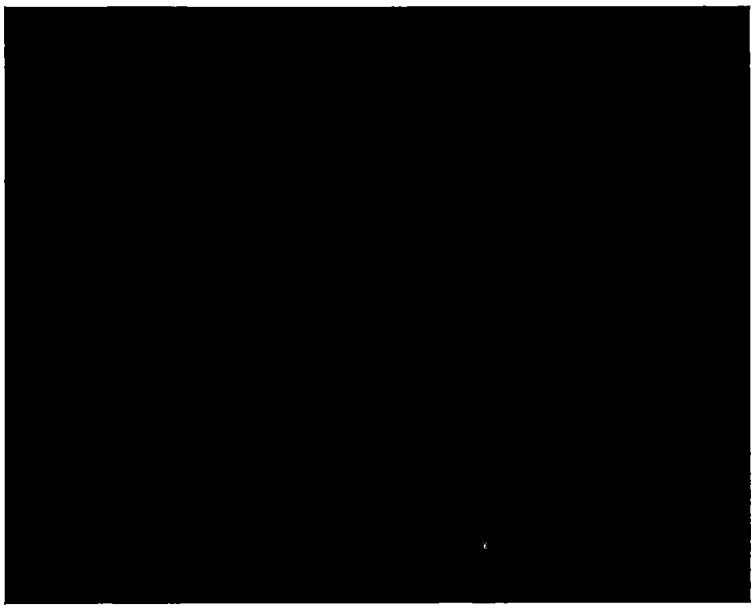


Figure 6.7.6-8 BWR Minimum Tube Spacing – Square Tube – Biased Grind – Shifted

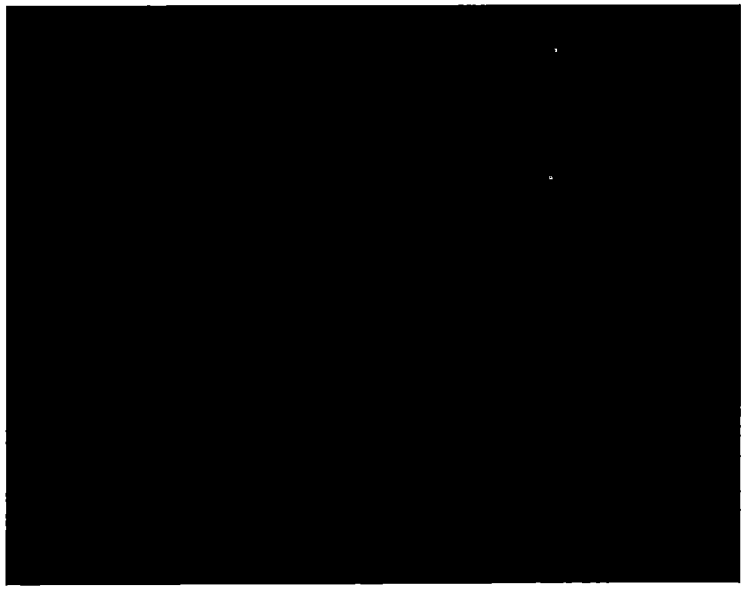


Figure 6.7.6-9 BWR Minimum Tube Spacing – Rectangular Tube – Even Grind – Shifted

[redacted]

Figure 6.7.6-10 BWR Minimum Tube Spacing – Rectangular Tube – Biased Grind – Shifted

[redacted]

Figure 6.7.6-11 Sample VISED Image – BWR Shifted Tube

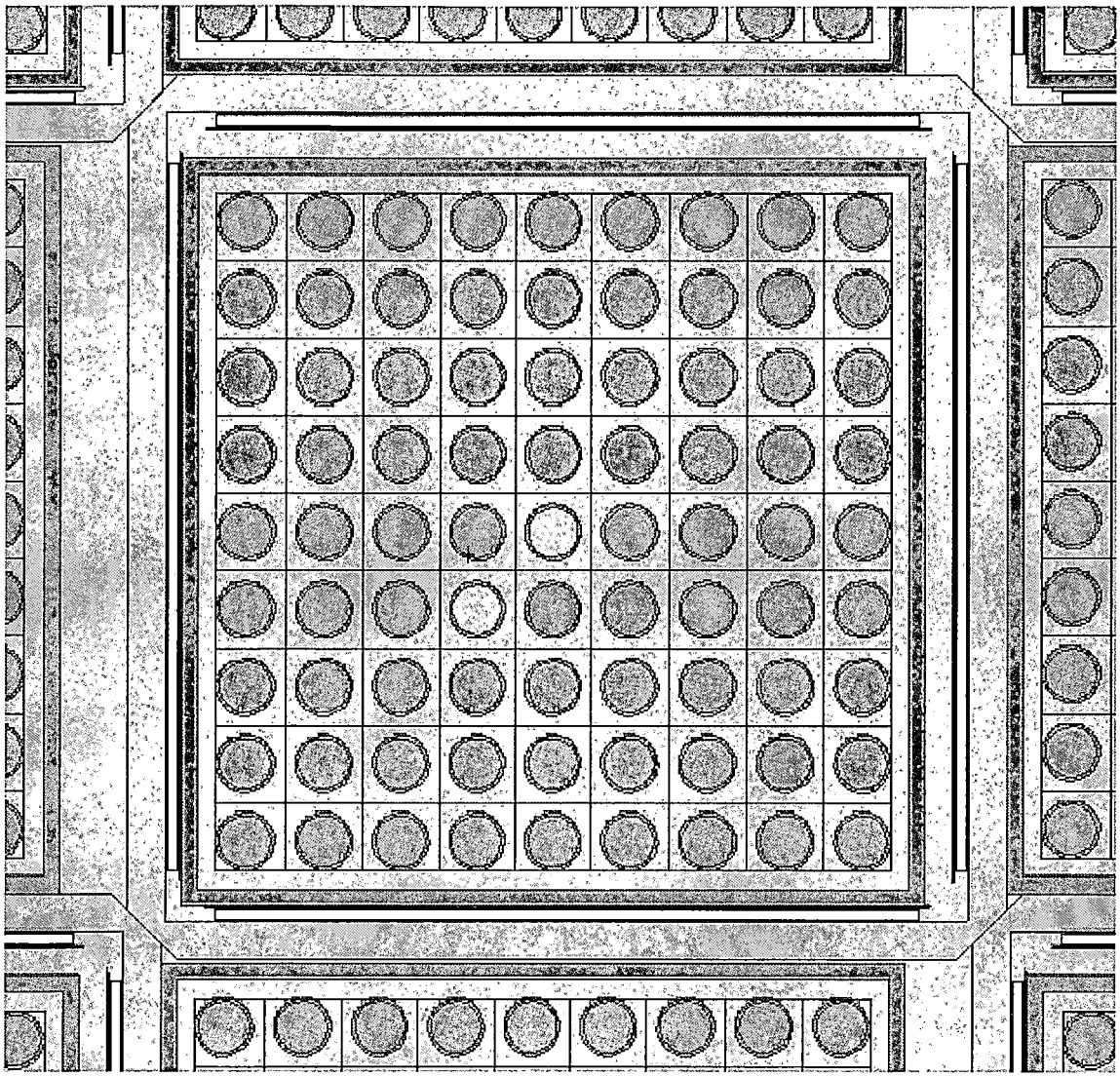


Table 6.7.6-1 BWR System Partial TSC Flood Evaluation

Assembly Type	Dry Gap Full Flood k_{eff}	Dry Gap Partial Flood k_{eff}	$\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.91775	0.1
B7_49A	0.92470	0.92290	-1.7
B7_49B	0.92610	0.92573	-0.3
B8_59A	0.91930	0.92071	1.3
B8_60A	0.92497	0.92501	0.0
B8_60B	0.92589	0.92556	-0.3
B8_61B	0.92650	0.92508	-1.3
B8_62A	0.93055	0.93021	-0.3
B8_63A	0.92687	0.92707	0.2
B8_64A	0.92594	0.92381	-2.0
B8_64B	0.94157	0.94100	-0.5
B9_72A	0.93299	0.93281	-0.2
B9_74A	0.94392	0.94389	0.0
B9_76A	0.95063	0.94907	-1.5
B9_79A	0.94155	0.94044	-1.1
B9_80A	0.92757	0.92671	-0.8
B10_91A	0.92961	0.92853	-1.0
B10_92A	0.92366	0.92532	1.5
B10_96A	0.93807	0.93749	-0.6
B10_100A	0.93827	0.93829	0.0

Table 6.7.6-2 BWR 87-Assembly Basket Component Tolerance and Shift Study Results (Independent Variations)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	Centered	0.92470	--	0.93055	--	0.95063	--	0.94155	--	0.92366	--
Nom	Nom	Nom	Min	Nom	Centered	0.92478	0.1	0.92946	-1.0	0.94894	-2.3	0.94026	-1.2	0.92559	1.8
Nom	Nom	Nom	Max	Nom	Centered	0.92400	-0.7	0.92923	-1.2	0.94751	-4.2	0.94124	-0.3	0.92542	1.7
Nom	Nom	Nom	Nom	Min	Centered	0.92329	-1.3	0.92996	-0.5	0.94914	-2.0	0.94168	0.1	0.92401	0.3
Nom	Nom	Nom	Nom	Max	Centered	0.92434	-0.3	0.92879	-1.6	0.94899	-2.2	0.94198	0.4	0.92519	1.4
Min	Nom	Nom	Nom	Nom	Centered	0.92485	0.1	0.93045	-0.1	0.94778	-3.8	0.94244	0.8	0.92430	0.6
Max	Nom	Nom	Nom	Nom	Centered	0.92329	-1.3	0.92768	-2.6	0.94892	-2.3	0.94192	0.3	0.92402	0.3
Nom	Min	Nom	Nom	Nom	Centered	0.92187	-2.8	0.92582	-4.2	0.94667	-5.2	0.93917	-2.2	0.92227	-1.3
Nom	Max	Nom	Nom	Nom	Centered	0.92660	1.8	0.93193	1.2	0.95095	0.4	0.94512	3.4	0.92850	4.5
Nom	Nom	Min	Nom	Nom	Centered	0.92481	0.1	0.92988	-0.6	0.94915	-2.0	0.94341	1.8	0.92487	1.1
Nom	Nom	Max	Nom	Nom	Centered	0.92248	-2.1	0.92926	-1.1	0.94718	-4.4	0.94155	--	0.92641	2.6
Nom	Nom	Nom	Nom	Nom	In	0.92890	3.9	0.93293	2.1	0.95324	3.5	0.94634	4.6	0.93168	7.5
Nom	Nom	Nom	Nom	Nom	Out	0.91191	-12.2	0.91606	-13.0	0.93809	-16.6	0.93148	-9.6	0.91466	-8.6

Table 6.7.6-3 BWR 87-Assembly Basket Component Tolerance and Shift Study Results (Combined Variations; Radial In Shift)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	In	0.92890	--	0.93293	--	0.95324	--	0.94634	--	0.93168	--
Min	Nom	Nom	Nom	Nom	In	0.93004	1.0	0.93433	1.3	0.95538	2.8	0.94814	1.7	0.93194	0.2
Max	Nom	Nom	Nom	Nom	In	0.92936	0.4	0.93435	1.3	0.95432	1.4	0.94558	-0.7	0.92987	-1.7
Nom	Min	Nom	Nom	Nom	In	0.92927	0.3	0.93188	-1.0	0.95412	1.2	0.94467	-1.5	0.92868	-2.7
Nom	Max	Nom	Nom	Nom	In	0.93194	2.8	0.93775	4.4	0.95475	2.0	0.94882	2.3	0.93563	3.7
Nom	Nom	Min	Nom	Nom	In	0.92865	-0.2	0.93379	0.8	0.95386	0.8	0.94770	1.3	0.93227	0.6
Nom	Nom	Max	Nom	Nom	In	0.92957	0.6	0.93290	0.0	0.95358	0.5	0.94679	0.4	0.93059	-1.0
Nom	Nom	Nom	Min	Nom	In	0.92964	0.7	0.93441	1.3	0.95188	-1.8	0.94832	1.8	0.93072	-0.9
Nom	Nom	Nom	Max	Nom	In	0.92801	-0.8	0.93396	1.0	0.95660	4.5	0.94514	-1.1	0.93082	-0.8
Nom	Nom	Nom	Nom	Min	In	0.93042	1.4	0.93469	1.6	0.95418	1.3	0.94708	0.7	0.93190	0.2
Nom	Nom	Nom	Nom	Max	In	0.92931	0.4	0.93533	2.3	0.95344	0.3	0.94530	-1.0	0.93019	-1.4
Min	Min	Min	Min	Min	In	0.92717	-1.6	0.93238	-0.5	0.95125	-2.6	0.94416	-2.0	0.92825	-3.2
Min	Nom	Min	Min	Nom	In	0.93058	1.6	0.93526	2.1	0.95631	4.0	0.94802	1.6	0.93081	-0.8
Max	Nom	Min	Min	Nom	In	0.92953	0.6	0.93465	1.6	0.95320	-0.1	0.94916	2.7	0.93372	1.9
Nom	Nom	Min	Min	Nom	In	0.93044	1.4	0.93504	1.9	0.95433	1.5	0.94750	1.1	0.93135	-0.3
Nom	Max	Nom	Nom	Max	In	0.93320	3.8	0.93701	3.8	0.95615	3.9	0.94918	2.7	0.93378	2.0
Min	Max	Min	Min	Max	In	0.93284	3.6	0.93816	4.9	0.95791	6.2	0.95034	3.8	0.93442	2.6

Table 6.7.6-4 BWR 82-Assembly Basket Component Tolerance and Shift Study Results (Combined Variations; Radial In Shift)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Min	Max	Min	Min	Max	In	0.88693	--	0.89367	--	0.91528	--	0.90858	--	0.88953	--
Min	Max	Min	Min	Max	Centered	0.88706	0.1	0.89379	0.1	0.91574	0.7	0.90671	-1.7	0.89070	1.1
Min	Max	Min	Min	Max	Out	0.88251	-4.0	0.88855	-4.8	0.91035	-6.8	0.90190	-6.1	0.88389	-5.4

Table 6.7.6-5 BWR 87-Assembly Basket Neutron Absorber Removal & Replacement Study Results

Assembly	Enrichment (wt % ^{235}U)	Nominal Absorber k_{eff}	Absorber Removal			Absorber Replacement		
			k_{eff}	Δk	$\Delta k/\sigma$	k_{eff}	Δk	$\Delta k/\sigma$
B7_48A	4.0	0.93146	0.93023	-0.00123	-1.7	0.93170	0.00024	0.3
B7_49A	4.0	0.94139	0.93975	-0.00164	-2.2	0.94033	-0.00106	-1.4
B7_49B	4.0	0.93978	0.93960	-0.00018	-0.2	0.93971	-0.00007	-0.1
B8_59A	4.0	0.93354	0.93489	0.00135	1.8	0.93408	0.00054	0.7
B8_60A	4.0	0.93932	0.93854	-0.00078	-1.1	0.93844	-0.00088	-1.2
B8_60B	4.0	0.93981	0.93974	-0.00007	-0.1	0.93870	-0.00111	-1.4
B8_61B	4.0	0.94021	0.94108	0.00087	1.2	0.94021	0.00000	0.0
B8_62A	4.0	0.94468	0.94274	-0.00194	-2.5	0.94248	-0.00220	-2.8
B8_63A	4.0	0.94427	0.94310	-0.00117	-1.5	0.94277	-0.00150	-2.0
B8_64A	4.0	0.94133	0.94113	-0.00020	-0.3	0.93912	-0.00221	-3.0
B8_64B	4.0	0.95409	0.95256	-0.00153	-2.1	0.95382	-0.00027	-0.4
B9_72A	4.0	0.94508	0.94404	-0.00104	-1.5	0.94493	-0.00015	-0.2
B9_74A	4.0	0.95198	0.95062	-0.00136	-1.8	0.94971	-0.00227	-2.9
B9_76A	4.0	0.95816	0.95864	0.00048	0.6	0.95749	-0.00067	-0.9
B9_79A	4.0	0.95125	0.95033	-0.00092	-1.2	0.94961	-0.00164	-2.1
B9_80A	4.0	0.93990	0.93934	-0.00056	-0.7	0.93960	-0.00030	-0.4
B10_91A	4.0	0.94279	0.94220	-0.00059	-0.8	0.94135	-0.00144	-2.0
B10_92A	4.0	0.93784	0.93967	0.00183	2.4	0.93990	0.00206	2.8
B10_96A	4.0	0.95060	0.95001	-0.00059	-0.8	0.95152	0.00092	1.2
B10_100A	4.0	0.95219	0.95225	0.00006	0.1	0.95175	-0.00044	-0.6

Table 6.7.6-6 BWR 82-Assembly Basket Neutron Absorber Removal & Replacement Study Results

Assembly	Enrichment (wt % ^{235}U)	Nominal Absorber k_{eff}	Absorber Removal			Absorber Replacement		
			k_{eff}	Δk	$\Delta k/\sigma$	k_{eff}	Δk	$\Delta k/\sigma$
B7_48A	4.5	0.91329	0.91427	0.00098	1.3	0.91435	0.00106	1.3
B7_49A	4.5	0.92148	0.92211	0.00063	0.8	0.92311	0.00163	2.1
B7_49B	4.5	0.92249	0.92244	-0.00005	-0.1	0.92115	-0.00134	-1.7
B8_59A	4.5	0.91678	0.91828	0.00150	2.0	0.91841	0.00163	2.2
B8_60A	4.5	0.92379	0.92406	0.00027	0.4	0.92460	0.00081	1.0
B8_60B	4.5	0.92363	0.92505	0.00142	2.0	0.92319	-0.00044	-0.6
B8_61B	4.5	0.92485	0.92597	0.00112	1.5	0.92466	-0.00019	-0.2
B8_62A	4.5	0.92685	0.92669	-0.00016	-0.2	0.92737	0.00052	0.6
B8_63A	4.5	0.92725	0.92723	-0.00002	0.0	0.92680	-0.00045	-0.5
B8_64A	4.5	0.92408	0.92392	-0.00016	-0.2	0.92524	0.00116	1.5
B8_64B	4.5	0.93936	0.93977	0.00041	0.5	0.93877	-0.00059	-0.8
B9_72A	4.5	0.93060	0.92841	-0.00219	-2.9	0.92850	-0.00210	-2.8
B9_74A	4.5	0.93649	0.93629	-0.00020	-0.3	0.93681	0.00032	0.4
B9_76A	4.5	0.94314	0.94277	-0.00037	-0.5	0.94299	-0.00015	-0.2
B9_79A	4.5	0.93237	0.93400	0.00163	2.1	0.93292	0.00055	0.7
B9_80A	4.5	0.92417	0.92364	-0.00053	-0.7	0.92458	0.00041	0.5
B10_91A	4.5	0.92684	0.92476	-0.00208	-2.7	0.92630	-0.00054	-0.7
B10_92A	4.5	0.92191	0.92287	0.00096	1.2	0.92232	0.00041	0.5
B10_96A	4.5	0.93438	0.93508	0.00070	0.9	0.93597	0.00159	2.0
B10_100A	4.5	0.93701	0.93720	0.00019	0.3	0.93767	0.00066	0.9

Table 6.7.6-7 BWR 87-Assembly Basket Neutron Absorber Attachment Modification Study Results

Assembly	Enrichment (wt % ^{235}U)	Base Evaluation		Modified Attachment			
		Weld Posts	k_{eff}	Weld Posts	k_{eff}	Δk	$\Delta k/\sigma$
B7_48A	4.1	4	0.93806	28	0.93891	0.00085	1.1
B7_49A	3.9	4	0.93303	28	0.93474	0.00171	2.3
B7_49B	3.9	4	0.93311	28	0.93471	0.00160	2.1
B8_59A	4.0	4	0.93354	28	0.93469	0.00115	1.6
B8_60A	3.9	4	0.93370	28	0.93473	0.00103	1.4
B8_60B	3.9	4	0.93355	28	0.93450	0.00095	1.3
B8_61B	3.9	4	0.93582	28	0.93547	-0.00035	-0.5
B8_62A	3.9	4	0.93668	28	0.93831	0.00163	2.1
B8_63A	3.8	4	0.93264	28	0.93369	0.00105	1.5
B8_64A	3.9	4	0.93416	28	0.93579	0.00163	2.2
B8_64B	3.7	4	0.93588	28	0.93778	0.00190	2.6
B9_72A	3.8	4	0.93198	28	0.93369	0.00171	2.3
B9_74A	3.7	4	0.93331	28	0.93392	0.00061	0.8
B9_76A	3.6	4	0.93391	28	0.93491	0.00100	1.3
B9_79A	3.7	4	0.93261	28	0.93227	-0.00034	-0.5
B9_80A	3.9	4	0.93383	28	0.93479	0.00096	1.3
B10_91A	3.8	4	0.93081	28	0.93256	0.00175	2.3
B10_92A	3.8	4	0.92729	28	0.92907	0.00178	2.4
B10_96A	3.7	4	0.93175	28	0.93355	0.00180	2.4
B10_100A	3.7	4	0.93318	28	0.93395	0.00077	1.0

Table 6.7.6-8 BWR System Maximum Reactivity Summary

Assembly Type	Number of Fuel Rods	87-Assembly Basket		82-Assembly Basket	
		Max Initial Enrich. (wt % ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt % ^{235}U)	Reactivity $k_{eff} + 2\sigma$
B7_48A	48	4.00%	0.93601	4.50%	0.91816
B7_49A	49	3.80%	0.93206	4.50%	0.92623
B7_49B	49	3.80%	0.93335	4.50%	0.92750
B8_59A	59	3.90%	0.93132	4.50%	0.92395
B8_60A	60	3.80%	0.93167	4.50%	0.92748
B8_60B	60	3.80%	0.93143	4.50%	0.93014
B8_61B	61	3.80%	0.93322	4.50%	0.92787
B8_62A	62	3.80%	0.93469	4.50%	0.93102
B8_63A	63	3.80%	0.93679	4.50%	0.93126
B8_64A	64	3.80%	0.93298	4.50%	0.92949
B8_64B	64	3.60%	0.93222	4.30%	0.93539
B9_72A	72	3.80%	0.93632	4.50%	0.93408
B9_74A	74	3.70%	0.93578	4.40%	0.93440
B9_76A	76	3.50%	0.92937	4.20%	0.93158
B9_79A	79	3.70%	0.93665	4.40%	0.93406
B9_80A	80	3.80%	0.93143	4.50%	0.92882
B10_91A	91	3.80%	0.93566	4.50%	0.93093
B10_92A	92	3.90%	0.93620	4.50%	0.92773
B10_96A	96	3.70%	0.93534	4.40%	0.93498
B10_100A	100	3.60%	0.93295	4.40%	0.93505
B9_74A[a]	74	3.70%	0.93575	4.30%	0.93223
B10_91A[a]	91	3.70%	0.92844	4.50%	0.93477
B10_92A[a]	92	3.80%	0.93488	4.50%	0.93570
B10_96A[a]	96	3.70%	0.93368	4.30%	0.93310
		86-Assembly Basket		Alternate 82-Assembly Basket	
B9_74A[b]	74	3.85%	0.93380	--	--
B10_91A[b]	91	--	--	4.55%	0.93220
B10_92A[b]	92	--	--	4.55%	0.93216

[a] Assemblies contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

[b] Evaluation results for the bounding case of full length and partial length rods.

Table 6.7.6-9 BWR System Generic Load Limits

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Loading (MTU)	87-Assy. Max Enrichment (wt % ^{235}U)	82-Assy Max Enrichment (wt % ^{235}U)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981	4.00%	4.50%
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034	3.80%	4.50%
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115	3.80%	4.50%
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828	3.90%	4.50%
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815	3.80%	4.50%
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841	3.80%	4.50%
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872	3.80%	4.50%
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921	3.80%	4.50%
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985	3.80%	4.50%
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017	3.80%	4.50%
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755	3.60%	4.30%
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803	3.80%	4.50%
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873	3.70%[b]	4.30%
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914	3.50%	4.20%
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000	3.70%	4.40%
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821	3.80%	4.50%
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906	3.70%	4.50%[c]
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966	3.80%	4.50%[c]
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787	3.70%	4.30%
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861	3.60%	4.40%

Note: Assembly characteristics represent cold, unirradiated, nominal configurations.

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[a] Assemblies contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

[b] 3.85% in the 86-assembly basket configuration.

[c] 4.55% in the alternate 82-assembly basket configuration.

Table 6.7.6-10 Absorber Tolerance Reactivity Change of BWR Models

Assembly Type	Maximum Enrichment 87 Assy.		Maximum Enrichment 82 Assy.	
	Δk	Δk/σ	Δk	Δk/σ
B7_48A	-0.00017	-0.16	-0.00016	-0.15
B7_49A	0.00116	1.12	0.00158	1.43
B7_49B	-0.00021	-0.20	0.00014	0.13
B8_59A	0.00062	0.62	-0.00026	-0.23
B8_60A	0.00045	0.41	0.00025	0.23
B8_60B	0.00057	0.54	-0.00018	-0.16
B8_61B	0.00009	0.09	0.00140	1.28
B8_62A	0.00123	1.14	0.00115	1.05
B8_63A	-0.00018	-0.17	0.00122	1.12
B8_64A	-0.00013	-0.12	-0.00046	-0.42
B8_64B	0.00005	0.05	-0.00049	-0.46
B9_72A	0.00009	0.09	-0.00023	-0.22
B9_74A	0.00000	0.00	0.00121	1.11
B9_76A	0.00130	1.23	0.00114	1.03
B9_79A	-0.00023	-0.22	0.00035	0.33
B9_80A	0.00009	0.08	-0.00010	-0.09
B10_91A	0.00016	0.16	-0.00037	-0.33
B10_92A	0.00096	0.89	0.00010	0.09
B10_96A	0.00047	0.45	0.00094	0.89
B10_100A	-0.00096	-0.94	0.00193	1.77
Partial Length Rods				
B9_74A	0.00139	1.35	0.00192	1.81
B10_91A	0.00124	1.19	0.00058	0.54
B10_92A	0.00161	1.57	-0.00002	-0.02
B10_96A	0.00006	0.06	0.00017	0.16

Table 6.7.6-11 BWR System Tube Location Study Summary

Configuration			Δk/σ from Baseline Square Tube @ 45°		
Tube	Tube Location	Grind	Average	Minimum	Maximum
Square	45°	Even	--		
Square	45°	Biased	0.9	-1.8	3.0
Square	Shift	Even	-1.1	-3.0	2.1
Square	Shift	Biased	0.2	-3.0	2.5
Rectangular	Shift	Even	N/A		
Rectangular	Shift	Biased	-8.7	-14.1	-5.0

Table 6.7.6-12 BWR System Tube Location Study Detail – Baseline to Square Tube/Biased Grind/45° Alignment

Assembly Type	87 Assy (wt% ^{235}U)	Δk/σ	82 Assy (wt% ^{235}U)	Δk/σ
B7_48A	4.00%	1.2	4.50%	0.6
B7_49A	3.80%	2.0	4.50%	2.7
B7_49B	3.80%	1.7	4.50%	1.2
B8_59A	3.90%	2.3	4.50%	0.2
B8_60A	3.80%	-0.6	4.50%	1.5
B8_60B	3.80%	2.5	4.50%	-0.5
B8_61B	3.80%	1.4	4.50%	2.9
B8_62A	3.80%	2.0	4.50%	3.0
B8_63A	3.80%	1.2	4.50%	0.2
B8_64A	3.80%	1.5	4.50%	0.7
B8_64B	3.60%	1.2	4.30%	0.6
B9_72A	3.80%	-0.4	4.50%	2.3
B9_74A	3.70%	1.7	4.40%	1.1
B9_76A	3.50%	1.9	4.20%	2.9
B9_79A	3.70%	0.1	4.40%	0.8
B9_80A	3.80%	2.7	4.50%	0.7
B10_91A	3.80%	1.2	4.50%	0.1
B10_92A	3.90%	2.9	4.50%	-0.8
B10_96A	3.70%	1.2	4.40%	0.8
B10_100A	3.60%	-1.1	4.40%	1.8
B9_74A	3.70%	1.1	4.30%	2.0
B10_91A	3.70%	2.2	4.50%	1.7
B10_92A	3.80%	2.0	4.50%	0.7
B10_96A	3.70%	1.3	4.30%	-0.2

Table 6.7.6-13 BWR Fuel Assembly Loading Criteria (Enrichment Limits)

	Max. Initial Enrichment[a] (wt % ^{235}U)					
	Absorber[b] 0.027 ^{10}B g/cm^2		Absorber 0.0225 ^{10}B g/cm^2		Absorber 0.02 ^{10}B g/cm^2	
	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket	87-Assy Basket	82-Assy Basket
B7_48A	4.0%	4.5%	3.7%	4.5%	3.6%	4.4%
B7_49A	3.8%	4.5%	3.6%	4.4%	3.5%	4.3%
B7_49B	3.8%	4.5%	3.6%	4.4%	3.5%	4.2%
B8_59A	3.9%	4.5%	3.7%	4.5%	3.6%	4.3%
B8_60A	3.8%	4.5%	3.7%	4.4%	3.5%	4.2%
B8_60B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_61B	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_62A	3.8%	4.5%	3.6%	4.3%	3.5%	4.1%
B8_63A	3.8%	4.5%	3.6%	4.3%	3.4%	4.2%
B8_64A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B8_64B	3.6%	4.3%	3.4%	4.1%	3.3%	4.0%
B9_72A	3.8%	4.5%	3.6%	4.3%	3.4%	4.1%
B9_74A	3.7%[c]	4.3%	3.4%	4.1%	3.4%	4.0%
B9_76A	3.5%	4.2%	3.4%	4.0%	3.3%	3.9%
B9_79A	3.7%	4.4%	3.4%	4.2%	3.3%	4.0%
B9_80A	3.8%	4.5%	3.6%	4.3%	3.5%	4.2%
B10_91A	3.7%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_92A	3.8%	4.5%[d]	3.6%	4.3%	3.5%	4.1%
B10_96A	3.7%	4.3%	3.5%	4.1%	3.4%	4.0%
B10_100A	3.6%	4.4%	3.5%	4.1%	3.4%	4.0%

[a] Maximum planar average.

[b] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

[c] 3.85% in the 86-assembly basket configuration.

[d] 4.55% in the alternate 82-assembly basket configuration.

6.7.7 Critical Benchmarks

From the International Handbook of Evaluated Criticality Safety Benchmark Experiments [8], 186 experiments are selected as basis of the MCNP benchmarking. Experiments were selected for compatibility of materials and geometry with the spent fuel casks. Of particular interest are benchmarks with rectangular arrays of low enriched uranium oxide fuel rods in which reactivity is controlled by soluble boron or borated plates (tubes).

MCNP benchmark cases represent a collection of files composed of inputs directly obtained from references (with cross-section sets adjusted to those used in the cask analysis), NAC modified input files representing unique geometries based on reference input files, and input files constructed from the experimental material and geometry information. All cases were reviewed on a "preparer/checker" principle for modeling consistency with the cask models and the choice of code options. Due to large variations in the benchmark complexities, not all options employed in the cask models are reflected in each of the benchmarks (e.g., UNIVERSE structure). A review of the criticality results did not indicate any result trend due to particular modeling choices (e.g., using the UNIVERSE structure versus a single universe, or employing KSRC versus SDEF sampling).

Key system parameters, the experimental uncertainty, and calculated k_{eff} and σ for each experiment are shown in Table 6.7.7-1. Stochastic Monte Carlo error is kept within ±0.2% and each output is checked to assure that the MCNP build-in statistical checks on the results are passed and that all fissile material is sampled.

Scatter plots of k_{eff} versus system parameters for 183 data point sets (full set minus three high lethargy points above 0.35 eV) are created (see Figure 6.7.7-1 through Figure 6.7.7-9). Included in these scatter plots are linear regression lines with a corresponding correlation coefficient (R^2) to statistically indicate any trend or lack thereof. Scatter plates are created for k_{eff} versus the following.

Enrichment in ^{235}U (wt % ^{235}U)
Fuel rod pitch (cm)
Fuel pellet outer diameter (cm)
Fuel rod outer diameter (cm)
Hydrogen/uranium (^{235}U) atom ratio
Soluble boron (ppm by weight)
Cluster gap spacing (spacing between assemblies in cm)
Boron (^{10}B) plate loading (g/cm^2)
Energy of average neutron lethargy causing fission (eV)

Figure 6.7.7-1 k_{eff} versus Fuel Enrichment

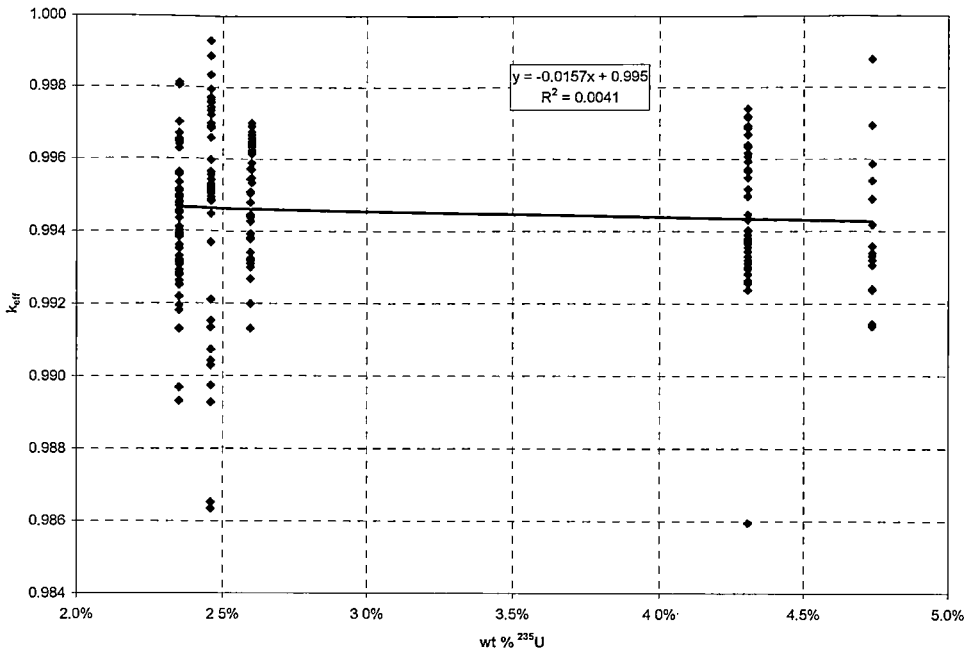


Figure 6.7.7-2 k_{eff} versus Rod Pitch

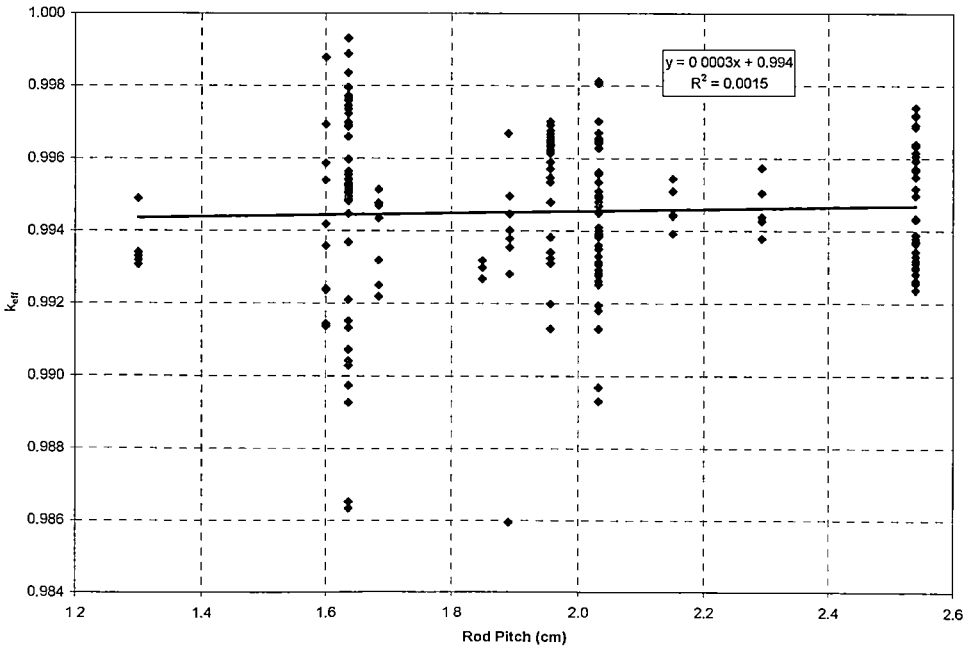


Figure 6.7.7-3 k_{eff} versus Fuel Pellet Diameter

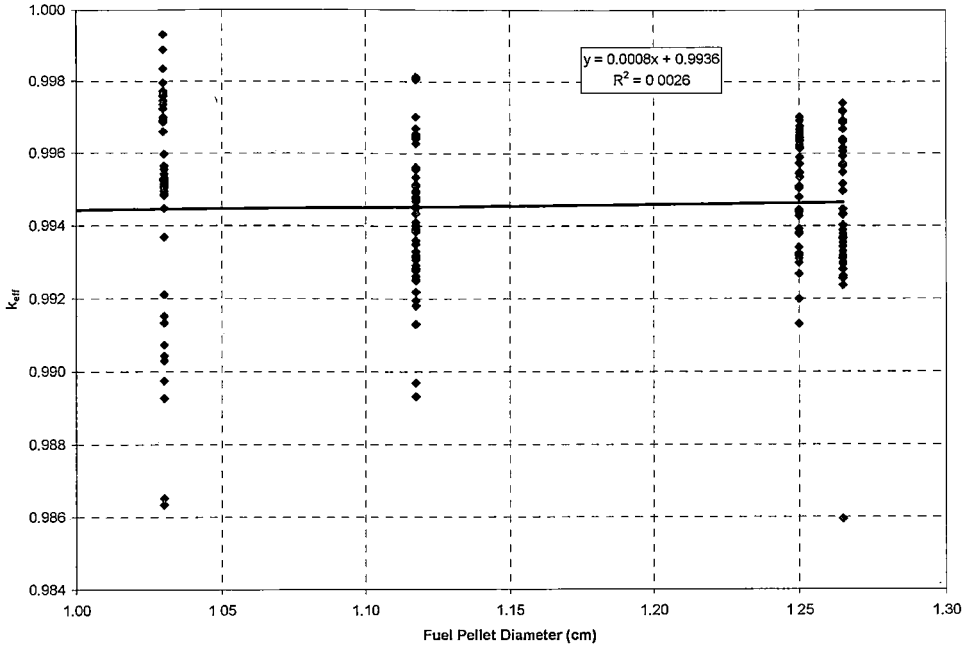


Figure 6.7.7-4 k_{eff} versus Fuel Rod Outside Diameter

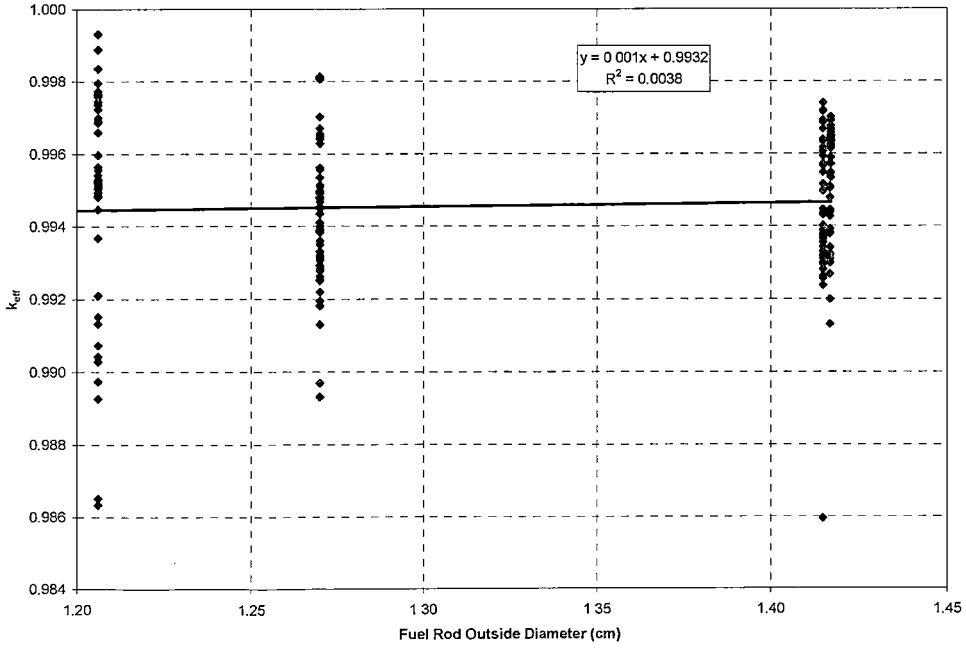


Figure 6.7.7-5 k_{eff} versus Hydrogen/^{235}U Atom Ratio

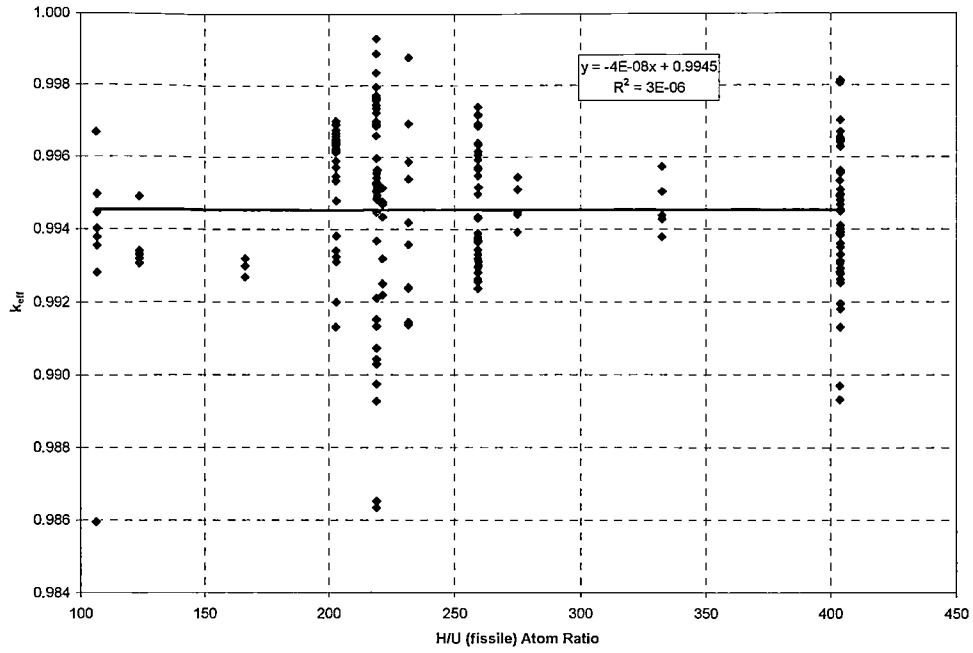


Figure 6.7.7-6 k_{eff} versus Soluble Boron Concentration

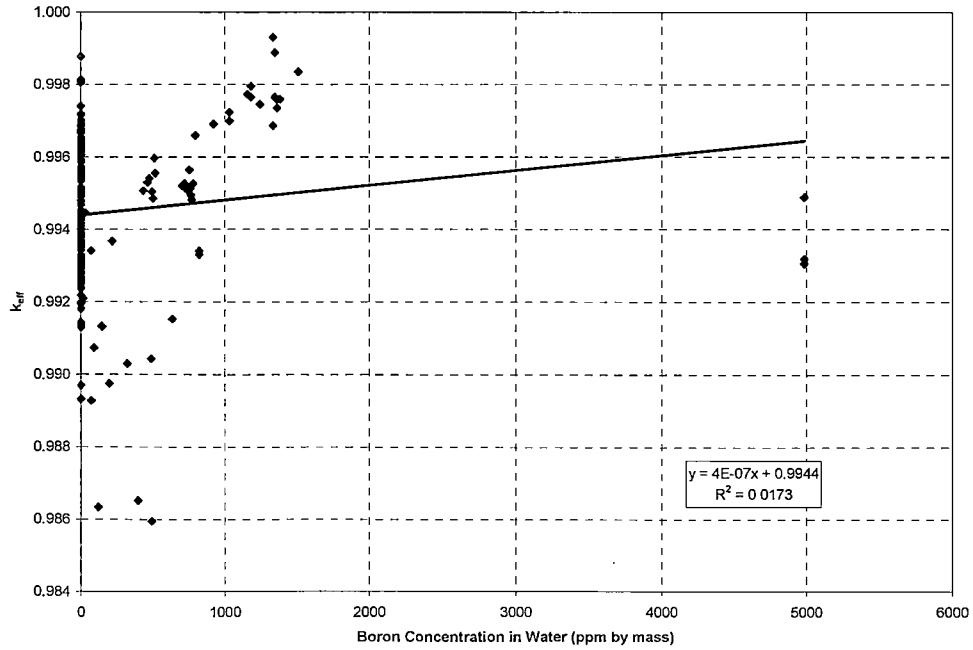


Figure 6.7.7-7 k_{eff} versus Cluster Gap Thickness

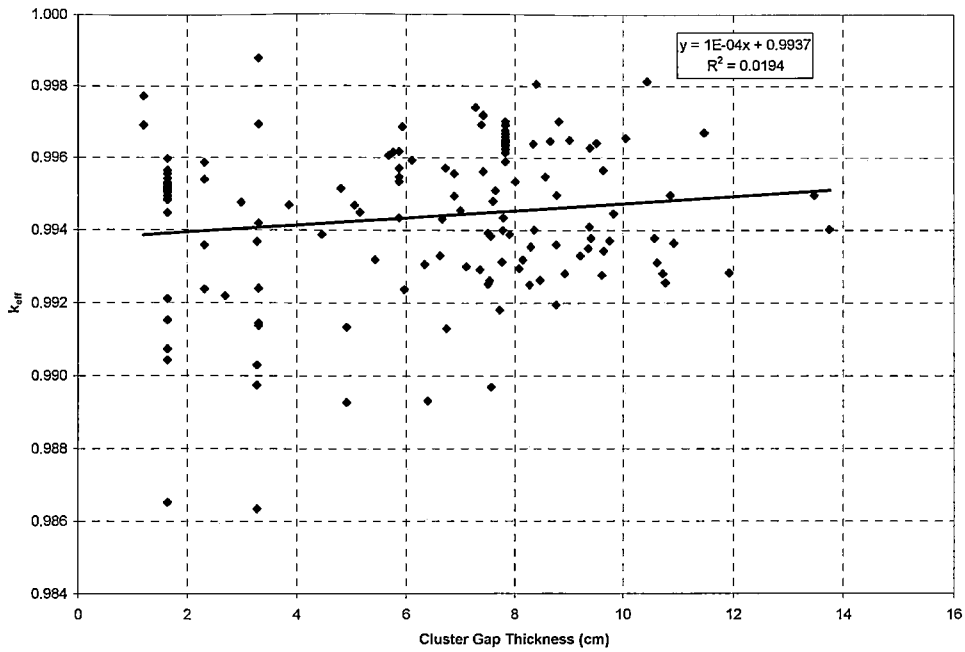


Figure 6.7.7-8 k_{eff} versus ^{10}B Plate Loading

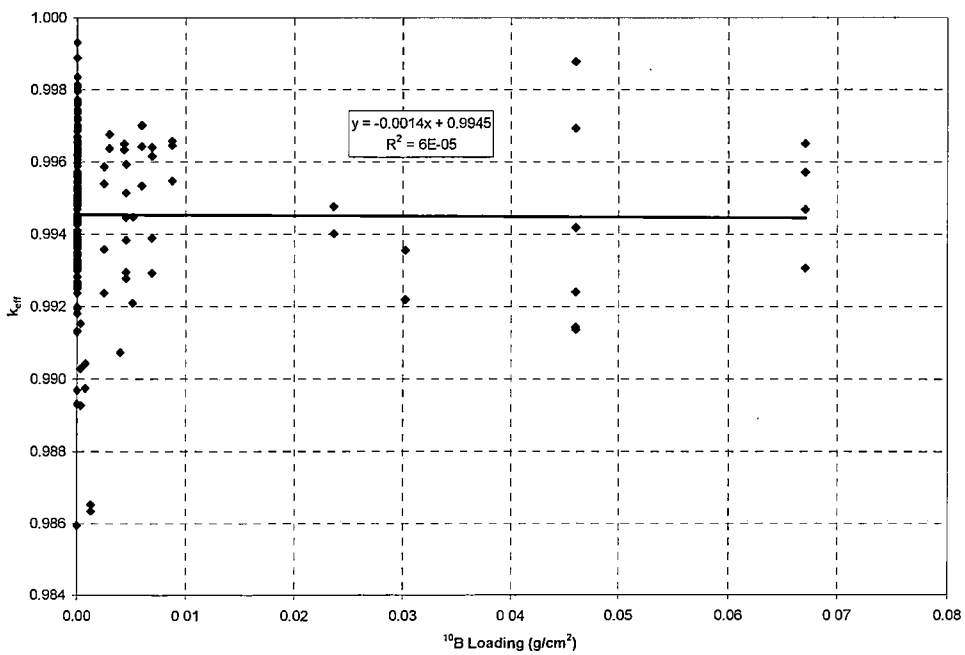


Figure 6.7.7-9 k_{eff} versus Energy of Average Neutron Lethargy Causing Fission

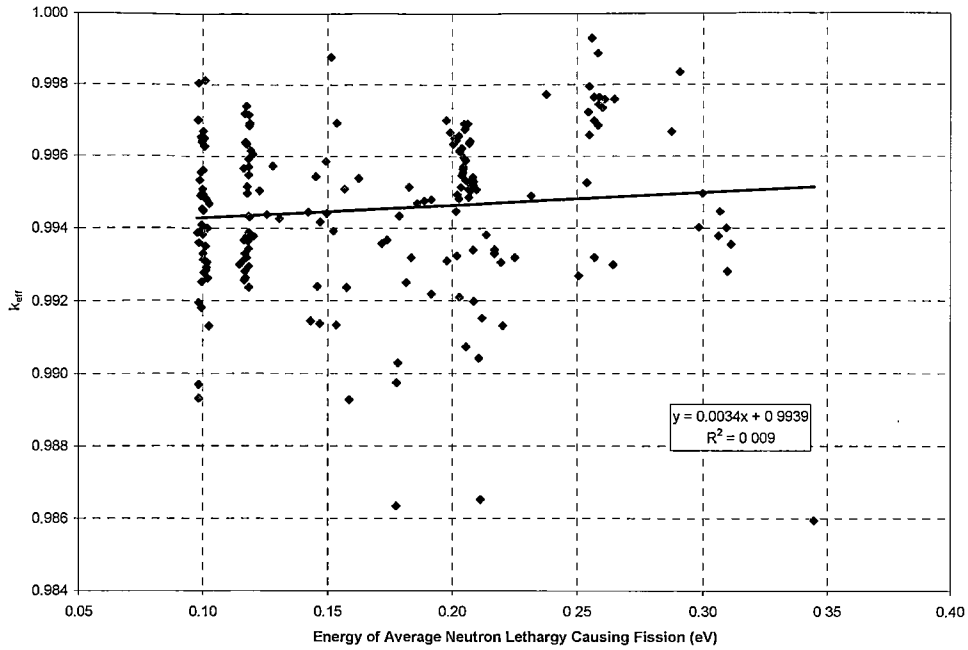


Table 6.7.7-1 MCNP Validation Statistics

Case	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Clusters	1	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Mat'l	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	11.9	8.4	10.1	6.4	8.0	4.5	7.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-
EALCF (MeV)	9.916E-8	1.010E-7	9.838E-8	9.933E-8	9.837E-8	9.874E-8	9.781E-8	9.826E-8
Exp. σ	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0031	0.0030
k_{eff}	0.99491	0.99283	0.99806	0.99655	0.98931	0.99534	0.99388	0.98969
σ	0.00165	0.00155	0.00155	0.00165	0.00169	0.00162	0.00150	0.00152

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	2.01	2.02	2.03	2.04	2.05
Clusters	1	1	1	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	10.6	7.1
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	1.177E-7	1.164E-7	1.175E-7	1.161E-7	1.146E-7
Exp. σ	0.0020	0.0020	0.0020	0.0018	0.0019
k_{eff}	0.99516	0.99367	0.99634	0.99311	0.99300
σ	0.00195	0.00157	0.00190	0.00193	0.00161

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	6.01	6.02	6.03	6.04	6.05	6.06	6.07	6.08	6.09
Clusters	1	1	1	1	1	1	1	1	1
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.849	1.849	1.849	1.956	1.956	1.956	1.956	1.956	2.150
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	166	166	166	203	203	203	203	203	275
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	2.506E-7	2.568E-7	2.642E-7	1.915E-7	1.978E-7	2.018E-7	2.085E-7	2.136E-7	1.422E-7
Exp. σ	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
k_{eff}	0.99268	0.99319	0.99299	0.99479	0.99310	0.99324	0.99199	0.99382	0.99445
σ	0.00065	0.00076	0.00074	0.00074	0.00069	0.00070	0.00071	0.00071	0.00069

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18
Clusters	1	1	1	1	1	1	1	1	1
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	2.150	2.150	2.150	2.150	2.293	2.293	2.293	2.293	2.293
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	275	275	275	275	332	332	332	332	332
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	1.453E-7	1.496E-7	1.523E-7	1.568E-7	1.202E-7	1.227E-7	1.257E-7	1.280E-7	1.306E-7
Exp. σ	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
k_{eff}	0.99544	0.99441	0.99392	0.99509	0.99378	0.99504	0.99438	0.99573	0.99427
σ	0.00073	0.00071	0.00078	0.00076	0.00070	0.00075	0.00067	0.00070	0.00076

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	8.01	8.02	8.03	8.04	8.05	8.06	8.07	8.08
Clusters	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3
Enrichment (wt % ^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219
Soluble B (ppm)	1511	1336	1336	1182	1182	1033	1033	794
Absorber Type	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g ^{10}B /cm^2)	-	-	-	-	-	-	-	-
EALCF (MeV)	2.907E-7	2.583E-7	2.559E-7	2.548E-7	2.566E-7	2.568E-7	2.544E-7	2.548E-7
Exp. σ	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
k_{eff}	0.99835	0.99686	0.99931	0.99795	0.99765	0.99699	0.99723	0.99659
σ	0.00060	0.00063	0.00032	0.00063	0.00069	0.00061	0.00066	0.00073

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	8.09	8.10	8.11	8.12	8.13	8.14	8.15	8.16	8.17
Clusters	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	5	5 x 5
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	779	1245	1384	1348	1348	1363	1363	1158	921
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	1.2	1.2
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	2.538E-7	2.586E-7	2.647E-7	2.587E-7	2.582E-7	2.600E-7	2.609E-7	2.379E-7	2.063E-7
Exp. σ	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
k_{eff}	0.99526	0.99745	0.99759	0.99765	0.99888	0.99735	0.99758	0.99772	0.99691
σ	0.00072	0.00065	0.00068	0.00065	0.00070	0.00067	0.00071	0.00070	0.00062

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	9.01	9.02	9.03	9.04	9.05	9.06	9.07	9.08	9.09	9.10	9.11	9.12	9.13
Clusters	3	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259	259	259	259	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (1.05% B)	304L SS (1.05% B)	304L SS (1.62% B)	304L SS (1.62% B)	Boral	Cu	Cu	Cu	Cu
Cluster Gap (cm)	8.6	9.7	9.2	9.8	6.1	8.1	5.8	7.9	6.7	8.2	9.4	8.5	9.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	0.00000	0.00000	0.00000	0.00455	0.00455	0.00690	0.00690	0.06704	-	-	-	-
EALCF(MeV)	1.183E-7	1.181E-7	1.168E-7	1.179E-7	1.182E-7	1.182E-7	1.191E-7	1.182E-7	1.183E-7	1.173E-7	1.176E-7	1.169E-7	1.163E-7
Exp. σ	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
k_{eff}	0.99548	0.99343	0.99330	0.99371	0.99593	0.99295	0.99616	0.99389	0.99571	0.99319	0.99378	0.99263	0.99566
σ	0.00191	0.00182	0.00187	0.00192	0.00174	0.00193	0.00198	0.00175	0.00209	0.00153	0.00178	0.00191	0.00177

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	9.14	9.15	9.16	9.17	9.18	9.19	9.20	9.21	9.22	9.23	9.24	9.25	9.26	9.27
Clusters	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259	259	259	259	259	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	Cu (0.989 wt % Cd)	Cu (0.989 wt % Cd)	Cd	Cd	Cd	Cd	Cd	Cd	Cd	Cd	Al (no B)	Al (no B)	Zircaloy-4	Zircaloy-4
Cluster Gap (cm)	6.7	8.4	5.9	7.4	6.0	7.4	5.9	7.4	5.7	7.3	10.7	10.8	10.9	10.9
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-	-	0.00000	0.00000	-	-
EALCF(MeV)	1.186E-7	1.171E-7	1.186E-7	1.183E-7	1.183E-7	1.168E-7	1.182E-7	1.187E-7	1.199E-7	1.173E-7	1.167E-7	1.165E-7	1.181E-7	1.177E-7
Exp. σ	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
k_{eff}	0.99431	0.99639	0.99686	0.99716	0.99237	0.99719	0.99434	0.99692	0.99606	0.99740	0.99281	0.99256	0.99365	0.99497
σ	0.00188	0.00207	0.00183	0.00166	0.00194	0.00187	0.00179	0.00183	0.00189	0.00206	0.00168	0.00197	0.00197	0.00193

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	11.03	11.04	11.05	11.06	11.07	11.08	11.09
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219
Soluble B (ppm)	769	764	762	753	739	721	702
Absorber Type	-	-	-	-	-	-	-
Cluster Gap (cm)	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-
EALCF [MeV]	2.027E-7	2.020E-7	2.035E-7	2.044E-7	2.065E-7	2.068E-7	2.085E-7
Exp. σ	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032
k_{eff}	0.99482	0.99494	0.99514	0.99564	0.99508	0.99526	0.99520
σ	0.00031	0.00030	0.00030	0.00030	0.00031	0.00030	0.00031

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	13.01	13.02	13.03	13.04	13.05	13.06	13.07
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	1.892	1.892	1.892	1.892	1.892	1.892	1.892
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	107	107	107	107	107	107	107
Soluble B (ppm)	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (1.05% B)	Boral B	Boroflex	Cd	Cu	Cu (0.989 wt % Cd)
Cluster Gap (cm)	13.8	9.8	8.3	8.4	8.9	13.5	10.6
Reflector	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Plate Loading (g^{10}B /cm^2)	0.00000	0.00455	0.03022	0.02361	-	-	-
EALCF (MeV)	2.982E-7	3.068E-7	3.111E-7	3.094E-7	3.097E-7	2.998E-7	3.061E-7
Exp. σ	0.0018	0.0018	0.0018	0.0018	0.0032	0.0018	0.0018
k_{eff}	0.99402	0.99446	0.99355	0.99401	0.99281	0.99496	0.99378
σ	0.00068	0.00064	0.00064	0.00064	0.00066	0.00063	0.00062

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	14.01	14.02	14.05	14.06	14.07
Clusters	1	1	1	1	1
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	1.890	1.890	1.890	1.715	1.715
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al
H/U (fissile)	106	106	106	73	73
Soluble B (ppm)	0	491	2539	0	1030
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	2.873E-7	3.447E-7	6.003E-7	5.175E-7	7.722E-7
Exp. σ	0.0019	0.0077	0.0069	0.0033	0.0051
k_{eff}	0.99668	0.98595	1.00221	1.00245	0.99973
σ	0.00044	0.00045	0.00043	0.00045	0.00044

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.01	16.02	16.03	16.04	16.05	16.06	16.07	16.08	16.09	16.10
Clusters	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (1.05% B)	304L SS (1.05% B)	304L SS (1.62% B)
Cluster Gap (cm)	6.9	7.6	7.5	7.4	7.8	10.4	11.5	7.6	9.6	7.4
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading ($g^{10}B/cm^2$)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00455	0.00455	0.00690
EALCF (MeV)	1.000E-7	9.983E-8	9.947E-8	1.001E-7	1.002E-7	1.009E-7	1.001E-7	9.993E-8	1.004E-7	1.012E-7
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99494	0.99509	0.99252	0.99562	0.99313	0.99813	0.99670	0.99383	0.99277	0.99292
σ	0.00171	0.00153	0.00157	0.00162	0.00173	0.00179	0.00175	0.00172	0.00157	0.00162

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.11	16.12	16.13	16.14	16.15	16.16	16.17	16.18	16.19	16.20	16.21	16.22
Clusters	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch(cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (1.62% B)	Boral	Boral	Boral	Cu	Cu	Cu	Cu	Cu	Cu (0.989 wt % Cd)	Cd	Cd
Cluster Gap (cm)	9.5	6.3	9.0	5.1	6.6	7.7	7.5	6.9	7.0	5.2	6.7	7.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading ($g^{10}B/cm^2$)	0.00690	0.06704	0.06704	0.06704	-	-	-	-	-	-	-	-
EALCF (MeV)	9.962E-8	1.016E-7	1.006E-7	1.025E-7	1.000E-7	9.944E-8	9.904E-8	9.919E-8	9.971E-8	1.001E-7	1.024E-7	1.014E-7
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99641	0.99306	0.99650	0.99468	0.99330	0.99181	0.99392	0.99556	0.99454	0.99449	0.99130	0.99480
σ	0.00154	0.00161	0.00152	0.00162	0.00157	0.00153	0.00155	0.00172	0.00165	0.00155	0.00166	0.00157

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.23	16.24	16.25	16.26	16.27	16.28	16.29	16.30	16.31	16.32
Clusters	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch(cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-
Absorber Type	Cd	Cd	Cd	Cd	Cd	Al (no B)	Al (no B)	Al (no B)	Zircaloy-4	Zircaloy-4
Cluster Gap cm)	9.4	7.8	9.4	7.5	9.4	8.7	8.8	8.8	8.8	8.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	0.00000	0.00000	0.00000	-	-
EALCF (MeV)	1.010E-7	1.018E-7	1.006E-7	1.019E-7	9.948E-8	9.991E-8	9.843E-8	9.807E-8	9.964E-8	9.834E-8
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99350	0.99400	0.99628	0.99262	0.99410	0.99647	0.99360	0.99702	0.99497	0.99195
σ	0.00184	0.00152	0.00169	0.00151	0.00168	0.00166	0.00157	0.00160	0.00163	0.00172

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	35.01	35.02	40.01	40.02	40.03	40.04	40.05	40.06	40.07	40.08	40.09	40.10
Clusters	1	1	4	4	4	4	4	4	4	4	4	4
Enrichment (wt %^{235}U)	2.60%	2.60%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%
Pitch (cm)	1.956	1.956	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Fuel OD (cm)	1.250	1.250	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790
Clad OD (cm)	1.417	1.417	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940
Clad Material	Al	Al	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy
H/U (fissile)	203	203	231	231	231	231	231	231	231	231	231	231
Soluble B (ppm)	70	148	-	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Boral	Boral	Boral	Boral	Boral	Boral
Cluster Gap (cm)	-	-	2.3	2.3	2.3	2.3	3.3	3.3	3.3	3.3	3.3	3.3
Reflector	H_2O	H_2O	H_2O	Lead	Lead	Lead	H_2O	Lead	Lead	Lead	Steel	Steel
Plate Loading (g^{10}B /cm^2)	-	-	0.00252	0.00252	0.00252	0.00252	0.04608	0.04608	0.04608	0.04608	0.04608	0.04608
EALCF (MeV)	2.170E-7	2.202E-7	1.493E-7	1.717E-7	1.625E-7	1.576E-7	1.432E-7	1.515E-7	1.470E-7	1.459E-7	1.537E-7	1.469E-7
Exp. σ	0.0018	0.0019	0.0039	0.0041	0.0041	0.0041	0.0042	0.0044	0.0044	0.0044	0.0046	0.0046
k_{eff}	0.99341	0.99131	0.99586	0.99358	0.99539	0.99237	0.99144	0.99878	0.99418	0.99240	0.99693	0.99137
σ	0.00070	0.00078	0.00195	0.00192	0.00203	0.00194	0.00193	0.00196	0.00224	0.00216	0.00190	0.00208

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	42.01	42.02	42.03	42.04	42.05	42.06	42.07
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	1.684	1.684	1.684	1.684	1.684	1.684	1.684
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Materiall	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	221	221	221	221	221	221	221
Soluble B (ppm)	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (1.05% B)	Boral B	Boroflex	Cd	Cu	Cu-Cd
Cluster Gap (cm)	8.3	4.8	2.7	3.0	3.9	7.8	5.4
Reflector	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Plate Loading (g^{10}B /cm^2)	0.00000	0.00455	0.03022	0.02361	-	-	-
EALCF (MeV)	1.813E-7	1.824E-7	1.915E-7	1.887E-7	1.857E-7	1.786E-7	1.833E-7
Exp. σ	0.0016	0.0016	0.0016	0.0017	0.0033	0.0016	0.0018
k_{eff}	0.99250	0.99514	0.99219	0.99476	0.99469	0.99434	0.99319
σ	0.00171	0.00183	0.00169	0.00169	0.00161	0.00191	0.00157

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	50.03	50.03	50.03	50.03	50.03
Clusters	1	1	1	1	1
Enrichment (wt %^{235}U)	4.74%	4.74%	4.74%	4.74%	4.74%
Pitch (cm)	1.300	1.300	1.300	1.300	1.300
Fuel OD (cm)	0.790	0.790	0.790	0.790	0.790
Clad OD (cm)	0.940	0.940	0.940	0.940	0.940
Clad Material	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy
H/U (fissile)	124	124	124	124	124
Soluble B (ppm)	821	821	4986	4986	4986
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	2.170E-7	2.083E-7	2.318E-7	2.252E-7	2.195E-7
Exp. σ	0.0010	0.0010	0.0010	0.0010	0.0010
k_{eff}	0.99330	0.99340	0.99489	0.99319	0.99306
σ	0.00080	0.00071	0.00075	0.00075	0.00080

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	51.01	51.02	51.03	51.04	51.05	51.06	51.07	51.08	51.09
Clusters	9	9	9	9	9	9	9	9	9
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	143	510	514	501	493	474	462	432	217
Absorber Type	none	SS	SS	SS	SS	SS	SS	SS	SS
Cluster Gap (cm)	4.9	1.6	1.6	1.6	1.6	1.6	1.6	1.6	3.3
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	-	-	-	-	-	-	-	-
EALCF (MeV)	1.535E-7	2.045E-7	2.043E-7	2.067E-7	2.074E-7	2.083E-7	2.085E-7	2.098E-7	1.737E-7
Exp. σ	0.0020	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0019
k_{eff}	0.99133	0.99597	0.99555	0.99486	0.99504	0.99542	0.99530	0.99507	0.99368
σ	0.00033	0.00035	0.00033	0.00034	0.00034	0.00034	0.00034	0.00034	0.00033

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	51.10	51.11	51.12	51.13	51.14	51.15	51.16	51.17	51.18	51.19
Clusters	9	9	9	9	9	9	9	9	9	9
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	15	28	92	395	121	487	197	634	320	72
Absorber Type	B/Al Set 5	B/Al Set 5A	B/Al Set 4	B/Al Set 3	B/Al Set 3	B/Al Set 2	B/Al Set 2	B/Al Set 1	B/Al Set 1	B/Al Set 1
Cluster Gap (cm)	1.6	1.6	1.6	1.6	3.3	1.6	3.3	1.6	3.3	4.9
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading ($g^{10}B/cm^2$)	0.00517	0.00519	0.00403	0.00128	0.00128	0.00078	0.00078	0.00032	0.00032	0.00032
EALCF (MeV)	2.029E-7	2.015E-7	2.056E-7	2.112E-7	1.773E-7	2.106E-7	1.775E-7	2.119E-7	1.780E-7	1.587E-7
p. σ	0.0019	0.0019	0.0019	0.0022	0.0019	0.0024	0.0020	0.0027	0.0021	0.0019
keff	0.99210	0.99447	0.99073	0.98652	0.98634	0.99042	0.98974	0.99152	0.99029	0.98927
σ	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00035	0.00035

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	65.01	65.02	65.03	65.04	65.05	65.06	65.07	65.08
Clusters	2	2	2	2	2	2	2	2
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	203	203	203	203	203	203	203	203
Soluble B (ppm)	-	-	-	-	-	-	-	-
Absorber Type	none	304L SS (No B)	304L SS (0.67% B)	304L SS (0.98% B)	none	304L SS (No B)	304L SS (No B)	304L SS (No B)
Cluster Gap (cm)	5.9	5.9	5.9	5.9	7.8	7.8	7.8	7.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	0.00000	0.00599	0.00875	-	0.00000	0.00000	0.00000
EALCF [MeV]	2.045E-7	2.030E-7	2.054E-7	2.038E-7	2.049E-7	2.030E-7	2.055E-7	2.040E-7
Exp. σ	0.0014	0.0014	0.0015	0.0015	0.0014	0.0014	0.0014	0.0016
k_{eff}	0.99571	0.99618	0.99534	0.99547	0.99691	0.99614	0.99589	0.99624
σ	0.00023	0.00022	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	65.09	65.10	65.11	65.12	65.13	65.14	65.15	65.16	65.17
Clusters	2	2	2	2	2	2	2	2	2
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	203	203	203	203	203	203	203	203	203
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (No B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.98% B)	304L SS (0.98% B)	304L SS (0.98% B)	304L SS (0.98% B)
Cluster Gap (cm)	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	0.00299	0.00299	0.00599	0.00599	0.00438	0.00438	0.00875	0.00875
EALCF [MeV]	1.993E-7	2.050E-7	2.069E-7	2.072E-7	1.977E-7	2.010E-7	2.004E-7	2.027E-7	2.017E-7
Exp. σ	0.0015	0.0016	0.0016	0.0017	0.0016	0.0016	0.0016	0.0017	0.0016
k_{eff}	0.99667	0.99676	0.99637	0.99643	0.99701	0.99650	0.99634	0.99658	0.99645
σ	0.00022	0.00022	0.00023	0.00023	0.00022	0.00023	0.00023	0.00022	0.00023

6.7.8 PWR Damaged Fuel Criticality Evaluation

The system is designed to safely store up to 37 fuel assemblies of which up to four may be classified as damaged and placed in damaged fuel cans (DFCs) in the TSC corners as shown in Figure 6.1.1-2. The DFC provides a screened container to prevent gross fissile material release into the TSC cavity from gross fuel rod clad failure.

The method used in the PWR damaged fuel criticality evaluation is as follows:

- Justify that maximum reactivity configuration for undamaged fuel applies to the damaged fuel configuration.
- Establish the maximum reactivity configuration for damaged fuel.
- Evaluate the optimum moderator density considering partial flooding of the canister and preferential flooding of the DFC.
- Demonstrate that the reactivity for the maximum reactivity damaged fuel configuration remains below the USL.

6.7.8.1 Model Details

Each DFC is comprised of a stainless steel rectangular box with a screened lid and bottom plate structure. The DFC is designed to freely drain and fill, thereby avoiding the potential of preferentially flooding the DFC.

DFC contents included in these evaluations are:

- Undamaged clad fuel assemblies with functional grids (i.e., fuel assemblies retaining clad and fuel rods in their as-designed configuration);
- A hypothetical fuel configuration, where the clad is conservatively removed from the model and rods are allowed to achieve increased pitch; and
- A homogenized fuel/water mixture model.

The unclad array fuel assemblies are modeled with no clad or end-fitting. Homogenized fuel is modeled as a simple rectangular volume with the optimal mixture height determined in the analysis. Material composition is then calculated based on the fuel mass within the DFC, the DFC cross-sectional area, and the moderator density within the mixture volume.

Within the unclad array calculations, a "missing fuel rod" study is included that considers the removal of fuel pellets/fuel material. Since the system relies on borated water as the supplemental absorber to the neutron absorber plates in the basket, removal of fuel rods not only decreases fissile material mass, but also inserts additional absorber into the system. These phenomena assure that a "missing rod" configuration is bounded.

Note that a floating array of fuel pellets, or a homogeneous mixture of water and fuel, represents a conservative physical configuration of the fuel material in the DFC. At a density of 10.5 g/cm^3, the uranium oxide fissile material has 10 times the density of the water moderator and would settle to the bottom of the DFC once released from the clad. There is no mechanism in the system that would allow moderator incursion at flow rates sufficient to re-suspend a significant amount of the material. As low enriched uranium requires moderator to reach k_{eff} levels near the USL, a collapsed fuel material would result in lower system reactivity.

The damaged fuel basket differs from the undamaged fuel basket in that the four corner assembly locations are weldments rather than standard fuel tubes. The weldment openings are slightly larger than the standard fuel tube in order to accommodate the damaged fuel can. Neutron absorber width is increased to account for the larger opening. The increased absorber width avoids an increase in any neutron streaming through absorber gaps from that considered in the undamaged basket. A sketch of a cross-section of the damaged fuel basket is shown in Figure 6.7.8-1.

6.7.8.2 Model Assumptions

Key assumptions for the analytical damaged fuel model are as follows.

- Analyses are performed with DFC heterogeneous fuel material located axially lined up with the undamaged fuel material. Assembly nozzles are expected to provide axial offset for any loose fuel material within the DFCs. DFCs are limited to one per quadrant. When the TSC is flooded, which presents the system maximum reactivity condition, there is no neutronic interaction between DFCs and no significant interaction between DFC contained material located outside the undamaged fuel region and the fissile material region of the undamaged assemblies. Mixture analysis, documented in Section 6.7.8.4, places DFC fuel material outside the undamaged fuel region and does not result in a reactivity increase.

- Tolerances on the 1.125-inch thick DFC inner formed plate and on the 0.750-inch thick DFC outer formed plate are not modeled. The DFC outer formed plate is on the sides of the DFC corner locations facing the periphery of the cask, and the DFC inner formed plate is on the sides of the DFC locations facing the interior of the cask. Based on the small magnitude of the plate critical tolerance, a possible 0.01-inch reduction, and the peripheral locations of the DFC weldments, application of these tolerances will not

significantly affect system reactivity. Increased plate thickness would add parasitic absorber to the system, while further separating fissile material masses and, therefore, does not represent a criticality concern.

6.7.8.3 Sample Input Files

Three sample damaged fuel basket input files are provided. Figure 6.7.8-2 contains an input file for an undamaged assembly loaded into the four DFCs. Figure 6.7.8-3 contains an input file for an unclad rod array input file without inserts. Figure 6.7.8-4 contains a mixture input file that is also partially flooded. In this input file, the flooded mixture elevation is at the top of the active fuel in the DFC.

6.7.8.4 Damaged Fuel Characterization

Starting with the most reactive basket configuration determined for undamaged fuel, various damaged fuel configurations are evaluated. Each DFC configuration is evaluated at 0.036, 0.030 and 0.027 g ^{10}B /cm^2 effective absorber densities with and without inserts in the fuel assembly guide tubes. Use of the maximum reactivity configuration for undamaged fuel as the baseline is appropriate because it maintains the most reactive configuration of the 33 undamaged fuel assemblies and minimizes the separation between the damaged fuel assemblies and the rest of the payload.

Clad Rods – Grid Undamaged

DFC evaluations are initiated by placing undamaged fuel assemblies into the DFC to demonstrate the effect of the additional stainless steel shell and thicker corner weldment. Undamaged rods within a nominal lattice/pitch configuration are identified by the acronym "IAA" in the DFC content description.

With all 37 assemblies modeled as undamaged at their limiting enrichments (see Section 6.7.3.2), the DFC and corner weldment material has no statisically significant effect on system reactivity with average reactivity changes of 0.44, 0.55 and 0.48 $\Delta k/\sigma$ for the 0.036, 0.030 and 0.027 g ^{10}B/cm^2 absorbers, respectively. Sample results for the 0.036 g ^{10}B/cm^2 without inserts are presented in Table 6.7.8-1. Similar to results of the undamaged fuel basket evaluations, the presence or absence of the inserts has no statistically significant effect on system performance.

As the undamaged fuel basket enrichment limits resulted in reactivties (eigenvalues) within a very small margin to the USL, the statistical nature of the Monte Carlo evaluation resulted in a limited number of enrichment/soluble boron/fuel type combinations exceeding the USL. The

maximum required reduction in enrichment for all combinations to remain below the USL is 0.1 wt % ^{235}U under the undamaged fuel basket limits.

The system is designed to allow loading of undamaged fuel assemblies into the four designated DFC locations in the DF basket assembly without the use of a DFC. The difference between this configuration and undamaged fuel in the DFC evaluated previously in this section is the presence of the 0.048-inch thick DFC wall. Given that the 1.125-inch inner wall plate separates DFC content from adjoining assemblies in both models, there is no expectation of statistically resolvable reactivity differences between models with and without a DFC. Evaluating each primary array type at 0.036 and 0.027 g/cm^2 ^{10}B concentration in the absorber sheets, with minimum (1500 ppm) and maximum (2500ppm) borated water concentrations, resulted in an absolute average change in reactivity of 0.30 $\Delta k/\sigma$. All cases remain under the USL of 0.9376. Loading of undamaged fuel into the four designated DFC locations in the DF basket assembly without a DFC is, therefore, acceptable.

Unclad Rods – Loose Pellet Stack

In this stage of the DFC evaluations, damaged fuel is postulated to lose its cladding and pellets are allowed to separate. As PWR assemblies are typically undermoderated, the removal of cladding, in conjunctions with pitch variations, has the potential to increase system reactivity. Pellet array pitch is allowed to increase until it fills the DFC opening. Clad removal and pitch modification affects system reactivity by varying moderator between fuel rods, therefore, changing neutron thermalization and utilization, while simultaneously varying the neutron absorber quantity in the form of soluble boron in the moderator. These are offsetting phenomena (i.e., increasing pitch increases the borated moderator quantity between fuel rods, which improves thermalization of fast fission neutron for absorption in the fuel, while also increasing the ^{10}B absorber quantity between rods and thereby reducing thermal neutron flux). As shown in Table 6.7.8-2, a sample analysis using the 0.036 g B^{10}/cm^2 absorber at a 2250 ppm soluble boron content, the result of the offsetting phenomena is that there is no statistically resolvable trend of pellet pitch to system reactivity (pitch indicated is either the nominal, as assembly design pitch, the maximum pitch allowed by the DFC opening, or the average pitch between nominal and maximum). As lower soluble boron shifts the trend towards increasing system reactivity as a function of increasing pitch, maximum pitch is applied to the remaining pellet evaluations.

Similar to the undamaged fuel assembly in the DFC evaluation, the loose pellets study results in no statistically significant change in system reactivity, with average reactivity changes of 0.57, 0.52, and 0.49 $\Delta k/\sigma$ for the 0.036, 0.030, and 0.027 g $^{10}B/cm^2$ absorbers, respectively. Sample results for the 0.036 g $^{10}B/cm^2$ without inserts are presented in Table 6.7.8-3.

As the undamaged fuel basket enrichment limits resulted in reactivties (eigenvalues) within a very small margin to the USL, the statistical nature of the Monte Carlo evaluation resulted in a limited number of enrichment/soluble boron/fuel type combinations exceeding the USL. The maximum required reduction in enrichment for all combinations to remain below the USL is 0.1 wt % ^{235}U under the undamaged fuel basket limits.

Included in the damaged fuel definition are fuel assemblies with fuel rods removed and not replaced by either fuel rods or inert rods. As the physical change in the system is similar to that of the clad removal and pitch evaluation, i.e., increasing the moderator quantity while adding absorber in the form of soluble boron, with the additional negative reactivity effect of removing fissile material, it is expected that this configuration is bounded by the reactivity of the undamaged fuel in the basket. The results presented in Table 6.7.8-4 for a sample evaluation at 1500 ppm (chosen to minimize the additional soluble boron added) demonstrate that the system behaves as expected, i.e., removal of fuel rods does not affect system reactivtity.

Fuel/Water Mixture

In addition to the heterogeneous (rod array) evaluations, a set of mixture analyses are run. Mixtures are designed to fill various heights of the DFC and simulate small fuel rubble inside the canister. Mixtures are assumed to fill the DFC from the DFC bottom plate up, which places fissile material below the neutron absorber (maximum exposure is less than 3 inches). Conservatively, the water-fuel mixture was modeled not to contain soluble boron.

The fuel mixture studies model fuel material at various material fractions, expressed as mixture height (i.e., fuel/water mixture height in DFC). At the lower bound, the material is modeled at a mixture height of 50% of the DFC (50% of DFC cavity height is 214 cm, which presents 40% collapse for a 144-inch [366-cm] typical active fuel height). At the upper bound, the fuel water mixture fills the DFC cavity. Mixtures are evaluated at 10% height increments. Water within the mixture is set to full density (0.9982 g/cm^3) in all base cases as moderator density scoping studies confirmed that maximum moderator density is bounding. This is confirmed in the optimum moderator density section of the analysis.

Each fuel type is evaluated as a function of mixture height at each effective absorber level, with and without the nonfuel insert in the undamaged fuel guide tube. Sample results for each primary fuel assembly array (e.g., WE15H1) at three of the soluble boron concentrations are listed in Table 6.7.8-5 at a 0.036 g ^{10}B /cm^2 effective absorber sheet. As demonstrated in this table, variations in the maximum allowed enrichment are primarily due to statistical variations from the Monte Carlo analysis, but do account for a slight increase in reactivity resulting from

the geometry and material change associated with the debris/mixture in the DFC. Maximum reactivites, allowed enrichments, and percent cavity height are summarized in sample Table 6.7.8-6 and Table 6.7.8-7 for the 0.036 g $^{10}B/cm^2$ absorber with and without insert. Similar tables are constructed for the remaining absorbers options to determine a complete matrix of allowable enrichments. Figure 6.7.8-5 contains an example of reactivity behavior as a function of mixture height at undamged fuel maximum allowed enrichment and at the reduced enrichment detemined to be acceptable for loading (note that not the fuel/water mixture, but the removal of soluble boron from the mixture is primarily responsible for the reduced enrichment required for these cases).

With the exception of the BW15H4 hybrid at the 0.027 g $^{10}B/cm^2$ effective absorber sheet density and 2500 ppm soluble boron, all loading combinations are found to be below the USL with either no or a 0.1% ^{235}U reduction in initial enrichment. The BW15H4 hybrid required a 0.2 wt% ^{235}U reduction at the 2500 ppm soluble boron, 0.027 g $^{10}B/cm^2$ sheet statepoint.

6.7.8.5 Optimum Moderation

Moderator density studies are performed on the preferentially flooded DFC, partially flooded cask, and mixture moderator density. Similar to the undamaged fuel analysis, a uniform reduction in moderator density reduces reactivity.

Preferential Flooding

Preferential flooding cases consider:

- TSC cavity is wet and the DFC moderator density varies
- TSC cavity is void (low density moderator) and the DFC moderator density varies
- TSC cavity varies with a wet DFC
- TSC cavity varies with a dry DFC

Results of these analysis, plotted in Figure 6.7.8-6 for the BW15H3 hybrid, clearly demonstrate that maximum system reactivity is achieved by a fully flooded TSC and DFC.

Partial Flooding

Within the scope of the moderator density evaluations is a partial drain-down of the TSC to the top of the active fuel, which is also called partial flooding. Draining the cask to the top of the active fuel region changes the axial reflection from the moderator to the steel TSC lid. The partial flooding study in Section 6.7.3.1 determined that there is no statistically significant reactivity change from the undamaged fuel assembly region due to partial flooding. Additional

evaluations are performed to address a drain-down of the DFC—in particular, when related to the fuel mixture cases, as the fissile material in this region may extend higher than the fissile material in the undamaged assemblies. Figure 6.7.8-7 indicates that partial DFC flooding in this region results in lower reactivity for mixture heights.

Mixture Moderator Density

Decreasing the density of the moderator in the mixture configuration lowers the system reactivity. This is summarized in Table 6.7.8-8 and Figure 6.7.8-8. The moderator in the TSC is left at a constant 0.9982 g/cc for this study. The highest reactivity is for a mixture with 0.9982 g/cc moderator in both the canister and DFC.

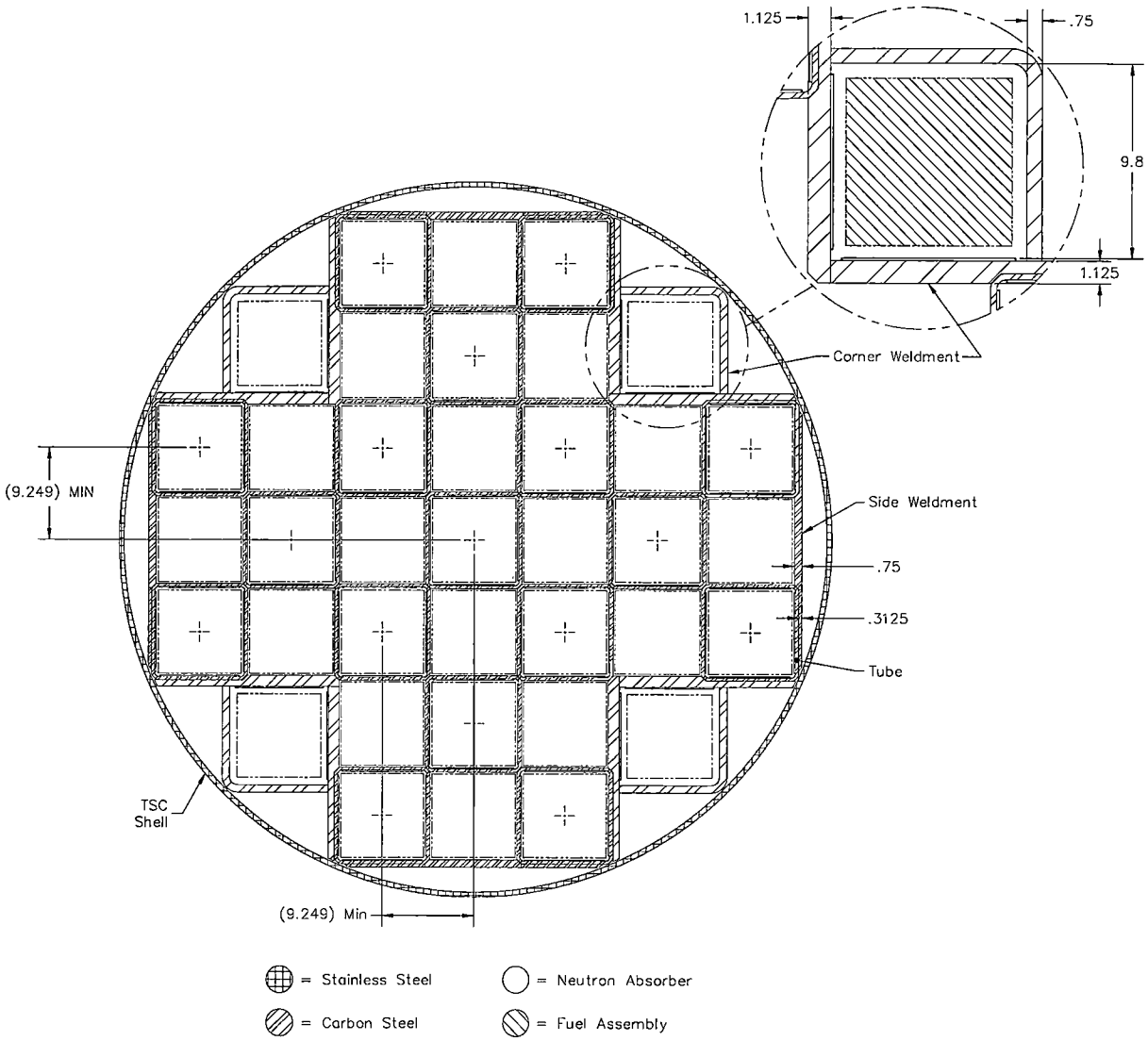
6.7.8.6 Storage Cask Evaluations

Each DFC content configuration (i.e., undamaged assembly, unclad pellets, fuel/water mixture) is evaluated to determine the maximum system reactivity in the storage cask (i.e., dry TSC configuration). At dry TSC conditions, system reactivity is determined by fast neutron fission versus a thermal fission spectrum in the wet TSC. At the fast fission spectrum in the dry TSC, minor variations in fuel geometry (i.e., location of fuel within the DFC or presence of neutron transparent zircaloy clad), or quantity of thermal neutron absorber in the basket sheets has no significant effect on system reactivity. The BW15H3 assembly was chosen for evaluation because it has the highest fuel mass, which is the fundamental consideration in a dry system. Results of this evaluation are shown in Table 6.7.8-9.

6.7.8.7 PWR Damaged Fuel Limiting Enrichments

Based on the results of the previous sections, limiting ^{235}U enrichments for effective ^{10}B loadings of 0.036, 0.030 and 0.027 g/cm^2 are summarized in Table 6.7.8-10. The listed enrichments bound undamaged fuel assemblies with and without nonfuel inserts. Nonfuel inserts are not expected to be loaded into DFCs.

Figure 6.7.8-1 PWR Damaged Fuel Basket



Note: All dimensions in inches.

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
Transfer Cask Model - CE14H1
c
c  MAGNASTOR Canister Class 1
c   Neutron Poison Loading -  75 %
c   Nominal Fuel Characteristics
c   Insert Configuration - Yes
c
c   Boron Content in Water - 1750 ppm
c   Cavity Water Density 1.0012 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Selected Partial Flood - No
c
c   Damaged Fuel Can Option - Yes
c   Damaged Fuel Can Configuration - IAA
c
c
c
c   Model Revision 4.90
c
c Cells - Fuel Rod - CE14H1 - CE Core - 14x14
1 1 -1.0522E+01 -1   u=13 $ Fuel
2 13 -0.9982 -2 +1  u=13 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=13 $ Clad + End Plugs
4 3 -1.0012 +3   u=13 $ Outside Fuel Rod
c Array_14x14_176
7 3 -1.0012 -7 +8 -9 +10
      trcl=(0.7366 0.7366 8.1399)   lat=1 u=12 fill=-7:6 -7:6 0:0
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 12 12 13 13 13 13 13 13 12 12 13 13
      13 13 12 12 13 13 13 13 13 13 12 12 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 12 12 13 13 13 13 13 13
      13 13 13 13 13 13 12 12 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 12 12 13 13 13 13 13 13 12 12 13 13
      13 13 12 12 13 13 13 13 13 13 12 12 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13
c Cells - Fuel Assembly Array Inserted Into Assembly - cellCEAssy
11 3 -1.0012 -11 #12 #13 #14 #15 #16 #17 #18 #19 #20 #21      fill=12 u=11 $ Array
12 2 -6.5600 -5  -11     u=11 $ Inside CE Guide
13 2 -6.56 -6 +5 -11     u=11 $ CE Guide Tube
14 like 12 but   *trcl=( 5.8928 5.8928 0.0000 )       u=11 $ Inside CE Guide
15 like 13 but   *trcl=( 5.8928 5.8928 0.0000 )       u=11 $ CE Guide Tube
16 like 12 but   *trcl=( -5.8928 5.8928 0.0000 )       u=11 $ Inside CE Guide
17 like 13 but   *trcl=( -5.8928 5.8928 0.0000 )       u=11 $ CE Guide Tube
18 like 12 but   *trcl=( 5.8928 -5.8928 0.0000 )       u=11 $ Inside CE Guide
19 like 13 but   *trcl=( 5.8928 -5.8928 0.0000 )       u=11 $ CE Guide Tube
20 like 12 but   *trcl=( -5.8928 -5.8928 0.0000 )       u=11 $ Inside CE Guide
21 like 13 but   *trcl=( -5.8928 -5.8928 0.0000 )       u=11 $ CE Guide Tube
22 3 -1.0012 -12 +11 -11.6 -11.5    u=11 $ Fuel Width Envelope
23 4 -2.4224 -12  +11.6     u=11 $ Lower Nozzle
24 5 -2.4439 -12   +11.5    u=11 $ Upper Nozzle
25 3 -1.0012 +12       u=11 $ Remaining Space
c Cell Cards - DFC
60 3 -1.0012 -60      u=10 $ DFC Cavity
61 6 -7.94 -61 +60     u=10 $ DFC Body
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
62 3 -1.0012 +61       u=10 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -1.965 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  -Y
103 12 -1.965 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  +Y
105 6 -7.940 -105 +215 +216   u=9 $ Retainer -Y
106 6 -7.940 -106 +215 +216   u=9 $ Retainer+Y
107 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber -Y
108 3 -1.0012 -102 #101  #102  #107   u=9 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber +Y
110 3 -1.0012 -104 #103  #104  #109   u=9 $ Gap Weld Post to Absorber +Y
111 12 -1.965 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber -X
112 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  -X
113 12 -1.965 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber +X
114 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  +X
115 6 -7.940 -221 +331 +332   u=9 $ Retainer -X
116 6 -7.940 -222 +331 +332   u=9 $ Retainer+X
117 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber -X
118 3 -1.0012 -218 #111  #112  #117   u=9 $ Gap Weld Post to Absorber -X
119 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber
120 3 -1.0012 -220 #113  #114  #119   u=9 $ Gap Weld Post to Absorber +X
121 3 -1.0012 -333
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
       +102 +104 #105 #106
       +218 +220 #115 #116      u=9 $ Space in Tube
122 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=9 $ Fuel
Tube
123 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=9 $ Fuel Tube Weld Posts
124 3 -1.0012 -334 +333  #122  #123
             u=9 $ Space Around Weld Posts
125 3 -1.0012 +333 +334    u=9 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -1.965 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  +Y
130 6 -7.940 -105 +215 +216   u=8 $ Retainer -Y
131 6 -7.9400 -106 +215 +216   u=8 $ Retainer+Y
132 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber -Y
133 3 -1.0012 -102 #126  #127  #132   u=8 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber +Y
135 3 -1.0012 -104 #128  #129  #134   u=8 $ Gap Weld Post to Absorber +Y
136 12 -1.965 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber -X
137 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  -X
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
138 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber +X
139 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  +X
140 6 -7.940 -221 +331 +332   u=8 $ Retainer -X
141 6 -7.9400 -222 +331 +332   u=8 $ Retainer+X
142 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate-X
143 3 -1.0012 -218 #136  #137  #142   u=8 $ Gap Weld Post to Plate -X
144 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate +X
145 3 -1.0012 -220 #138  #139  #144   u=8 $ Gap Weld Post to Plate +X
146 3 -1.0012 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=8 $ Space in Tube
147 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=8 $ Fuel
Tube
148 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=8 $ Fuel Tube Weld Posts
149 3 -1.0012 -334 +333  #147  #148
             u=8 $ Space Around Weld Posts
150 3 -1.0012 +333 +334    u=8 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -1.965 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  +Y
155 6 -7.940 -105 +215 +216   u=7 $ Retainer -Y
156 6 -7.9400 -106 +215 +216   u=7 $ Retainer+Y
157 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber -Y
158 3 -1.0012 -102 #151  #152  #157   u=7 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber +Y
160 3 -1.0012 -104 #153  #154  #159   u=7 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber -X
162 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  -X
163 12 -1.965 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber +X
164 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  +X
165 6 -7.9400 -221 +331 +332   u=7 $ Retainer -X
166 6 -7.940 -222 +331 +332   u=7 $ Retainer+X
167 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate-X
168 3 -1.0012 -218 #161  #162  #167   u=7 $ Gap Weld Post to Plate -X
169 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate +X
170 3 -1.0012 -220 #163  #164  #169   u=7 $ Gap Weld Post to Plate +X
171 3 -1.0012 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=7 $ Space in Tube
172 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=7 $ Fuel
Tube
173 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
        -295:-296:-297:-298:-299:-300:-301:-302:-303:
        -304:-305:-306:-307:-308:-309:-310:-311:-312:
        -313:-314:-315:-316:-317:-318:-319:-320:-321:
        -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=7 $ Fuel Tube Weld Posts
174 3 -1.0012 -334 +333  #172  #173
              u=7 $ Space Around Weld Posts
175 3 -1.0012 +333 +334    u=7 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  -Y
178 12 -1.965 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  +Y
180 6 -7.9400 -105 +215 +216   u=6 $ Retainer -Y
181 6 -7.940 -106 +215 +216   u=6 $ Retainer+Y
182 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber -Y
183 3 -1.0012 -102 #176  #177  #182   u=6 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber +Y
185 3 -1.0012 -104 #178  #179  #184   u=6 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber -X
187 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  -X
188 12 -1.965 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber +X
189 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  +X
190 6 -7.9400 -221 +331 +332   u=6 $ Retainer -X
191 6 -7.940 -222 +331 +332   u=6 $ Retainer+X
192 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate-X
193 3 -1.0012 -218 #186  #187  #192   u=6 $ Gap Weld Post to Plate -X
194 6 -7.940 -220
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate +X
195 3 -1.0012 -220 #188  #189  #194   u=6 $ Gap Weld Post to Plate +X
196 3 -1.0012 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=6 $ Space in Tube
197 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=6 $ Fuel
Tube
198 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=6 $ Fuel Tube Weld Posts
199 3 -1.0012 -334 +333  #197  #198
             u=6 $ Space Around Weld Posts
200 3 -1.0012 +333 +334    u=6 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  -Y
203 12 -1.965 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  +Y
205 6 -7.9400 -105 +215 +216   u=5 $ Retainer -Y
206 6 -7.940 -106 +215 +216   u=5 $ Retainer+Y
207 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber -Y
208 3 -1.0012 -102 #201  #202  #207   u=5 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber +Y
210 3 -1.0012 -104 #203  #204  #209   u=5 $ Gap Weld Post to Absorber +Y
211 12 -1.965 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber -X
212 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  -X
213 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber +X
214 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  +X
215 6 -7.940 -221 +331 +332   u=5 $ Retainer -X
216 6 -7.9400 -222 +331 +332   u=5 $ Retainer+X
217 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate-X
218 3 -1.0012 -218 #211  #212  #217   u=5 $ Gap Weld Post to Plate -X
219 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate +X
220 3 -1.0012 -220 #213  #214  #219   u=5 $ Gap Weld Post to Plate +X
221 3 -1.0012 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=5 $ Space in Tube
222 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=5 $ Fuel
Tube
223 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=5 $ Fuel Tube Weld Posts
224 3 -1.0012 -334 +333  #222  #223
             u=5 $ Space Around Weld Posts
225 3 -1.0012 +333 +334    u=5 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in Y direction
351 8 -7.821 -351 +357 +358  +395 +396 +397 +398 +399 +400
        +401 +402 +403 +404 +405 +406 +407 +408 +409 +410
        +411 +412 +413 +414 +415 +416 +417 +418 +419 +420
        +421 +422 +423 +424 +425 +426 +427 +428 +429 +430      u=4 $ DFC Inner Formed Plt
352 12 -1.965 -353 +351 +357 +358  +359 +360 +361 +362 +363 +364
        +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
        +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
        +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $  Absorber
353 7 -2.702 -352 +353 +357 +358  +359 +360 +361 +362 +363 +364
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
        +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
        +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
        +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $ Absorber Clad
354 6 -7.940 -354 +357 +358     u=4 $ Retainer +Y
355 6 -7.940 -352
       (-431:-432:-433:-434:-435:-436:-437:-438:-439:
       -440:-441:-442:-443:-444:-445:-446:-447:-448:
       -449:-450:-451:-452:-453:-454:-455:-456:-457:
       -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Post in Absorber +Y
356 3 -1.001 -352 #352  #353  #355    u=4 $ Gap Weld Post to Absorber +Y
357 6 -7.940 -351
       (-431:-432:-433:-434:-435:-436:-437:-438:-439:
       -440:-441:-442:-443:-444:-445:-446:-447:-448:
       -449:-450:-451:-452:-453:-454:-455:-456:-457:
       -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Posts in Plate +Y
358 3 -1.0012 -351 #351  #357     u=4 $ Space Around Weld Posts+Y
359 3 -1.0012 -354 #354      u=4 $ Space Inside Retainer +Y
360 8 -7.821 -355      u=4 $ Outer Plate Part +Y
361 8 -7.821 -356 +351     u=4 $ Inner Plate Part +Y
362 3 -1.0012 +351 +352 +353 +354 +355 +356 +357 +358
              u=4 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in X direction
471 8 -7.821 -471 +476 +477  +514 +515 +516 +517 +518 +519
        +520 +521 +522 +523 +524 +525 +526 +527 +528 +529
        +530 +531 +532 +533 +534 +535 +536 +537 +538 +539
        +540 +541 +542 +543 +544 +545 +546 +547 +548 +549      u=3 $ DFC Inner Formed Plt
472 12 -1.965 -473  +476 +477  +478 +479 +480 +481 +482 +483
        +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
        +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
        +508 +509 +510 +511 +512 +513      u=3 $ Absorber
473 7 -2.702 -472 +473 +476 +477  +478 +479 +480 +481 +482 +483
        +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
        +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
        +508 +509 +510 +511 +512 +513      u=3 $ Absorber Clad
474 6 -7.940 -474 +476 +477     u=3 $Retainer +X
475 6 -7.940 -472
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
       -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Post in Absorber +X
476 3 -1.0012 -472  #472  #473  #475   u=3 $ Gap Weld Post to Absorber +X
477 6 -7.940 -471
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
       -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Posts in Plate +X
478 3 -1.0012 -471 #471   #477    u=3 $ Space Around Weld Posts +X
479 3 -1.0012 -474 #474      u=3 $ Space Inside Retainer +X
480 8 -7.821 -475      u=3 $ Outer Plate Part +X
481 3 -1.0012 +471 +472 +473 +474 +475 +476 +477
              u=3 $ Exterior Space
C Cells - Basket
601 3 -1.0012 -601 -602 fill=7 *trcl=( -23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 1
602 like 601 but     fill=8 *trcl=( 23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 2
603 like 601 but     fill=9 *trcl=( 0.0000 46.9849 0.0000 )   u=2 $ Tube Loc 4
604 like 601 but     fill=7 *trcl=( -70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 6
605 like 601 but     fill=9 *trcl=( -23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 7
606 like 601 but     fill=9 *trcl=( 23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 8
607 like 601 but     fill=8 *trcl=( 70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 9
608 like 601 but     fill=9 *trcl=( -46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 10
609 like 601 but     fill=9 *trcl=( 0.0000 0.0000 0.0000 )   u=2 $ Tube Loc 11
610 like 601 but     fill=9 *trcl=( 46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 12
611 like 601 but     fill=6 *trcl=( -70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 13
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
612 like 601 but     fill=9 *trcl=( -23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 14
613 like 601 but     fill=9 *trcl=( 23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 15
614 like 601 but     fill=5 *trcl=( 70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 16
615 like 601 but     fill=9 *trcl=( 0.0000 -46.9849 0.0000 )   u=2 $ Tube Loc 18
616 like 601 but     fill=6 *trcl=( -23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 20
617 like 601 but     fill=5 *trcl=( 23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 21
618 3 -1.0012 -61  fill=10 *trcl=( -49.4170 49.4170 13.8684 )   u=2 $ Empty DFC Loc 3
619 like 618 but      *trcl=( 49.4170 49.4170 13.8684 )   u=2 $ Empty DFC Loc 5
620 like 618 but      *trcl=( -49.4170 -49.4170 13.8684 )   u=2 $ Empty DFC Loc 17
621 like 618 but      *trcl=( 49.4170 -49.4170 13.8684 )   u=2 $ Empty DFC Loc 19
622 8 -7.821 -603 +604
                #601  #602  #616  #617    u=2 $ Side Weldment Y
623 8 -7.821 -605 +606
                #604  #611  #607  #614    u=2 $ Side Weldment X
624 8 -7.821 -607 #601  #604 #605    fill=3 (5) u=2 $ Loc 3 DFC In Formed Plt
625 8 -7.821 -608 #601  #604 #605    fill=4 (5) u=2 $ Loc 3 DFC In Formed Plt
626 8 -7.821 -609 +610 #601  #604 #605    u=2 $ Loc 3 DFC Out Formed Pl
627 8 -7.821 -610 #601  #604 #605     u=2 $ Loc 3 DFC Out Formed Pl
628 8 -7.821 -611 #602  #606 #607    fill=4 u=2 $ Loc 5 DFC In Formed Plt
629 8 -7.821 -612 #602  #606 #607  +611  fill=3 u=2 $ Loc 5 DFC In Formed Plt
630 8 -7.821 -613 +614 #602  #606 #607    u=2 $ Loc 5 DFC Out Formed Pl
631 8 -7.821 -614 #602  #606 #607     u=2 $ Loc 5 DFC Out Formed Pl
632 8 -7.821 -615 #616  #611 #612    fill=4 (4) u=2 $ Loc 17 DFC In Formed Plt
633 8 -7.821 -616 #616  #611 #612    fill=3 (4) u=2 $ Loc 17 DFC In Formed Plt
634 8 -7.821 -617 +618 #616  #611 #612    u=2 $ Loc 17 DFC Out Formed Pl
635 8 -7.821 -618 #616  #611 #612     u=2 $ Loc 17 DFC Out Formed Pl
636 8 -7.821 -619 #617  #613 #614    fill=3 (3) u=2 $ Loc 19 DFC In Formed Plt
637 8 -7.821 -620 #617  #613 #614    fill=4 (3) u=2 $ Loc 19 DFC In Formed Plt
638 8 -7.821 -621 +622 #617  #613 #614    u=2 $ Loc 19 DFC Out Formed Pl
639 8 -7.821 -622 #617  #613 #614     u=2 $ Loc 19 DFC Out Formed Pl
640 3 -1.0012 #601 #602 #603 #604 #605 #606 #607 #608 #609 #610
      +607 +608 +609 +610 +611 +612 +613 +614
      #622  #623  #618  #619  +623    u=2 $ Remaining Space +Y=0
641 3 -1.0012 #608 #609 #610 #611 #612 #613 #614 #615 #616 #617
      +615 +616 +617 +618 +619 +620 +621 +622
      #622  #623  #620 #621   -623    u=2 $ Remaining Space -Y=0
c Cell Cards - Canister
701 3 -1.0012 -12  fill=11 *trcl=( -22.5871 69.5720 15.4559 )    u=1 $ Assy loc 1
702 like 701 but      *trcl=( 22.5871 69.5720 15.4559 )    u=1 $ Assy loc 2
703 like 701 but      *trcl=( -48.5662 48.5662 15.4559 )    u=1 $ Assy loc 3 DFC
704 like 701 but      *trcl=( 0.0000 46.0796 15.4559 )    u=1 $ Assy loc 4
705 like 701 but      *trcl=( 48.5662 48.5662 15.4559 )    u=1 $ Assy loc 5 DFC
706 like 701 but      *trcl=( -69.5720 22.5871 15.4559 )    u=1 $ Assy loc 6
707 like 701 but      *trcl=( -22.5871 22.5871 15.4559 )    u=1 $ Assy loc 7
708 like 701 but      *trcl=( 22.5871 22.5871 15.4559 )    u=1 $ Assy loc 8
709 like 701 but      *trcl=( 69.5720 22.5871 15.4559 )    u=1 $ Assy loc 9
710 like 701 but      *trcl=( -46.0796 0.0000 15.4559 )    u=1 $ Assy loc 10
711 like 701 but      *trcl=( 0.0000 0.0000 15.4559 )    u=1 $ Assy loc 11
712 like 701 but      *trcl=( 46.0796 0.0000 15.4559 )    u=1 $ Assy loc 12
713 like 701 but      *trcl=( -69.5720 -22.5871 15.4559 )    u=1 $ Assy loc 13
714 like 701 but      *trcl=( -22.5871 -22.5871 15.4559 )    u=1 $ Assy loc 14
715 like 701 but      *trcl=( 22.5871 -22.5871 15.4559 )    u=1 $ Assy loc 15
716 like 701 but      *trcl=( 69.5720 -22.5871 15.4559 )    u=1 $ Assy loc 16
717 like 701 but      *trcl=( -48.5662 -48.5662 15.4559 )    u=1 $ Assy loc 17 DFC
718 like 701 but      *trcl=( 0.0000 -46.0796 15.4559 )    u=1 $ Assy loc 18
719 like 701 but      *trcl=( 48.5662 -48.5662 15.4559 )    u=1 $ Assy loc 19 DFC
720 like 701 but      *trcl=( -22.5871 -69.5720 15.4559 )    u=1 $ Assy loc 20
721 like 701 but      *trcl=( 22.5871 -69.5720 15.4559 )    u=1 $ Assy loc 21
722 like 701 but      *trcl=( 0.0000 69.5531 15.4559 )    u=1 $ Assy loc 22
723 like 701 but      *trcl=( -22.5682 46.0607 15.4559 )    u=1 $ Assy loc 23
724 like 701 but      *trcl=( 22.5682 46.0607 15.4559 )    u=1 $ Assy loc 24
725 like 701 but      *trcl=( -46.0607 22.5682 15.4559 )    u=1 $ Assy loc 25
726 like 701 but      *trcl=( 0.0000 22.5682 15.4559 )    u=1 $ Assy loc 26
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
727 like 701 but      *trcl=( 46.0607 22.5682 15.4559 )    u=1 $ Assy loc 27
728 like 701 but      *trcl=( -69.5531 0.0000 15.4559 )    u=1 $ Assy loc 28
729 like 701 but      *trcl=( -22.5682 0.0000 15.4559 )    u=1 $ Assy loc 29
730 like 701 but      *trcl=( 22.5682 0.0000 15.4559 )    u=1 $ Assy loc 30
731 like 701 but      *trcl=( 69.5531 0.0000 15.4559 )    u=1 $ Assy loc 31
732 like 701 but      *trcl=( -46.0607 -22.5682 15.4559 )    u=1 $ Assy loc 32
733 like 701 but      *trcl=( 0.0000 -22.5682 15.4559 )    u=1 $ Assy loc 33
734 like 701 but      *trcl=( 46.0607 -22.5682 15.4559 )    u=1 $ Assy loc 34
735 like 701 but      *trcl=( -22.5682 -46.0607 15.4559 )    u=1 $ Assy loc 35
736 like 701 but      *trcl=( 22.5682 -46.0607 15.4559 )    u=1 $ Assy loc 36
737 like 701 but      *trcl=( 0.0000 -69.5531 15.4559 )    u=1 $ Assy loc 37
738 3 -1.0012 -701
                 #701 #702 #703 #704 #705 #706 #707 #708 #709 #710
                 #711 #712 #713 #714 #715 #716 #717 #718 #719 #720
                 #721 #722 #723 #724 #725 #726 #727 #728 #729 #730
                 #731 #732 #733 #734 #735 #736 #737       fill=2 u=1 $ Cavity
739 6 -7.940 -702  +701     u=1 $ Canister Shell / Lid / Bottom
740 13 -0.0001 +702       u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
801 13 -0.0001 -801 -802  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
802 8 -7.821 -801 +802 -806     $ Bottom plate
803 8 -7.821 -803 +802 +806 -807    $ Inner shell
804 9 -11.344 -804 +803 +806 -807    $ Lead shell
805 10 -1.632 -805 +804 +806 -807    $ NS-4-FR
806 8 -7.821 -801 +805 +806 -807    $ Outer shell
807 8 -7.821 -801 +802 +807     $ Top plate
808 8 -7.821 -808 +809  -814    $ Door rail
809 8 -7.821 -808 -810  -814    $ Door rail
810 8 -7.821 -813 -811 +812 -814    $ Door steel
811 13 -0.0001 -814 +801 #808 #809 #810      $ Exterior space to Reflector
812 0         +814       $ Exterior space

c Surfaces - Fuel Rod - CE14H1 - CE Core - 14x14
1 RCC 0.0000 0.0000 2.4511 0.0000 0.0000 347.9800 0.4833 $ Fuel pellet stack
2 RCC 0.0000 0.0000 2.4511 0.0000 0.0000 369.1010 0.4928 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.2227 0.0000 0.0000 372.6705 0.5588 $ Clad + End-Caps
c Surfaces - Guide Tube - CE14H1 - CE Core - 14x14
5 CZ 1.3246       $ Guide tube inner surface
6 CZ 1.4161       $ Guide tube outer surface
c Surfaces - Pitch - CE14H1 - CE Core - 14x14
7 PX 0.7366       $ Lattice Cell Boundaries
8 PX -0.7366
9 PY 0.7366
10 PY -0.7366
c Surfaces - Fuel Assembly Array Inserted Into Assembly - CE14H1 - CE Core - 14x14
11 RPP -10.1346 10.1346 -10.1346 10.1346 8.1399 385.4882  $ Array
12 RPP -10.1981 10.1981 -10.1981 10.1981 0.0000 398.7275  $ Assembly Outer Dims
c Surface Cards - DFC
60 RPP -11.0490 11.0490 -11.0490 11.0490 1.5875 418.0904 $  Space inside DFC Shell
61 RPP -11.1709 11.1709 -11.1709 11.1709 0.0000 419.8366 $  DFC body
c Surface Cards - Tube, Absorber and Retainer
101 RPP -10.1346 10.1346 -11.4478 -11.1938 8.8900 428.6250 $ Absorber -Y
102 RPP -10.1346 10.1346 -11.4999 -11.1417 8.8900 428.6250 $ Absorber Clad  -Y
103 RPP -10.1346 10.1346 11.1938 11.4478 8.8900 428.6250 $ Absorber +Y
104 RPP -10.1346 10.1346 11.1417 11.4999 8.8900 428.6250 $ Absorber Clad  +Y
105 RPP -10.3378 10.3378 -11.1417 -11.1036 7.6200 430.5300 $ Retainer -Y
106 RPP -10.3378 10.3378 11.1036 11.1417 7.6200 430.5300 $ Retainer  +Y
107 RPP 4.2799 5.8801 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
108 RPP 4.2799 5.8801 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
109 RPP 4.2799 5.8801 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
110 RPP 4.2799 5.8801 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
111 RPP 4.2799 5.8801 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
112 RPP 4.2799 5.8801 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
113 RPP 4.2799 5.8801 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
114 RPP 4.2799 5.8801 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
115 RPP 4.2799 5.8801 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
116 RPP 4.2799 5.8801 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
117 RPP 4.2799 5.8801 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
118 RPP 4.2799 5.8801 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
119 RPP 4.2799 5.8801 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
120 RPP 4.2799 5.8801 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
121 RPP 4.2799 5.8801 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
122 RPP 4.2799 5.8801 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
123 RPP 4.2799 5.8801 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
124 RPP 4.2799 5.8801 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
125 RPP -5.8801 -4.2799 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
126 RPP -5.8801 -4.2799 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
127 RPP -5.8801 -4.2799 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
128 RPP -5.8801 -4.2799 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
129 RPP -5.8801 -4.2799 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
130 RPP -5.8801 -4.2799 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
131 RPP -5.8801 -4.2799 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
132 RPP -5.8801 -4.2799 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
133 RPP -5.8801 -4.2799 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
134 RPP -5.8801 -4.2799 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
135 RPP -5.8801 -4.2799 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
136 RPP -5.8801 -4.2799 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
137 RPP -5.8801 -4.2799 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
138 RPP -5.8801 -4.2799 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
139 RPP -5.8801 -4.2799 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
140 RPP -5.8801 -4.2799 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
141 RPP -5.8801 -4.2799 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
142 RPP -5.8801 -4.2799 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
143 C/Y 5.0800 12.0650 0.4191    $ Weld Post Hole Y
144 C/Y 5.0800 28.5750 0.4191    $ Weld Post Hole Y
145 C/Y 5.0800 53.9750 0.4191    $ Weld Post Hole Y
146 C/Y 5.0800 79.3750 0.4191    $ Weld Post Hole Y
147 C/Y 5.0800 104.7750 0.4191    $ Weld Post Hole Y
148 C/Y 5.0800 130.1750 0.4191    $ Weld Post Hole Y
149 C/Y 5.0800 155.5750 0.4191    $ Weld Post Hole Y
150 C/Y 5.0800 180.9750 0.4191    $ Weld Post Hole Y
151 C/Y 5.0800 206.3750 0.4191    $ Weld Post Hole Y
152 C/Y 5.0800 231.7750 0.4191    $ Weld Post Hole Y
153 C/Y 5.0800 257.1750 0.4191    $ Weld Post Hole Y
154 C/Y 5.0800 282.5750 0.4191    $ Weld Post Hole Y
155 C/Y 5.0800 307.9750 0.4191    $ Weld Post Hole Y
156 C/Y 5.0800 333.3750 0.4191    $ Weld Post Hole Y
157 C/Y 5.0800 358.7750 0.4191    $ Weld Post Hole Y
158 C/Y 5.0800 384.1750 0.4191    $ Weld Post Hole Y
159 C/Y 5.0800 409.5750 0.4191    $ Weld Post Hole Y
160 C/Y 5.0800 426.0850 0.4191    $ Weld Post Hole Y
161 C/Y -5.0800 12.0650 0.4191    $ Weld Post Hole Y
162 C/Y -5.0800 28.5750 0.4191    $ Weld Post Hole Y
163 C/Y -5.0800 53.9750 0.4191    $ Weld Post Hole Y
164 C/Y -5.0800 79.3750 0.4191    $ Weld Post Hole Y
165 C/Y -5.0800 104.7750 0.4191    $ Weld Post Hole Y
166 C/Y -5.0800 130.1750 0.4191    $ Weld Post Hole Y
167 C/Y -5.0800 155.5750 0.4191    $ Weld Post Hole Y
168 C/Y -5.0800 180.9750 0.4191    $ Weld Post Hole Y
169 C/Y -5.0800 206.3750 0.4191    $ Weld Post Hole Y
170 C/Y -5.0800 231.7750 0.4191    $ Weld Post Hole Y
171 C/Y -5.0800 257.1750 0.4191    $ Weld Post Hole Y
172 C/Y -5.0800 282.5750 0.4191    $ Weld Post Hole Y
173 C/Y -5.0800 307.9750 0.4191    $ Weld Post Hole Y
174 C/Y -5.0800 333.3750 0.4191    $ Weld Post Hole Y
175 C/Y -5.0800 358.7750 0.4191    $ Weld Post Hole Y
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
176 C/Y -5.0800 384.1750 0.4191    $ Weld Post Hole Y
177 C/Y -5.0800 409.5750 0.4191    $ Weld Post Hole Y
178 C/Y -5.0800 426.0850 0.4191    $ Weld Post Hole Y
179 C/Y 5.0800 12.0650 0.3175    $ Weld Post Y
180 C/Y 5.0800 28.5750 0.3175    $ Weld Post Y
181 C/Y 5.0800 53.9750 0.3175    $ Weld Post Y
182 C/Y 5.0800 79.3750 0.3175    $ Weld Post Y
183 C/Y 5.0800 104.7750 0.3175    $ Weld Post Y
184 C/Y 5.0800 130.1750 0.3175    $ Weld Post Y
185 C/Y 5.0800 155.5750 0.3175    $ Weld Post Y
186 C/Y 5.0800 180.9750 0.3175    $ Weld Post Y
187 C/Y 5.0800 206.3750 0.3175    $ Weld Post Y
188 C/Y 5.0800 231.7750 0.3175    $ Weld Post Y
189 C/Y 5.0800 257.1750 0.3175    $ Weld Post Y
190 C/Y 5.0800 282.5750 0.3175    $ Weld Post Y
191 C/Y 5.0800 307.9750 0.3175    $ Weld Post Y
192 C/Y 5.0800 333.3750 0.3175    $ Weld Post Y
193 C/Y 5.0800 358.7750 0.3175    $ Weld Post Y
194 C/Y 5.0800 384.1750 0.3175    $ Weld Post Y
195 C/Y 5.0800 409.5750 0.3175    $ Weld Post Y
196 C/Y 5.0800 426.0850 0.3175    $ Weld Post Y
197 C/Y -5.0800 12.0650 0.3175    $ Weld Post Y
198 C/Y -5.0800 28.5750 0.3175    $ Weld Post Y
199 C/Y -5.0800 53.9750 0.3175    $ Weld Post Y
200 C/Y -5.0800 79.3750 0.3175    $ Weld Post Y
201 C/Y -5.0800 104.7750 0.3175    $ Weld Post Y
202 C/Y -5.0800 130.1750 0.3175    $ Weld Post Y
203 C/Y -5.0800 155.5750 0.3175    $ Weld Post Y
204 C/Y -5.0800 180.9750 0.3175    $ Weld Post Y
205 C/Y -5.0800 206.3750 0.3175    $ Weld Post Y
206 C/Y -5.0800 231.7750 0.3175    $ Weld Post Y
207 C/Y -5.0800 257.1750 0.3175    $ Weld Post Y
208 C/Y -5.0800 282.5750 0.3175    $ Weld Post Y
209 C/Y -5.0800 307.9750 0.3175    $ Weld Post Y
210 C/Y -5.0800 333.3750 0.3175    $ Weld Post Y
211 C/Y -5.0800 358.7750 0.3175    $ Weld Post Y
212 C/Y -5.0800 384.1750 0.3175    $ Weld Post Y
213 C/Y -5.0800 409.5750 0.3175    $ Weld Post Y
214 C/Y -5.0800 426.0850 0.3175    $ Weld Post Y
215 C/Y 0.0000 415.2900 1.5875    $ Water Circulation Hole Y
216 C/Y 0.0000 22.8600 1.5875    $ Water Circulation Hole Y
217 RPP -11.4478 -11.1938 -10.1346 10.1346 8.8900 428.6250 $ Absorber -X
218 RPP -11.4999 -11.1417 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  -X
219 RPP 11.1938 11.4478 -10.1346 10.1346 8.8900 428.6250 $ Absorber +X
220 RPP 11.1417 11.4999 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  +X
221 RPP -11.1417 -11.1036 -10.3378 10.3378 7.6200 430.5300 $ Retainer -X
222 RPP 11.1036 11.1417 -10.3378 10.3378 7.6200 430.5300 $ Retainer  +X
223 RPP -12.3698 12.3698 4.2799 5.8801 10.4648 13.6652 $ Weld Post Slot X Absorber
224 RPP -12.3698 12.3698 4.2799 5.8801 26.9748 30.1752 $ Weld Post Slot X Absorber
225 RPP -12.3698 12.3698 4.2799 5.8801 52.3748 55.5752 $ Weld Post Slot X Absorber
226 RPP -12.3698 12.3698 4.2799 5.8801 77.7748 80.9752 $ Weld Post Slot X Absorber
227 RPP -12.3698 12.3698 4.2799 5.8801 103.1748 106.3752 $ Weld Post Slot X Absorber
228 RPP -12.3698 12.3698 4.2799 5.8801 128.5748 131.7752 $ Weld Post Slot X Absorber
229 RPP -12.3698 12.3698 4.2799 5.8801 153.9748 157.1752 $ Weld Post Slot X Absorber
230 RPP -12.3698 12.3698 4.2799 5.8801 179.3748 182.5752 $ Weld Post Slot X Absorber
231 RPP -12.3698 12.3698 4.2799 5.8801 204.7748 207.9752 $ Weld Post Slot X Absorber
232 RPP -12.3698 12.3698 4.2799 5.8801 230.1748 233.3752 $ Weld Post Slot X Absorber
233 RPP -12.3698 12.3698 4.2799 5.8801 255.5748 258.7752 $ Weld Post Slot X Absorber
234 RPP -12.3698 12.3698 4.2799 5.8801 280.9748 284.1752 $ Weld Post Slot X Absorber
235 RPP -12.3698 12.3698 4.2799 5.8801 306.3748 309.5752 $ Weld Post Slot X Absorber
236 RPP -12.3698 12.3698 4.2799 5.8801 331.7748 334.9752 $ Weld Post Slot X Absorber
237 RPP -12.3698 12.3698 4.2799 5.8801 357.1748 360.3752 $ Weld Post Slot X Absorber
238 RPP -12.3698 12.3698 4.2799 5.8801 382.5748 385.7752 $ Weld Post Slot X Absorber
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
239 RPP -12.3698 12.3698 4.2799 5.8801 407.9748 411.1752 $ Weld Post Slot X Absorber
240 RPP -12.3698 12.3698 4.2799 5.8801 424.4848 427.6852 $ Weld Post Slot X Absorber
241 RPP -12.3698 12.3698 -5.8801 -4.2799 10.4648 13.6652 $ Weld Post Slot X Absorber
242 RPP -12.3698 12.3698 -5.8801 -4.2799 26.9748 30.1752 $ Weld Post Slot X Absorber
243 RPP -12.3698 12.3698 -5.8801 -4.2799 52.3748 55.5752 $ Weld Post Slot X Absorber
244 RPP -12.3698 12.3698 -5.8801 -4.2799 77.7748 80.9752 $ Weld Post Slot X Absorber
245 RPP -12.3698 12.3698 -5.8801 -4.2799 103.1748 106.3752 $ Weld Post Slot X Absorber
246 RPP -12.3698 12.3698 -5.8801 -4.2799 128.5748 131.7752 $ Weld Post Slot X Absorber
247 RPP -12.3698 12.3698 -5.8801 -4.2799 153.9748 157.1752 $ Weld Post Slot X Absorber
248 RPP -12.3698 12.3698 -5.8801 -4.2799 179.3748 182.5752 $ Weld Post Slot X Absorber
249 RPP -12.3698 12.3698 -5.8801 -4.2799 204.7748 207.9752 $ Weld Post Slot X Absorber
250 RPP -12.3698 12.3698 -5.8801 -4.2799 230.1748 233.3752 $ Weld Post Slot X Absorber
251 RPP -12.3698 12.3698 -5.8801 -4.2799 255.5748 258.7752 $ Weld Post Slot X Absorber
252 RPP -12.3698 12.3698 -5.8801 -4.2799 280.9748 284.1752 $ Weld Post Slot X Absorber
253 RPP -12.3698 12.3698 -5.8801 -4.2799 306.3748 309.5752 $ Weld Post Slot X Absorber
254 RPP -12.3698 12.3698 -5.8801 -4.2799 331.7748 334.9752 $ Weld Post Slot X Absorber
255 RPP -12.3698 12.3698 -5.8801 -4.2799 357.1748 360.3752 $ Weld Post Slot X Absorber
256 RPP -12.3698 12.3698 -5.8801 -4.2799 382.5748 385.7752 $ Weld Post Slot X Absorber
257 RPP -12.3698 12.3698 -5.8801 -4.2799 407.9748 411.1752 $ Weld Post Slot X Absorber
258 RPP -12.3698 12.3698 -5.8801 -4.2799 424.4848 427.6852 $ Weld Post Slot X Absorber
259 C/X 5.0800 12.0650 0.4191    $ Weld Post Hole X
260 C/X 5.0800 28.5750 0.4191    $ Weld Post Hole X
261 C/X 5.0800 53.9750 0.4191    $ Weld Post Hole X
262 C/X 5.0800 79.3750 0.4191    $ Weld Post Hole X
263 C/X 5.0800 104.7750 0.4191    $ Weld Post Hole X
264 C/X 5.0800 130.1750 0.4191    $ Weld Post Hole X
265 C/X 5.0800 155.5750 0.4191    $ Weld Post Hole X
266 C/X 5.0800 180.9750 0.4191    $ Weld Post Hole X
267 C/X 5.0800 206.3750 0.4191    $ Weld Post Hole X
268 C/X 5.0800 231.7750 0.4191    $ Weld Post Hole X
269 C/X 5.0800 257.1750 0.4191    $ Weld Post Hole X
270 C/X 5.0800 282.5750 0.4191    $ Weld Post Hole X
271 C/X 5.0800 307.9750 0.4191    $ Weld Post Hole X
272 C/X 5.0800 333.3750 0.4191    $ Weld Post Hole X
273 C/X 5.0800 358.7750 0.4191    $ Weld Post Hole X
274 C/X 5.0800 384.1750 0.4191    $ Weld Post Hole X
275 C/X 5.0800 409.5750 0.4191    $ Weld Post Hole X
276 C/X 5.0800 426.0850 0.4191    $ Weld Post Hole X
277 C/X -5.0800 12.0650 0.4191    $ Weld Post Hole X
278 C/X -5.0800 28.5750 0.4191    $ Weld Post Hole X
279 C/X -5.0800 53.9750 0.4191    $ Weld Post Hole X
280 C/X -5.0800 79.3750 0.4191    $ Weld Post Hole X
281 C/X -5.0800 104.7750 0.4191    $ Weld Post Hole X
282 C/X -5.0800 130.1750 0.4191    $ Weld Post Hole X
283 C/X -5.0800 155.5750 0.4191    $ Weld Post Hole X
284 C/X -5.0800 180.9750 0.4191    $ Weld Post Hole X
285 C/X -5.0800 206.3750 0.4191    $ Weld Post Hole X
286 C/X -5.0800 231.7750 0.4191    $ Weld Post Hole X
287 C/X -5.0800 257.1750 0.4191    $ Weld Post Hole X
288 C/X -5.0800 282.5750 0.4191    $ Weld Post Hole X
289 C/X -5.0800 307.9750 0.4191    $ Weld Post Hole X
290 C/X -5.0800 333.3750 0.4191    $ Weld Post Hole X
291 C/X -5.0800 358.7750 0.4191    $ Weld Post Hole X
292 C/X -5.0800 384.1750 0.4191    $ Weld Post Hole X
293 C/X -5.0800 409.5750 0.4191    $ Weld Post Hole X
294 C/X -5.0800 426.0850 0.4191    $ Weld Post Hole X
295 C/X 5.0800 12.0650 0.3175    $ Weld Post X
296 C/X 5.0800 28.5750 0.3175    $ Weld Post X
297 C/X 5.0800 53.9750 0.3175    $ Weld Post X
298 C/X 5.0800 79.3750 0.3175    $ Weld Post X
299 C/X 5.0800 104.7750 0.3175    $ Weld Post X
300 C/X 5.0800 130.1750 0.3175    $ Weld Post X
301 C/X 5.0800 155.5750 0.3175    $ Weld Post X
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
302 C/X 5.0800 180.9750 0.3175    $ Weld Post X
303 C/X 5.0800 206.3750 0.3175    $ Weld Post X
304 C/X 5.0800 231.7750 0.3175    $ Weld Post X
305 C/X 5.0800 257.1750 0.3175    $ Weld Post X
306 C/X 5.0800 282.5750 0.3175    $ Weld Post X
307 C/X 5.0800 307.9750 0.3175    $ Weld Post X
308 C/X 5.0800 333.3750 0.3175    $ Weld Post X
309 C/X 5.0800 358.7750 0.3175    $ Weld Post X
310 C/X 5.0800 384.1750 0.3175    $ Weld Post X
311 C/X 5.0800 409.5750 0.3175    $ Weld Post X
312 C/X 5.0800 426.0850 0.3175    $ Weld Post X
313 C/X -5.0800 12.0650 0.3175    $ Weld Post X
314 C/X -5.0800 28.5750 0.3175    $ Weld Post X
315 C/X -5.0800 53.9750 0.3175    $ Weld Post X
316 C/X -5.0800 79.3750 0.3175    $ Weld Post X
317 C/X -5.0800 104.7750 0.3175    $ Weld Post X
318 C/X -5.0800 130.1750 0.3175    $ Weld Post X
319 C/X -5.0800 155.5750 0.3175    $ Weld Post X
320 C/X -5.0800 180.9750 0.3175    $ Weld Post X
321 C/X -5.0800 206.3750 0.3175    $ Weld Post X
322 C/X -5.0800 231.7750 0.3175    $ Weld Post X
323 C/X -5.0800 257.1750 0.3175    $ Weld Post X
324 C/X -5.0800 282.5750 0.3175    $ Weld Post X
325 C/X -5.0800 307.9750 0.3175    $ Weld Post X
326 C/X -5.0800 333.3750 0.3175    $ Weld Post X
327 C/X -5.0800 358.7750 0.3175    $ Weld Post X
328 C/X -5.0800 384.1750 0.3175    $ Weld Post X
329 C/X -5.0800 409.5750 0.3175    $ Weld Post X
330 C/X -5.0800 426.0850 0.3175    $ Weld Post X
331 C/X 0.0000 415.2900 1.5875    $ Water Circulation Hole X
332 C/X 0.0000 22.8600 1.5875    $ Water Circulation Hole X
333 RPP -11.4999 11.4999 -11.4999 11.4999 0.0000 440.6900 $  Space inside tube - cavity
extent
334 RPP -12.3698 12.3698 -12.3698 12.3698 7.6200 430.5300 $  Fuel tube
c Surface Cards - Plates, Absorber, and Retainer in Y direction
351  RPP 34.9921 37.8497 34.9921 82.5919 7.6200 430.5300  $ DFC Inner Formed Plt
352  RPP 37.8497 38.2078 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber Clad
353  RPP 37.9018 38.1558 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber
354  RPP 38.2078 38.2460 39.2340 61.7130 8.8900 428.6250  $ DFC Retainer
355  RPP 37.8497 40.8497 63.1100 65.0150 7.6200 430.5300  $ Plate Outer Part
356  RPP 37.8497 40.8497 34.9921 37.8497 7.6200 430.5300  $ Plate Inner Part
357  C/X 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
358  C/X 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
359  RPP 34.9921 38.2460 44.5934 46.1936 10.4648 13.6652  $ Weld Post Slot Y Absorber
360  RPP 34.9921 38.2460 44.5934 46.1936 26.9748 30.1752  $ Weld Post Slot Y Absorber
361  RPP 34.9921 38.2460 44.5934 46.1936 52.3748 55.5752  $ Weld Post Slot Y Absorber
362  RPP 34.9921 38.2460 44.5934 46.1936 77.7748 80.9752  $ Weld Post Slot Y Absorber
363  RPP 34.9921 38.2460 44.5934 46.1936 103.1748 106.3752  $ Weld Post Slot Y Absorber
364  RPP 34.9921 38.2460 44.5934 46.1936 128.5748 131.7752  $ Weld Post Slot Y Absorber
365  RPP 34.9921 38.2460 44.5934 46.1936 153.9748 157.1752  $ Weld Post Slot Y Absorber
366  RPP 34.9921 38.2460 44.5934 46.1936 179.3748 182.5752  $ Weld Post Slot Y Absorber
367  RPP 34.9921 38.2460 44.5934 46.1936 204.7748 207.9752  $ Weld Post Slot Y Absorber
368  RPP 34.9921 38.2460 44.5934 46.1936 230.1748 233.3752  $ Weld Post Slot Y Absorber
369  RPP 34.9921 38.2460 44.5934 46.1936 255.5748 258.7752  $ Weld Post Slot Y Absorber
370  RPP 34.9921 38.2460 44.5934 46.1936 280.9748 284.1752  $ Weld Post Slot Y Absorber
371  RPP 34.9921 38.2460 44.5934 46.1936 306.3748 309.5752  $ Weld Post Slot Y Absorber
372  RPP 34.9921 38.2460 44.5934 46.1936 331.7748 334.9752  $ Weld Post Slot Y Absorber
373  RPP 34.9921 38.2460 44.5934 46.1936 357.1748 360.3752  $ Weld Post Slot Y Absorber
374  RPP 34.9921 38.2460 44.5934 46.1936 382.5748 385.7752  $ Weld Post Slot Y Absorber
375  RPP 34.9921 38.2460 44.5934 46.1936 407.9748 411.1752  $ Weld Post Slot Y Absorber
376  RPP 34.9921 38.2460 44.5934 46.1936 424.4848 427.6852  $ Weld Post Slot Y Absorber
377  RPP 34.9921 38.2460 54.7534 56.3536 10.4648 13.6652  $ Weld Post Slot Y Absorber
378  RPP 34.9921 38.2460 54.7534 56.3536 26.9748 30.1752  $ Weld Post Slot Y Absorber
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
RPP 34.9921 38.2460 54.7534 56.3536 52.3748 55.5752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 77.7748 80.9752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 103.1748 106.3752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 128.5748 131.7752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 153.9748 157.1752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 179.3748 182.5752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 204.7748 207.9752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 230.1748 233.3752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 255.5748 258.7752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 280.9748 284.1752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 306.3748 309.5752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 331.7748 334.9752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 357.1748 360.3752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 382.5748 385.7752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 407.9748 411.1752  $ Weld Post Slot Y Absorber
RPP 34.9921 38.2460 54.7534 56.3536 424.4848 427.6852  $ Weld Post Slot Y Absorber
C/X 55.5535 12.0650 0.4191     $ Weld Post Hole Y
C/X 55.5535 28.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 53.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 79.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 104.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 130.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 155.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 180.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 206.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 231.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 257.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 282.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 307.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 333.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 358.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 384.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 409.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 426.0850 0.4191     $ Weld Post Hole Y
C/X 45.3935 12.0650 0.4191     $ Weld Post Hole Y
C/X 45.3935 28.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 53.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 79.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 104.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 130.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 155.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 180.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 206.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 231.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 257.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 282.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 307.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 333.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 358.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 384.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 409.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 426.0850 0.4191     $ Weld Post Hole Y
C/X 55.5535 12.0650 0.3175     $ Weld Post Y
C/X 55.5535 28.5750 0.3175     $ Weld Post Y
C/X 55.5535 53.9750 0.3175     $ Weld Post Y
C/X 55.5535 79.3750 0.3175     $ Weld Post Y
C/X 55.5535 104.7750 0.3175     $ Weld Post Y
C/X 55.5535 130.1750 0.3175     $ Weld Post Y
C/X 55.5535 155.5750 0.3175     $ Weld Post Y
C/X 55.5535 180.9750 0.3175     $ Weld Post Y
C/X 55.5535 206.3750 0.3175     $ Weld Post Y
C/X 55.5535 231.7750 0.3175     $ Weld Post Y
C/X 55.5535 257.1750 0.3175     $ Weld Post Y
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
442  C/X 55.5535 282.5750 0.3175     $ Weld Post Y
443  C/X 55.5535 307.9750 0.3175     $ Weld Post Y
444  C/X 55.5535 333.3750 0.3175     $ Weld Post Y
445  C/X 55.5535 358.7750 0.3175     $ Weld Post Y
446  C/X 55.5535 384.1750 0.3175     $ Weld Post Y
447  C/X 55.5535 409.5750 0.3175     $ Weld Post Y
448  C/X 55.5535 426.0850 0.3175     $ Weld Post Y
449  C/X 45.3935 12.0650 0.3175     $ Weld Post Y
450  C/X 45.3935 28.5750 0.3175     $ Weld Post Y
451  C/X 45.3935 53.9750 0.3175     $ Weld Post Y
452  C/X 45.3935 79.3750 0.3175     $ Weld Post Y
453  C/X 45.3935 104.7750 0.3175     $ Weld Post Y
454  C/X 45.3935 130.1750 0.3175     $ Weld Post Y
455  C/X 45.3935 155.5750 0.3175     $ Weld Post Y
456  C/X 45.3935 180.9750 0.3175     $ Weld Post Y
457  C/X 45.3935 206.3750 0.3175     $ Weld Post Y
458  C/X 45.3935 231.7750 0.3175     $ Weld Post Y
459  C/X 45.3935 257.1750 0.3175     $ Weld Post Y
460  C/X 45.3935 282.5750 0.3175     $ Weld Post Y
461  C/X 45.3935 307.9750 0.3175     $ Weld Post Y
462  C/X 45.3935 333.3750 0.3175     $ Weld Post Y
463  C/X 45.3935 358.7750 0.3175     $ Weld Post Y
464  C/X 45.3935 384.1750 0.3175     $ Weld Post Y
465  C/X 45.3935 409.5750 0.3175     $ Weld Post Y
466  C/X 45.3935 426.0850 0.3175     $ Weld Post Y
c Surface Cards - Plates, Absorber, and Retainer in X direction
471  RPP 37.8496 82.6046 34.9921 37.8497 7.6200 430.5300  $ DFC Inner Formed Plt
472  RPP 39.4372 61.5098 37.8497 38.2078 8.8900 428.6250  $ DFC Absorber Clad
473  RPP 39.4372 61.5098 37.9018 38.1558 8.8900 428.6250  $ DFC Absorber
474  RPP 39.2340 61.7130 38.2078 38.2460 8.8900 428.6250  $ DFC Retainer
475  RPP 63.1100 65.0150 37.8497 42.8497 7.6200 430.5300  $ Plate Outer Part
476  C/Y 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
477  C/Y 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
478  RPP 44.5934 46.1936 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
479  RPP 44.5934 46.1936 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
480  RPP 44.5934 46.1936 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
481  RPP 44.5934 46.1936 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
482  RPP 44.5934 46.1936 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
483  RPP 44.5934 46.1936 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
484  RPP 44.5934 46.1936 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
485  RPP 44.5934 46.1936 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
486  RPP 44.5934 46.1936 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
487  RPP 44.5934 46.1936 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
488  RPP 44.5934 46.1936 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
489  RPP 44.5934 46.1936 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
490  RPP 44.5934 46.1936 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
491  RPP 44.5934 46.1936 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
492  RPP 44.5934 46.1936 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
493  RPP 44.5934 46.1936 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
494  RPP 44.5934 46.1936 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
495  RPP 44.5934 46.1936 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
496  RPP 54.7534 56.3536 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
497  RPP 54.7534 56.3536 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
498  RPP 54.7534 56.3536 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
499  RPP 54.7534 56.3536 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
500  RPP 54.7534 56.3536 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
501  RPP 54.7534 56.3536 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
502  RPP 54.7534 56.3536 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
503  RPP 54.7534 56.3536 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
504  RPP 54.7534 56.3536 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
505  RPP 54.7534 56.3536 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
506  RPP 54.7534 56.3536 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
507  RPP 54.7534 56.3536 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
508  RPP 54.7534 56.3536 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
509  RPP 54.7534 56.3536 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
510  RPP 54.7534 56.3536 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
511  RPP 54.7534 56.3536 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
512  RPP 54.7534 56.3536 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
513  RPP 54.7534 56.3536 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
514  C/Y 55.5535 12.0650 0.4191     $ Weld Post Hole X
515  C/Y 55.5535 28.5750 0.4191     $ Weld Post Hole X
516  C/Y 55.5535 53.9750 0.4191     $ Weld Post Hole X
517  C/Y 55.5535 79.3750 0.4191     $ Weld Post Hole X
518  C/Y 55.5535 104.7750 0.4191     $ Weld Post Hole X
519  C/Y 55.5535 130.1750 0.4191     $ Weld Post Hole X
520  C/Y 55.5535 155.5750 0.4191     $ Weld Post Hole X
521  C/Y 55.5535 180.9750 0.4191     $ Weld Post Hole X
522  C/Y 55.5535 206.3750 0.4191     $ Weld Post Hole X
523  C/Y 55.5535 231.7750 0.4191     $ Weld Post Hole X
524  C/Y 55.5535 257.1750 0.4191     $ Weld Post Hole X
525  C/Y 55.5535 282.5750 0.4191     $ Weld Post Hole X
526  C/Y 55.5535 307.9750 0.4191     $ Weld Post Hole X
527  C/Y 55.5535 333.3750 0.4191     $ Weld Post Hole X
528  C/Y 55.5535 358.7750 0.4191     $ Weld Post Hole X
529  C/Y 55.5535 384.1750 0.4191     $ Weld Post Hole X
530  C/Y 55.5535 409.5750 0.4191     $ Weld Post Hole X
531  C/Y 55.5535 426.0850 0.4191     $ Weld Post Hole X
532  C/Y 45.3935 12.0650 0.4191     $ Weld Post Hole X
533  C/Y 45.3935 28.5750 0.4191     $ Weld Post Hole X
534  C/Y 45.3935 53.9750 0.4191     $ Weld Post Hole X
535  C/Y 45.3935 79.3750 0.4191     $ Weld Post Hole X
536  C/Y 45.3935 104.7750 0.4191     $ Weld Post Hole X
537  C/Y 45.3935 130.1750 0.4191     $ Weld Post Hole X
538  C/Y 45.3935 155.5750 0.4191     $ Weld Post Hole X
539  C/Y 45.3935 180.9750 0.4191     $ Weld Post Hole X
540  C/Y 45.3935 206.3750 0.4191     $ Weld Post Hole X
541  C/Y 45.3935 231.7750 0.4191     $ Weld Post Hole X
542  C/Y 45.3935 257.1750 0.4191     $ Weld Post Hole X
543  C/Y 45.3935 282.5750 0.4191     $ Weld Post Hole X
544  C/Y 45.3935 307.9750 0.4191     $ Weld Post Hole X
545  C/Y 45.3935 333.3750 0.4191     $ Weld Post Hole X
546  C/Y 45.3935 358.7750 0.4191     $ Weld Post Hole X
547  C/Y 45.3935 384.1750 0.4191     $ Weld Post Hole X
548  C/Y 45.3935 409.5750 0.4191     $ Weld Post Hole X
549  C/Y 45.3935 426.0850 0.4191     $ Weld Post Hole X
550  C/Y 55.5535 12.0650 0.3175     $ Weld Post X
551  C/Y 55.5535 28.5750 0.3175     $ Weld Post X
552  C/Y 55.5535 53.9750 0.3175     $ Weld Post X
553  C/Y 55.5535 79.3750 0.3175     $ Weld Post X
554  C/Y 55.5535 104.7750 0.3175     $ Weld Post X
555  C/Y 55.5535 130.1750 0.3175     $ Weld Post X
556  C/Y 55.5535 155.5750 0.3175     $ Weld Post X
557  C/Y 55.5535 180.9750 0.3175     $ Weld Post X
558  C/Y 55.5535 206.3750 0.3175     $ Weld Post X
559  C/Y 55.5535 231.7750 0.3175     $ Weld Post X
560  C/Y 55.5535 257.1750 0.3175     $ Weld Post X
561  C/Y 55.5535 282.5750 0.3175     $ Weld Post X
562  C/Y 55.5535 307.9750 0.3175     $ Weld Post X
563  C/Y 55.5535 333.3750 0.3175     $ Weld Post X
564  C/Y 55.5535 358.7750 0.3175     $ Weld Post X
565  C/Y 55.5535 384.1750 0.3175     $ Weld Post X
566  C/Y 55.5535 409.5750 0.3175     $ Weld Post X
567  C/Y 55.5535 426.0850 0.3175     $ Weld Post X
568  C/Y 45.3935 12.0650 0.3175     $ Weld Post X
569  C/Y 45.3935 28.5750 0.3175     $ Weld Post X
570  C/Y 45.3935 53.9750 0.3175     $ Weld Post X
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
571  C/Y 45.3935 79.3750 0.3175      $ Weld Post X
572  C/Y 45.3935 104.7750 0.3175      $ Weld Post X
573  C/Y 45.3935 130.1750 0.3175      $ Weld Post X
574  C/Y 45.3935 155.5750 0.3175      $ Weld Post X
575  C/Y 45.3935 180.9750 0.3175      $ Weld Post X
576  C/Y 45.3935 206.3750 0.3175      $ Weld Post X
577  C/Y 45.3935 231.7750 0.3175      $ Weld Post X
578  C/Y 45.3935 257.1750 0.3175      $ Weld Post X
579  C/Y 45.3935 282.5750 0.3175      $ Weld Post X
580  C/Y 45.3935 307.9750 0.3175      $ Weld Post X
581  C/Y 45.3935 333.3750 0.3175      $ Weld Post X
582  C/Y 45.3935 358.7750 0.3175      $ Weld Post X
583  C/Y 45.3935 384.1750 0.3175      $ Weld Post X
584  C/Y 45.3935 409.5750 0.3175      $ Weld Post X
585  C/Y 45.3935 426.0850 0.3175      $ Weld Post X
C Surfaces - Basket
601  RPP -12.3698 12.3698 -12.3698 12.3698 0.0000 440.6900  $ Tube Cavity Height
602 1 RPP -16.6116 16.6116 -16.6116 16.6116 0.0000 440.6900  $ Tube Corner Cuts
603  RPP -33.9471 33.9471 -83.6409 83.6409 7.6200 430.5300  $ Outer Surface Side Weld.
604  RPP -33.9471 33.9471 -81.7359 81.7359 7.6200 430.5300  $ Inner Surface Side Weld.
605  RPP -83.6409 83.6409 -33.9471 33.9471 7.6200 430.5300  $ Outer Surface Side Weld.
606  RPP -81.7359 81.7359 -33.9471 33.9471 7.6200 430.5300  $ Inner Surface Side Weld.
607  RPP -38.2459 -34.9922 38.2459 82.6045 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
608  RPP -82.5918 -34.9922 34.9922 38.2459 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
609  RPP -65.0150 -38.2459 63.1100 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
610  RPP -65.0150 -63.1100 38.2459 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
611  RPP 34.9922 38.2459 34.9922 82.5918 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
612  RPP 38.2459 82.6045 34.9922 38.2459 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
613  RPP 38.2459 65.0150 63.1100 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
614  RPP 63.1100 65.0150 38.2459 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
615  RPP -38.2459 -34.9922 -82.5918 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
616  RPP -82.6045 -38.2459 -38.2459 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
617  RPP -65.0150 -38.2459 -65.0150 -63.1100 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
618  RPP -65.0150 -63.1100 -65.0150 -38.2459 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
619  RPP 34.9922 38.2459 -82.6045 -38.2459 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
620  RPP 34.9922 82.5918 -38.2459 -34.9922 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
621  RPP 38.2459 65.0150 -65.0150 -63.1100 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
622  RPP 63.1100 65.0150 -65.0150 -38.2459 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
623  PY 0.0000       $ Cut Plane for Remaining Area
c Surface Cards - Canister
701 RCC 0.0000 0.0000  0.0000 0.0000 0.0000 440.6900  90.1700 $ Canister cavity
702 RCC 0.0000 0.0000  -6.9850 0.0000 0.0000 469.2650  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
801 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
802 CZ 92.7100        $ Cask cavity radius
803 CZ 94.6150        $ Inner shell OR
804 CZ 102.7430        $ Lead shell OR
805 CZ 108.5850        $ Outer shell IR
806 PZ 30.4800        $ Top of bottom plate
807 PZ 453.3900        $ Bottom of top plate
808 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
809 PY 97.0026        $ Inside rail surface
810 PY -97.0026        $ Inside rail surface
811 PY 96.52        $ Door surface
812 PY -96.52        $ Door surface
813 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*814 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
c Fuel Pellet Material  4.70%  Weight UO2 [amu]  269.9085
m1    92235.66c -4.143E-02 92238.66c -8.400E-01  8016.62c -1.186E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.108E-01  8016.62c -8.792E-01
       1001.62c -4.890E-04  8016.62c -7.762E-03  5010.66c -3.093E-04
                                                 5011.66c -1.441E-03
mt3  lwtr.01t
c Lower Nozzle Material
m4
       1001.62c -3.642E-02  8016.62c -2.890E-01
       1001.62c -1.607E-04  8016.62c -2.551E-03  5010.66c -1.017E-04
                                                 5011.66c -4.735E-04
      24050.62c -5.330E-03 26054.62c -2.636E-02 28058.62c -4.286E-02
      24052.62c -1.068E-01 26056.62c -4.288E-01 28060.62c -1.707E-02
      24053.62c -1.234E-02 26057.62c -1.008E-02 28061.62c -7.548E-04
      24054.62c -3.123E-03 26058.62c -1.355E-03 28062.62c -2.443E-03
                                                28064.62c -6.460E-04
      25055.62c -1.343E-02
mt4  lwtr.01t
c Upper Nozzle Material
m5
       1001.62c -3.595E-02  8016.62c -2.853E-01
       1001.62c -1.587E-04  8016.62c -2.519E-03  5010.66c -1.004E-04
                                                 5011.66c -4.675E-04
      24050.62c -5.363E-03 26054.62c -2.653E-02 28058.62c -4.312E-02
      24052.62c -1.074E-01 26056.62c -4.314E-01 28060.62c -1.718E-02
      24053.62c -1.241E-02 26057.62c -1.015E-02 28061.62c -7.594E-04
      24054.62c -3.142E-03 26058.62c -1.364E-03 28062.62c -2.458E-03
                                                28064.62c -6.500E-04
      25055.62c -1.351E-02
mt5  lwtr.01t
c SS304
m6    24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                28064.62c -9.623E-04
      25055.62c -2.000E-02
c Aluminum
m7    13027.62c -1.000E+00
c Carbon Steel
m8    26054.62c -5.594E-02  6000.66c -1.000E-02
      26056.62c -9.098E-01
      26057.62c -2.140E-02
      26058.62c -2.876E-03
c Lead
m9    82206.66c -2.534E-01
      82207.66c -2.207E-01
      82208.66c -5.259E-01
c NS-F-FR
m10    5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
       5011.66c -3.772E-03  7015.66c -7.852E-05
      13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11   26054.62c -7.911E-04 14000.60c -3.370E-01
      26056.62c -1.287E-02
      26057.62c -3.026E-04
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
      26058.62c -4.067E-05
       1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
       8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12    5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
       5011.66c -2.799E-01
c Water Exterior
m13    1001.62c 2.0
       8016.62c 1.0
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c DFC fuel mixture material (if applicable)    Mix Height=291.552in
m24   92235.66c -3.436E-02 92238.66c -6.967E-01  8016.62c -9.833E-02
       1001.62c -1.910E-02  8016.62c -1.515E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
*TR3 0.0 0.0 0.0 90 180 90 0 90 90 90 90 0  $ z-rotation 90 degrees
*TR4 0.0 0.0 0.0 180 270 90 90 180 90 90 90 0  $ z-rotation 180 degrees
*TR5 0.0 0.0 0.0 -90 0 90 -180 -90 90 90 90 0  $ z-rotation -90 degrees
c
c Cell Importances
c
mode n
imp:n 1 262r 0
c
c
c Criticality Controls
c
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= 801:D2:11:7:-1
      ERG= D1
      POS= 0.0000 0.00 2.4511
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          1        d
      701 1
```

Figure 6.7.8-2 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Intact Array with Inserts

```
      702 1
      703 1
      704 1
      705 1
      706 1
      707 1
      708 1
      709 1
      710 1
      711 1
      712 1
      713 1
      714 1
      715 1
      716 1
      717 1
      718 1
      719 1
      720 1
      721 1
      722 1
      723 1
      724 1
      725 1
      726 1
      727 1
      728 1
      729 1
      730 1
      731 1
      732 1
      733 1
      734 1
      735 1
      736 1
      737 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4833 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      347.98 1.0
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
Transfer Cask Model - BW15H3
c
c  MAGNASTOR Canister Class 1
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c   Insert Configuration - No
c
c   Boron Content in Water - 2250 ppm
c   Cavity Water Density 1.0021 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Selected Partial Flood - No
c
c   Damaged Fuel Can Option - Yes
c   Damaged Fuel Can Configuration - URA
c
c
c
c   Model Revision 4.90
c
c Cells - Fuel Rod - BW15H3 - B&W Core - 15x15
1 1 -1.0522E+01 -1   u=18 $ Fuel
2 13 -0.9982 -2 +1  u=18 $ Plenum + Fuel to Clad Gap
3 2 -6.56 -3 +2  u=18 $ Clad + End Plugs
4 3 -1.0021 +3   u=18 $ Outside Fuel Rod
c Cells - Guide Tube - BW15H3 - B&W Core - 15x15
5 3 -1.0021 -5       u=17 $ Inside Guide Tube
6 2 -6.56 -6 +5      u=17 $ Guide Tube
7 3 -1.0021 +6       u=17 $ Outside Guide Tube
c Cell Cards Instrument Tube - BW15H3 - B&W Core - 15x15
8 3 -1.0021 -8       u=16 $ Inside Inst. Tube
9 2 -6.56 -9 +8      u=16 $ Inst. Tube
10 3 -1.0021 +9       u=16 $ Outside Inst. Tube
c Array_15x15_208
13 3 -1.0021 -13 +14 -15 +16
      trcl=(0 0 5.08)   lat=1 u=15 fill=-7:7 -7:7 0:0
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 18 18 18 17 18 18 18 17 18 18 18 18 18
      18 18 18 17 18 18 18 18 18 18 18 17 18 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 17 18 18 17 18 18 18 17 18 18 17 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 18 18 18 18 18 16 18 18 18 18 18 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 17 18 18 17 18 18 18 17 18 18 17 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 18 17 18 18 18 18 18 18 18 17 18 18 18
      18 18 18 18 18 17 18 18 18 17 18 18 18 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
      18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
c Cells - Fuel Assembly Array Inserted Into Assembly - cellPWRAssy
17 3 -1.0021 -17      fill=15 u=14 $ Array
18 3 -1.0021 -18 +17 -17.6 -17.5    u=14 $ Fuel Width Envelope
19 4 -4.5184 -18  +17.6     u=14 $ Lower Nozzle
20 5 -1.7995 -18   +17.5    u=14 $ Upper Nozzle
21 3 -1.0021 +18       u=14 $ Remaining Space
c Cells - DFC Content
30 1 -10.522 -30            u=13  $ Pellet Stack
31 3 -0.9982 30            u=13  $ Exterior
c cellDFCPelletArrayArray_15x15_208
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
35 3 -0.9982 -35 +36 -37 +38
      trcl=(0 0 0)   lat=1 u=12 fill=-7:7 -7:7 0:0
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 17 13 13 13 17 13 13 13 13 13
      13 13 13 17 13 13 13 13 13 13 13 17 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 17 13 13 17 13 13 13 17 13 13 17 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 16 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 17 13 13 17 13 13 13 17 13 13 17 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 17 13 13 13 13 13 13 13 17 13 13 13
      13 13 13 13 13 17 13 13 13 17 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
      13 13 13 13 13 13 13 13 13 13 13 13 13 13 13
c Cells - Fuel Assembly Array Inserted Into Assembly - cellAssyDFC
40 3 -1.0021 -40        fill=12 trcl=(0 0 16.6688)    u=11 $ Array
41 3 -0.9982 #40             u=11 $ Remaining Space
c Cell Cards - DFC
60 3 -1.0021 -60      u=10 $ DFC Cavity
61 6 -7.94 -61 +60     u=10 $ DFC Body
62 3 -1.0021 +61      u=10 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  +Y
105 6 -7.940 -105 +215 +216   u=9 $ Retainer -Y
106 6 -7.940 -106 +215 +216   u=9 $ Retainer+Y
107 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber -Y
108 3 -1.0021 -102 #101  #102  #107   u=9 $ Gap Weld Post to Absorber -Y
109 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber +Y
110 3 -1.0021 -104 #103  #104  #109   u=9 $ Gap Weld Post to Absorber +Y
111 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber -X
112 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  -X
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
113 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber +X
114 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  +X
115 6 -7.940 -221 +331 +332   u=9 $ Retainer -X
116 6 -7.940 -222 +331 +332   u=9 $ Retainer+X
117 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber -X
118 3 -1.0021 -218 #111  #112  #117   u=9 $ Gap Weld Post to Absorber -X
119 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber
120 3 -1.0021 -220 #113  #114  #119   u=9 $ Gap Weld Post to Absorber +X
121 3 -1.0021 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=9 $ Space in Tube
122 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=9 $ Fuel Tube
123 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=9 $ Fuel Tube Weld Posts
124 3 -1.0021 -334 +333  #122  #123
             u=9 $ Space Around Weld Posts
125 3 -1.0021 +333 +334    u=9 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  +Y
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
130 6 -7.940 -105 +215 +216   u=8 $ Retainer -Y
131 6 -7.9400 -106 +215 +216   u=8 $ Retainer+Y
132 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber -Y
133 3 -1.0021 -102 #126  #127  #132   u=8 $ Gap Weld Post to Absorber -Y
134 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber +Y
135 3 -1.0021 -104 #128  #129  #134   u=8 $ Gap Weld Post to Absorber +Y
136 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber -X
137 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  -X
138 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber +X
139 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  +X
140 6 -7.940 -221 +331 +332   u=8 $ Retainer -X
141 6 -7.9400 -222 +331 +332   u=8 $ Retainer+X
142 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate-X
143 3 -1.0021 -218 #136  #137  #142   u=8 $ Gap Weld Post to Plate -X
144 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate +X
145 3 -1.0021 -220 #138  #139  #144   u=8 $ Gap Weld Post to Plate +X
146 3 -1.0021 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=8 $ Space in Tube
147 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=8 $ Fuel Tube
148 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=8 $ Fuel Tube Weld Posts
149 3 -1.0021 -334 +333  #147  #148
             u=8 $ Space Around Weld Posts
150 3 -1.0021 +333 +334    u=8 $ Exterior Space
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  +Y
155 6 -7.940 -105 +215 +216   u=7 $ Retainer -Y
156 6 -7.9400 -106 +215 +216   u=7 $ Retainer+Y
157 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber -Y
158 3 -1.0021 -102 #151  #152  #157   u=7 $ Gap Weld Post to Absorber -Y
159 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber +Y
160 3 -1.0021 -104 #153  #154  #159   u=7 $ Gap Weld Post to Absorber +Y
161 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber -X
162 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  -X
163 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber +X
164 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  +X
165 6 -7.9400 -221 +331 +332   u=7 $ Retainer -X
166 6 -7.940 -222 +331 +332   u=7 $ Retainer+X
167 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate-X
168 3 -1.0021 -218 #161  #162  #167   u=7 $ Gap Weld Post to Plate -X
169 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate +X
170 3 -1.0021 -220 #163  #164  #169   u=7 $ Gap Weld Post to Plate +X
171 3 -1.0021 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=7 $ Space in Tube
172 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=7 $ Fuel Tube
173 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=7 $ Fuel Tube Weld Posts
174 3 -1.0021 -334 +333  #172  #173
            u=7 $ Space Around Weld Posts
175 3 -1.0021 +333 +334    u=7 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  +Y
180 6 -7.9400 -105 +215 +216   u=6 $ Retainer -Y
181 6 -7.940 -106 +215 +216   u=6 $ Retainer+Y
182 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber -Y
183 3 -1.0021 -102 #176  #177  #182   u=6 $ Gap Weld Post to Absorber -Y
184 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber +Y
185 3 -1.0021 -104 #178  #179  #184   u=6 $ Gap Weld Post to Absorber +Y
186 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber -X
187 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  -X
188 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber +X
189 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  +X
190 6 -7.9400 -221 +331 +332   u=6 $ Retainer -X
191 6 -7.940 -222 +331 +332   u=6 $ Retainer+X
192 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate-X
193 3 -1.0021 -218 #186  #187  #192   u=6 $ Gap Weld Post to Plate -X
194 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate +X
195 3 -1.0021 -220 #188  #189  #194   u=6 $ Gap Weld Post to Plate +X
196 3 -1.0021 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=6 $ Space in Tube
197 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=6 $ Fuel Tube
198 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=6 $ Fuel Tube Weld Posts
199 3 -1.0021 -334 +333  #197  #198
            u=6 $ Space Around Weld Posts
200 3 -1.0021 +333 +334    u=6 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  -Y
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  +Y
205 6 -7.9400 -105 +215 +216   u=5 $ Retainer -Y
206 6 -7.940 -106 +215 +216   u=5 $ Retainer+Y
207 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber -Y
208 3 -1.0021 -102 #201  #202  #207   u=5 $ Gap Weld Post to Absorber -Y
209 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber +Y
210 3 -1.0021 -104 #203  #204  #209   u=5 $ Gap Weld Post to Absorber +Y
211 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber -X
212 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  -X
213 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber +X
214 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  +X
215 6 -7.940 -221 +331 +332   u=5 $ Retainer -X
216 6 -7.9400 -222 +331 +332   u=5 $ Retainer+X
217 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate-X
218 3 -1.0021 -218 #211  #212  #217   u=5 $ Gap Weld Post to Plate -X
219 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate +X
220 3 -1.0021 -220 #213  #214  #219   u=5 $ Gap Weld Post to Plate +X
221 3 -1.0021 -333
       +102 +104 #105 #106
       +218 +220 #115 #116      u=5 $ Space in Tube
222 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=5 $ Fuel Tube
223 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=5 $ Fuel Tube Weld Posts
224 3 -1.0021 -334 +333  #222  #223
             u=5 $ Space Around Weld Posts
225 3 -1.0021 +333 +334    u=5 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in Y direction
351 8 -7.821 -351 +357 +358  +395 +396 +397 +398 +399 +400
        +401 +402 +403 +404 +405 +406 +407 +408 +409 +410
        +411 +412 +413 +414 +415 +416 +417 +418 +419 +420
        +421 +422 +423 +424 +425 +426 +427 +428 +429 +430      u=4 $ DFC Inner Formed Plt
352 12 -2.358 -353 +351 +357 +358  +359 +360 +361 +362 +363 +364
        +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
        +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
        +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $  Absorber
353 7 -2.702 -352 +353 +357 +358  +359 +360 +361 +362 +363 +364
        +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
        +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
        +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $ Absorber Clad
354 6 -7.940 -354 +357 +358     u=4 $ Retainer +Y
355 6 -7.940 -352
       (-431:-432:-433:-434:-435:-436:-437:-438:-439:
       -440:-441:-442:-443:-444:-445:-446:-447:-448:
       -449:-450:-451:-452:-453:-454:-455:-456:-457:
       -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Post in Absorber +Y
356 3 -1.001 -352 #352  #353  #355    u=4 $ Gap Weld Post to Absorber +Y
357 6 -7.940 -351
       (-431:-432:-433:-434:-435:-436:-437:-438:-439:
       -440:-441:-442:-443:-444:-445:-446:-447:-448:
       -449:-450:-451:-452:-453:-454:-455:-456:-457:
       -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Posts in Plate +Y
358 3 -1.0021 -351 #351  #357     u=4 $ Space Around Weld Posts+Y
359 3 -1.0021 -354 #354      u=4 $ Space Inside Retainer +Y
360 8 -7.821 -355      u=4 $ Outer Plate Part +Y
361 8 -7.821 -356 +351     u=4 $ Inner Plate Part +Y
362 3 -1.0021 +351 +352 +353 +354 +355 +356 +357 +358
              u=4 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in X direction
471 8 -7.821 -471 +476 +477  +514 +515 +516 +517 +518 +519
        +520 +521 +522 +523 +524 +525 +526 +527 +528 +529
        +530 +531 +532 +533 +534 +535 +536 +537 +538 +539
        +540 +541 +542 +543 +544 +545 +546 +547 +548 +549      u=3 $ DFC Inner Formed Plt
472 12 -2.358 -473  +476 +477  +478 +479 +480 +481 +482 +483
        +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
        +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
        +508 +509 +510 +511 +512 +513      u=3 $ Absorber
473 7 -2.702 -472 +473 +476 +477  +478 +479 +480 +481 +482 +483
        +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
        +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
        +508 +509 +510 +511 +512 +513      u=3 $ Absorber Clad
474 6 -7.940 -474 +476 +477     u=3 $Retainer +X
475 6 -7.940 -472
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
       -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Post in Absorber +X
476 3 -1.0021 -472  #472  #473  #475   u=3 $ Gap Weld Post to Absorber +X
477 6 -7.940 -471
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
      -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Posts in Plate +X
478 3 -1.0021 -471 #471   #477    u=3 $ Space Around Weld Posts +X
479 3 -1.0021 -474 #474      u=3 $ Space Inside Retainer +X
480 8 -7.821 -475      u=3 $ Outer Plate Part +X
481 3 -1.0021 +471 +472 +473 +474 +475 +476 +477
              u=3 $ Exterior Space
C Cells - Basket
601 3 -1.0021 -601 -602 fill=7 *trcl=( -23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 1
602 like 601 but     fill=8 *trcl=( 23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 2
603 like 601 but     fill=9 *trcl=( 0.0000 46.9849 0.0000 )   u=2 $ Tube Loc 4
604 like 601 but     fill=7 *trcl=( -70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 6
605 like 601 but     fill=9 *trcl=( -23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 7
606 like 601 but     fill=9 *trcl=( 23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 8
607 like 601 but     fill=8 *trcl=( 70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 9
608 like 601 but     fill=9 *trcl=( -46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 10
609 like 601 but     fill=9 *trcl=( 0.0000 0.0000 0.0000 )   u=2 $ Tube Loc 11
610 like 601 but     fill=9 *trcl=( 46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 12
611 like 601 but     fill=6 *trcl=( -70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 13
612 like 601 but     fill=9 *trcl=( -23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 14
613 like 601 but     fill=9 *trcl=( 23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 15
614 like 601 but     fill=5 *trcl=( 70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 16
615 like 601 but     fill=9 *trcl=( 0.0000 -46.9849 0.0000 )   u=2 $ Tube Loc 18
616 like 601 but     fill=6 *trcl=( -23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 20
617 like 601 but     fill=5 *trcl=( 23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 21
618 3 -1.0021 -61  fill=10 *trcl=( -49.4170 49.4170 0.0000 )   u=2 $ Empty DFC Loc 3
619 like 618 but      *trcl=( 49.4170 49.4170 0.0000 )   u=2 $ Empty DFC Loc 5
620 like 618 but      *trcl=( -49.4170 -49.4170 0.0000 )   u=2 $ Empty DFC Loc 17
621 like 618 but      *trcl=( 49.4170 -49.4170 0.0000 )   u=2 $ Empty DFC Loc 19
622 8 -7.821 -603 +604
               #601  #602  #616  #617    u=2 $ Side Weldment Y
623 8 -7.821 -605 +606
               #604  #611  #607  #614    u=2 $ Side Weldment X
624 8 -7.821 -607 #601  #604 #605    fill=3 (5) u=2 $ Loc 3 DFC In Formed Plt
625 8 -7.821 -608 #601  #604 #605    fill=4 (5) u=2 $ Loc 3 DFC In Formed Plt
626 8 -7.821 -609 +610 #601  #604 #605    u=2 $ Loc 3 DFC Out Formed Pl
627 8 -7.821 -610 #601  #604 #605     u=2 $ Loc 3 DFC Out Formed Pl
628 8 -7.821 -611 #602  #606 #607    fill=4 u=2 $ Loc 5 DFC In Formed Plt
629 8 -7.821 -612 #602  #606 #607  +611  fill=3 u=2 $ Loc 5 DFC In Formed Plt
630 8 -7.821 -613 +614 #602  #606 #607    u=2 $ Loc 5 DFC Out Formed Pl
631 8 -7.821 -614 #602  #606 #607     u=2 $ Loc 5 DFC Out Formed Pl
632 8 -7.821 -615 #616  #611 #612    fill=4 (4) u=2 $ Loc 17 DFC In Formed Plt
633 8 -7.821 -616 #616  #611 #612    fill=3 (4) u=2 $ Loc 17 DFC In Formed Plt
634 8 -7.821 -617 +618 #616  #611 #612    u=2 $ Loc 17 DFC Out Formed Pl
635 8 -7.821 -618 #616  #611 #612     u=2 $ Loc 17 DFC Out Formed Pl
636 8 -7.821 -619 #617  #613 #614    fill=3 (3) u=2 $ Loc 19 DFC In Formed Plt
637 8 -7.821 -620 #617  #613 #614    fill=4 (3) u=2 $ Loc 19 DFC In Formed Plt
638 8 -7.821 -621 +622 #617  #613 #614    u=2 $ Loc 19 DFC Out Formed Pl
639 8 -7.821 -622 #617  #613 #614     u=2 $ Loc 19 DFC Out Formed Pl
640 3 -1.0021 #601 #602 #603 #604 #605 #606 #607 #608 #609 #610
      +607 +608 +609 +610 +611 +612 +613 +614
      #622  #623  #618  #619  +623    u=2 $ Remaining Space +Y=0
641 3 -1.0021 #608 #609 #610 #611 #612 #613 #614 #615 #616 #617
      +615 +616 +617 +618 +619 +620 +621 +622
      #622  #623  #620 #621   -623    u=2 $ Remaining Space -Y=0
c Cell Cards - Canister
701 3 -1.0021 -18  fill=14 *trcl=( -23.2298 70.2147 0.0000 )    u=1 $ Assy loc 1
702 like 701 but      *trcl=( 23.2298 70.2147 0.0000 )    u=1 $ Assy loc 2
703 3 -1.0021 -60  fill=11 *trcl=( -49.4170 49.4170 0.0000 )    u=1 $ Assy loc 3 DFC
704 like 701 but      *trcl=( 0.0000 46.7222 0.0000 )    u=1 $ Assy loc 4
705 3 -1.0021 -60  fill=11 *trcl=( 49.4170 49.4170 0.0000 )    u=1 $ Assy loc 5 DFC
706 like 701 but      *trcl=( -70.2147 23.2298 0.0000 )    u=1 $ Assy loc 6
707 like 701 but      *trcl=( -23.2298 23.2298 0.0000 )    u=1 $ Assy loc 7
708 like 701 but      *trcl=( 23.2298 23.2298 0.0000 )    u=1 $ Assy loc 8
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
709 like 701 but      *trcl=( 70.2147 23.2298 0.0000 )    u=1 $ Assy loc 9
710 like 701 but      *trcl=( -46.7222 0.0000 0.0000 )    u=1 $ Assy loc 10
711 like 701 but      *trcl=( 0.0000 0.0000 0.0000 )    u=1 $ Assy loc 11
712 like 701 but      *trcl=( 46.7222 0.0000 0.0000 )    u=1 $ Assy loc 12
713 like 701 but      *trcl=( -70.2147 -23.2298 0.0000 )    u=1 $ Assy loc 13
714 like 701 but      *trcl=( -23.2298 -23.2298 0.0000 )    u=1 $ Assy loc 14
715 like 701 but      *trcl=( 23.2298 -23.2298 0.0000 )    u=1 $ Assy loc 15
716 like 701 but      *trcl=( 70.2147 -23.2298 0.0000 )    u=1 $ Assy loc 16
717 3 -1.0021 -60  fill=11 *trcl=( -49.4170 -49.4170 0.0000 )    u=1 $ Assy loc 17 DFC
718 like 701 but      *trcl=( 0.0000 -46.7222 0.0000 )    u=1 $ Assy loc 18
719 3 -1.0021 -60  fill=11 *trcl=( 49.4170 -49.4170 0.0000 )    u=1 $ Assy loc 19 DFC
720 like 701 but      *trcl=( -23.2298 -70.2147 0.0000 )    u=1 $ Assy loc 20
721 like 701 but      *trcl=( 23.2298 -70.2147 0.0000 )    u=1 $ Assy loc 21
722 like 701 but      *trcl=( 0.0000 70.1957 0.0000 )    u=1 $ Assy loc 22
723 like 701 but      *trcl=( -23.2108 46.7033 0.0000 )    u=1 $ Assy loc 23
724 like 701 but      *trcl=( 23.2108 46.7033 0.0000 )    u=1 $ Assy loc 24
725 like 701 but      *trcl=( -46.7033 23.2108 0.0000 )    u=1 $ Assy loc 25
726 like 701 but      *trcl=( 0.0000 23.2108 0.0000 )    u=1 $ Assy loc 26
727 like 701 but      *trcl=( 46.7033 23.2108 0.0000 )    u=1 $ Assy loc 27
728 like 701 but      *trcl=( -70.1957 0.0000 0.0000 )    u=1 $ Assy loc 28
729 like 701 but      *trcl=( -23.2108 0.0000 0.0000 )    u=1 $ Assy loc 29
730 like 701 but      *trcl=( 23.2108 0.0000 0.0000 )    u=1 $ Assy loc 30
731 like 701 but      *trcl=( 70.1957 0.0000 0.0000 )    u=1 $ Assy loc 31
732 like 701 but      *trcl=( -46.7033 -23.2108 0.0000 )    u=1 $ Assy loc 32
733 like 701 but      *trcl=( 0.0000 -23.2108 0.0000 )    u=1 $ Assy loc 33
734 like 701 but      *trcl=( 46.7033 -23.2108 0.0000 )    u=1 $ Assy loc 34
735 like 701 but      *trcl=( -23.2108 -46.7033 0.0000 )    u=1 $ Assy loc 35
736 like 701 but      *trcl=( 23.2108 -46.7033 0.0000 )    u=1 $ Assy loc 36
737 like 701 but      *trcl=( 0.0000 -70.1957 0.0000 )    u=1 $ Assy loc 37
738 3 -1.0021 -701
                #701 #702 #703 #704 #705 #706 #707 #708 #709 #710
                #711 #712 #713 #714 #715 #716 #717 #718 #719 #720
                #721 #722 #723 #724 #725 #726 #727 #728 #729 #730
                #731 #732 #733 #734 #735 #736 #737       fill=2 u=1 $ Cavity
739 6 -7.940 -702  +701     u=1 $ Canister Shell / Lid / Bottom
740 13 -0.0001 +702       u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
801 13 -0.0001 -801 -802  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
802 8 -7.821 -801 +802 -806     $ Bottom plate
803 8 -7.821 -803 +802 +806 -807    $ Inner shell
804 9 -11.344 -804 +803 +806 -807    $ Lead shell
805 10 -1.632 -805 +804 +806 -807    $ NS-4-FR
806 8 -7.821 -801 +805 +806 -807    $ Outer shell
807 8 -7.821 -801 +802 +807     $ Top plate
808 8 -7.821 -808 +809  -814    $ Door rail
809 8 -7.821 -808 -810  -814    $ Door rail
810 8 -7.821 -813 -811 +812 -814    $ Door steel
811 13 -0.0001 -814 +801 #808 #809 #810      $ Exterior space to Reflector
812 0         +814       $ Exterior space

c Surfaces - Fuel Rod - BW15H3 - B&W Core - 15x15
1 RCC 0.0000 0.0000 11.5888 0.0000 0.0000 365.7600 0.4753 $ Fuel pellet stack
2 RCC 0.0000 0.0000 0.2540 0.0000 0.0000 388.4295 0.4852 $ Annulus + Plenum
3 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 388.9375 0.5436 $ Clad + End-Caps
c Surfaces - Guide Tube - BW15H3 - B&W Core - 15x15
5 CZ 0.5906       $ Guide tube inner surface
6 CZ 0.6261       $ Guide tube outer surface
c Surfaces - Instrument Tube - BW15H3 - B&W Core - 15x15
8 CZ 0.5906       $ Inst tube inner surface
9 CZ 0.6261       $ Inst tube outer surface
c Surfaces - Pitch - BW15H3 - B&W Core - 15x15
13 PX 0.7214       $ Lattice Cell Boundaries
14 PX -0.7214
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
15 PY 0.7214
16 PY -0.7214
c Surfaces - Fuel Assembly Array Inserted Into Assembly - BW15H3 - B&W Core - 15x15
17 RPP -10.6425 10.6425 -10.6425 10.6425 5.0800 395.6050  $ Array
18 RPP -10.8407 10.8407 -10.8407 10.8407 0.0000 420.6875  $ Assembly Outer Dims
c Surfaces - DFC Content - Fuel Pellet Stack
30 RCC 0.000 0.000 0.000 0.000 0.000 365.760 0.47525 $ Fuel pellet stack
c Surfaces - DFC Content - Array
35 PX 0.75515       $ Lattice Cell Boundaries
36 PX -0.75515
37 PY 0.75515
38 PY -0.75515
c Surfaces - DFC Content - Envelope of Array
40 RPP -11.0473 11.0473 -11.0473 11.0473 0.000 365.759  $ Array
c Surface Cards - DFC
60 RPP -11.0490 11.0490 -11.0490 11.0490 1.5875 430.4348 $  Space inside DFC Shell
61 RPP -11.1709 11.1709 -11.1709 11.1709 0.0000 432.1810 $  DFC body
c Surface Cards - Tube, Absorber and Retainer
101 RPP -10.1346 10.1346 -11.4478 -11.1938 8.8900 428.6250 $ Absorber -Y
102 RPP -10.1346 10.1346 -11.4999 -11.1417 8.8900 428.6250 $ Absorber Clad  -Y
103 RPP -10.1346 10.1346 11.1938 11.4478 8.8900 428.6250 $ Absorber +Y
104 RPP -10.1346 10.1346 11.1417 11.4999 8.8900 428.6250 $ Absorber Clad  +Y
105 RPP -10.3378 10.3378 -11.1417 -11.1036 7.6200 430.5300 $ Retainer -Y
106 RPP -10.3378 10.3378 11.1036 11.1417 7.6200 430.5300 $ Retainer  +Y
107 RPP 4.2799 5.8801 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
108 RPP 4.2799 5.8801 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
109 RPP 4.2799 5.8801 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
110 RPP 4.2799 5.8801 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
111 RPP 4.2799 5.8801 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
112 RPP 4.2799 5.8801 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
113 RPP 4.2799 5.8801 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
114 RPP 4.2799 5.8801 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
115 RPP 4.2799 5.8801 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
116 RPP 4.2799 5.8801 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
117 RPP 4.2799 5.8801 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
118 RPP 4.2799 5.8801 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
119 RPP 4.2799 5.8801 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
120 RPP 4.2799 5.8801 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
121 RPP 4.2799 5.8801 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
122 RPP 4.2799 5.8801 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
123 RPP 4.2799 5.8801 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
124 RPP 4.2799 5.8801 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
125 RPP -5.8801 -4.2799 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
126 RPP -5.8801 -4.2799 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
127 RPP -5.8801 -4.2799 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
128 RPP -5.8801 -4.2799 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
129 RPP -5.8801 -4.2799 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
130 RPP -5.8801 -4.2799 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
131 RPP -5.8801 -4.2799 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
132 RPP -5.8801 -4.2799 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
133 RPP -5.8801 -4.2799 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
134 RPP -5.8801 -4.2799 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
135 RPP -5.8801 -4.2799 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
136 RPP -5.8801 -4.2799 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
137 RPP -5.8801 -4.2799 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
138 RPP -5.8801 -4.2799 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
139 RPP -5.8801 -4.2799 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
140 RPP -5.8801 -4.2799 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
141 RPP -5.8801 -4.2799 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
142 RPP -5.8801 -4.2799 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
143 C/Y 5.0800 12.0650 0.4191    $ Weld Post Hole Y
144 C/Y 5.0800 28.5750 0.4191    $ Weld Post Hole Y
145 C/Y 5.0800 53.9750 0.4191    $ Weld Post Hole Y
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
146 C/Y 5.0800 79.3750 0.4191    $ Weld Post Hole Y
147 C/Y 5.0800 104.7750 0.4191    $ Weld Post Hole Y
148 C/Y 5.0800 130.1750 0.4191    $ Weld Post Hole Y
149 C/Y 5.0800 155.5750 0.4191    $ Weld Post Hole Y
150 C/Y 5.0800 180.9750 0.4191    $ Weld Post Hole Y
151 C/Y 5.0800 206.3750 0.4191    $ Weld Post Hole Y
152 C/Y 5.0800 231.7750 0.4191    $ Weld Post Hole Y
153 C/Y 5.0800 257.1750 0.4191    $ Weld Post Hole Y
154 C/Y 5.0800 282.5750 0.4191    $ Weld Post Hole Y
155 C/Y 5.0800 307.9750 0.4191    $ Weld Post Hole Y
156 C/Y 5.0800 333.3750 0.4191    $ Weld Post Hole Y
157 C/Y 5.0800 358.7750 0.4191    $ Weld Post Hole Y
158 C/Y 5.0800 384.1750 0.4191    $ Weld Post Hole Y
159 C/Y 5.0800 409.5750 0.4191    $ Weld Post Hole Y
160 C/Y 5.0800 426.0850 0.4191    $ Weld Post Hole Y
161 C/Y -5.0800 12.0650 0.4191    $ Weld Post Hole Y
162 C/Y -5.0800 28.5750 0.4191    $ Weld Post Hole Y
163 C/Y -5.0800 53.9750 0.4191    $ Weld Post Hole Y
164 C/Y -5.0800 79.3750 0.4191    $ Weld Post Hole Y
165 C/Y -5.0800 104.7750 0.4191    $ Weld Post Hole Y
166 C/Y -5.0800 130.1750 0.4191    $ Weld Post Hole Y
167 C/Y -5.0800 155.5750 0.4191    $ Weld Post Hole Y
168 C/Y -5.0800 180.9750 0.4191    $ Weld Post Hole Y
169 C/Y -5.0800 206.3750 0.4191    $ Weld Post Hole Y
170 C/Y -5.0800 231.7750 0.4191    $ Weld Post Hole Y
171 C/Y -5.0800 257.1750 0.4191    $ Weld Post Hole Y
172 C/Y -5.0800 282.5750 0.4191    $ Weld Post Hole Y
173 C/Y -5.0800 307.9750 0.4191    $ Weld Post Hole Y
174 C/Y -5.0800 333.3750 0.4191    $ Weld Post Hole Y
175 C/Y -5.0800 358.7750 0.4191    $ Weld Post Hole Y
176 C/Y -5.0800 384.1750 0.4191    $ Weld Post Hole Y
177 C/Y -5.0800 409.5750 0.4191    $ Weld Post Hole Y
178 C/Y -5.0800 426.0850 0.4191    $ Weld Post Hole Y
179 C/Y 5.0800 12.0650 0.3175    $ Weld Post Y
180 C/Y 5.0800 28.5750 0.3175    $ Weld Post Y
181 C/Y 5.0800 53.9750 0.3175    $ Weld Post Y
182 C/Y 5.0800 79.3750 0.3175    $ Weld Post Y
183 C/Y 5.0800 104.7750 0.3175    $ Weld Post Y
184 C/Y 5.0800 130.1750 0.3175    $ Weld Post Y
185 C/Y 5.0800 155.5750 0.3175    $ Weld Post Y
186 C/Y 5.0800 180.9750 0.3175    $ Weld Post Y
187 C/Y 5.0800 206.3750 0.3175    $ Weld Post Y
188 C/Y 5.0800 231.7750 0.3175    $ Weld Post Y
189 C/Y 5.0800 257.1750 0.3175    $ Weld Post Y
190 C/Y 5.0800 282.5750 0.3175    $ Weld Post Y
191 C/Y 5.0800 307.9750 0.3175    $ Weld Post Y
192 C/Y 5.0800 333.3750 0.3175    $ Weld Post Y
193 C/Y 5.0800 358.7750 0.3175    $ Weld Post Y
194 C/Y 5.0800 384.1750 0.3175    $ Weld Post Y
195 C/Y 5.0800 409.5750 0.3175    $ Weld Post Y
196 C/Y 5.0800 426.0850 0.3175    $ Weld Post Y
197 C/Y -5.0800 12.0650 0.3175    $ Weld Post Y
198 C/Y -5.0800 28.5750 0.3175    $ Weld Post Y
199 C/Y -5.0800 53.9750 0.3175    $ Weld Post Y
200 C/Y -5.0800 79.3750 0.3175    $ Weld Post Y
201 C/Y -5.0800 104.7750 0.3175    $ Weld Post Y
202 C/Y -5.0800 130.1750 0.3175    $ Weld Post Y
203 C/Y -5.0800 155.5750 0.3175    $ Weld Post Y
204 C/Y -5.0800 180.9750 0.3175    $ Weld Post Y
205 C/Y -5.0800 206.3750 0.3175    $ Weld Post Y
206 C/Y -5.0800 231.7750 0.3175    $ Weld Post Y
207 C/Y -5.0800 257.1750 0.3175    $ Weld Post Y
208 C/Y -5.0800 282.5750 0.3175    $ Weld Post Y
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
209 C/Y -5.0800 307.9750 0.3175    $ Weld Post Y
210 C/Y -5.0800 333.3750 0.3175    $ Weld Post Y
211 C/Y -5.0800 358.7750 0.3175    $ Weld Post Y
212 C/Y -5.0800 384.1750 0.3175    $ Weld Post Y
213 C/Y -5.0800 409.5750 0.3175    $ Weld Post Y
214 C/Y -5.0800 426.0850 0.3175    $ Weld Post Y
215 C/Y 0.0000 415.2900 1.5875    $ Water Circulation Hole Y
216 C/Y 0.0000 22.8600 1.5875    $ Water Circulation Hole Y
217 RPP -11.4478 -11.1938 -10.1346 10.1346 8.8900 428.6250 $ Absorber -X
218 RPP -11.4999 -11.1417 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  -X
219 RPP 11.1938 11.4478 -10.1346 10.1346 8.8900 428.6250 $ Absorber +X
220 RPP 11.1417 11.4999 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  +X
221 RPP -11.1417 -11.1036 -10.3378 10.3378 7.6200 430.5300 $ Retainer -X
222 RPP 11.1036 11.1417 -10.3378 10.3378 7.6200 430.5300 $ Retainer  +X
223 RPP -12.3698 12.3698 4.2799 5.8801 10.4648 13.6652 $ Weld Post Slot X Absorber
224 RPP -12.3698 12.3698 4.2799 5.8801 26.9748 30.1752 $ Weld Post Slot X Absorber
225 RPP -12.3698 12.3698 4.2799 5.8801 52.3748 55.5752 $ Weld Post Slot X Absorber
226 RPP -12.3698 12.3698 4.2799 5.8801 77.7748 80.9752 $ Weld Post Slot X Absorber
227 RPP -12.3698 12.3698 4.2799 5.8801 103.1748 106.3752 $ Weld Post Slot X Absorber
228 RPP -12.3698 12.3698 4.2799 5.8801 128.5748 131.7752 $ Weld Post Slot X Absorber
229 RPP -12.3698 12.3698 4.2799 5.8801 153.9748 157.1752 $ Weld Post Slot X Absorber
230 RPP -12.3698 12.3698 4.2799 5.8801 179.3748 182.5752 $ Weld Post Slot X Absorber
231 RPP -12.3698 12.3698 4.2799 5.8801 204.7748 207.9752 $ Weld Post Slot X Absorber
232 RPP -12.3698 12.3698 4.2799 5.8801 230.1748 233.3752 $ Weld Post Slot X Absorber
233 RPP -12.3698 12.3698 4.2799 5.8801 255.5748 258.7752 $ Weld Post Slot X Absorber
234 RPP -12.3698 12.3698 4.2799 5.8801 280.9748 284.1752 $ Weld Post Slot X Absorber
235 RPP -12.3698 12.3698 4.2799 5.8801 306.3748 309.5752 $ Weld Post Slot X Absorber
236 RPP -12.3698 12.3698 4.2799 5.8801 331.7748 334.9752 $ Weld Post Slot X Absorber
237 RPP -12.3698 12.3698 4.2799 5.8801 357.1748 360.3752 $ Weld Post Slot X Absorber
238 RPP -12.3698 12.3698 4.2799 5.8801 382.5748 385.7752 $ Weld Post Slot X Absorber
239 RPP -12.3698 12.3698 4.2799 5.8801 407.9748 411.1752 $ Weld Post Slot X Absorber
240 RPP -12.3698 12.3698 4.2799 5.8801 424.4848 427.6852 $ Weld Post Slot X Absorber
241 RPP -12.3698 12.3698 -5.8801 -4.2799 10.4648 13.6652 $ Weld Post Slot X Absorber
242 RPP -12.3698 12.3698 -5.8801 -4.2799 26.9748 30.1752 $ Weld Post Slot X Absorber
243 RPP -12.3698 12.3698 -5.8801 -4.2799 52.3748 55.5752 $ Weld Post Slot X Absorber
244 RPP -12.3698 12.3698 -5.8801 -4.2799 77.7748 80.9752 $ Weld Post Slot X Absorber
245 RPP -12.3698 12.3698 -5.8801 -4.2799 103.1748 106.3752 $ Weld Post Slot X Absorber
246 RPP -12.3698 12.3698 -5.8801 -4.2799 128.5748 131.7752 $ Weld Post Slot X Absorber
247 RPP -12.3698 12.3698 -5.8801 -4.2799 153.9748 157.1752 $ Weld Post Slot X Absorber
248 RPP -12.3698 12.3698 -5.8801 -4.2799 179.3748 182.5752 $ Weld Post Slot X Absorber
249 RPP -12.3698 12.3698 -5.8801 -4.2799 204.7748 207.9752 $ Weld Post Slot X Absorber
250 RPP -12.3698 12.3698 -5.8801 -4.2799 230.1748 233.3752 $ Weld Post Slot X Absorber
251 RPP -12.3698 12.3698 -5.8801 -4.2799 255.5748 258.7752 $ Weld Post Slot X Absorber
252 RPP -12.3698 12.3698 -5.8801 -4.2799 280.9748 284.1752 $ Weld Post Slot X Absorber
253 RPP -12.3698 12.3698 -5.8801 -4.2799 306.3748 309.5752 $ Weld Post Slot X Absorber
254 RPP -12.3698 12.3698 -5.8801 -4.2799 331.7748 334.9752 $ Weld Post Slot X Absorber
255 RPP -12.3698 12.3698 -5.8801 -4.2799 357.1748 360.3752 $ Weld Post Slot X Absorber
256 RPP -12.3698 12.3698 -5.8801 -4.2799 382.5748 385.7752 $ Weld Post Slot X Absorber
257 RPP -12.3698 12.3698 -5.8801 -4.2799 407.9748 411.1752 $ Weld Post Slot X Absorber
258 RPP -12.3698 12.3698 -5.8801 -4.2799 424.4848 427.6852 $ Weld Post Slot X Absorber
259 C/X 5.0800 12.0650 0.4191    $ Weld Post Hole X
260 C/X 5.0800 28.5750 0.4191    $ Weld Post Hole X
261 C/X 5.0800 53.9750 0.4191    $ Weld Post Hole X
262 C/X 5.0800 79.3750 0.4191    $ Weld Post Hole X
263 C/X 5.0800 104.7750 0.4191    $ Weld Post Hole X
264 C/X 5.0800 130.1750 0.4191    $ Weld Post Hole X
265 C/X 5.0800 155.5750 0.4191    $ Weld Post Hole X
266 C/X 5.0800 180.9750 0.4191    $ Weld Post Hole X
267 C/X 5.0800 206.3750 0.4191    $ Weld Post Hole X
268 C/X 5.0800 231.7750 0.4191    $ Weld Post Hole X
269 C/X 5.0800 257.1750 0.4191    $ Weld Post Hole X
270 C/X 5.0800 282.5750 0.4191    $ Weld Post Hole X
271 C/X 5.0800 307.9750 0.4191    $ Weld Post Hole X
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
272 C/X 5.0800 333.3750 0.4191    $ Weld Post Hole X
273 C/X 5.0800 358.7750 0.4191    $ Weld Post Hole X
274 C/X 5.0800 384.1750 0.4191    $ Weld Post Hole X
275 C/X 5.0800 409.5750 0.4191    $ Weld Post Hole X
276 C/X 5.0800 426.0850 0.4191    $ Weld Post Hole X
277 C/X -5.0800 12.0650 0.4191    $ Weld Post Hole X
278 C/X -5.0800 28.5750 0.4191    $ Weld Post Hole X
279 C/X -5.0800 53.9750 0.4191    $ Weld Post Hole X
280 C/X -5.0800 79.3750 0.4191    $ Weld Post Hole X
281 C/X -5.0800 104.7750 0.4191    $ Weld Post Hole X
282 C/X -5.0800 130.1750 0.4191    $ Weld Post Hole X
283 C/X -5.0800 155.5750 0.4191    $ Weld Post Hole X
284 C/X -5.0800 180.9750 0.4191    $ Weld Post Hole X
285 C/X -5.0800 206.3750 0.4191    $ Weld Post Hole X
286 C/X -5.0800 231.7750 0.4191    $ Weld Post Hole X
287 C/X -5.0800 257.1750 0.4191    $ Weld Post Hole X
288 C/X -5.0800 282.5750 0.4191    $ Weld Post Hole X
289 C/X -5.0800 307.9750 0.4191    $ Weld Post Hole X
290 C/X -5.0800 333.3750 0.4191    $ Weld Post Hole X
291 C/X -5.0800 358.7750 0.4191    $ Weld Post Hole X
292 C/X -5.0800 384.1750 0.4191    $ Weld Post Hole X
293 C/X -5.0800 409.5750 0.4191    $ Weld Post Hole X
294 C/X -5.0800 426.0850 0.4191    $ Weld Post Hole X
295 C/X 5.0800 12.0650 0.3175    $ Weld Post X
296 C/X 5.0800 28.5750 0.3175    $ Weld Post X
297 C/X 5.0800 53.9750 0.3175    $ Weld Post X
298 C/X 5.0800 79.3750 0.3175    $ Weld Post X
299 C/X 5.0800 104.7750 0.3175    $ Weld Post X
300 C/X 5.0800 130.1750 0.3175    $ Weld Post X
301 C/X 5.0800 155.5750 0.3175    $ Weld Post X
302 C/X 5.0800 180.9750 0.3175    $ Weld Post X
303 C/X 5.0800 206.3750 0.3175    $ Weld Post X
304 C/X 5.0800 231.7750 0.3175    $ Weld Post X
305 C/X 5.0800 257.1750 0.3175    $ Weld Post X
306 C/X 5.0800 282.5750 0.3175    $ Weld Post X
307 C/X 5.0800 307.9750 0.3175    $ Weld Post X
308 C/X 5.0800 333.3750 0.3175    $ Weld Post X
309 C/X 5.0800 358.7750 0.3175    $ Weld Post X
310 C/X 5.0800 384.1750 0.3175    $ Weld Post X
311 C/X 5.0800 409.5750 0.3175    $ Weld Post X
312 C/X 5.0800 426.0850 0.3175    $ Weld Post X
313 C/X -5.0800 12.0650 0.3175    $ Weld Post X
314 C/X -5.0800 28.5750 0.3175    $ Weld Post X
315 C/X -5.0800 53.9750 0.3175    $ Weld Post X
316 C/X -5.0800 79.3750 0.3175    $ Weld Post X
317 C/X -5.0800 104.7750 0.3175    $ Weld Post X
318 C/X -5.0800 130.1750 0.3175    $ Weld Post X
319 C/X -5.0800 155.5750 0.3175    $ Weld Post X
320 C/X -5.0800 180.9750 0.3175    $ Weld Post X
321 C/X -5.0800 206.3750 0.3175    $ Weld Post X
322 C/X -5.0800 231.7750 0.3175    $ Weld Post X
323 C/X -5.0800 257.1750 0.3175    $ Weld Post X
324 C/X -5.0800 282.5750 0.3175    $ Weld Post X
325 C/X -5.0800 307.9750 0.3175    $ Weld Post X
326 C/X -5.0800 333.3750 0.3175    $ Weld Post X
327 C/X -5.0800 358.7750 0.3175    $ Weld Post X
328 C/X -5.0800 384.1750 0.3175    $ Weld Post X
329 C/X -5.0800 409.5750 0.3175    $ Weld Post X
330 C/X -5.0800 426.0850 0.3175    $ Weld Post X
331 C/X 0.0000 415.2900 1.5875    $ Water Circulation Hole X
332 C/X 0.0000 22.8600 1.5875    $ Water Circulation Hole X
333 RPP -11.4999 11.4999 -11.4999 11.4999 0.0000 440.6900 $  Space inside tube - cavity extent
334 RPP -12.3698 12.3698 -12.3698 12.3698 7.6200 430.5300 $  Fuel tube
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
c Surface Cards - Plates, Absorber, and Retainer in Y direction
351  RPP 34.9921 37.8497 34.9921 82.5919 7.6200 430.5300  $ DFC Inner Formed Plt
352  RPP 37.8497 38.2078 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber Clad
353  RPP 37.9018 38.1558 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber
354  RPP 38.2078 38.2460 39.2340 61.7130 8.8900 428.6250  $ DFC Retainer
355  RPP 37.8497 40.8497 63.1100 65.0150 7.6200 430.5300  $ Plate Outer Part
356  RPP 37.8497 40.8497 34.9921 37.8497 7.6200 430.5300  $ Plate Inner Part
357  C/X 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
358  C/X 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
359  RPP 34.9921 38.2460 44.5934 46.1936 10.4648 13.6652  $ Weld Post Slot Y Absorber
360  RPP 34.9921 38.2460 44.5934 46.1936 26.9748 30.1752  $ Weld Post Slot Y Absorber
361  RPP 34.9921 38.2460 44.5934 46.1936 52.3748 55.5752  $ Weld Post Slot Y Absorber
362  RPP 34.9921 38.2460 44.5934 46.1936 77.7748 80.9752  $ Weld Post Slot Y Absorber
363  RPP 34.9921 38.2460 44.5934 46.1936 103.1748 106.3752  $ Weld Post Slot Y Absorber
364  RPP 34.9921 38.2460 44.5934 46.1936 128.5748 131.7752  $ Weld Post Slot Y Absorber
365  RPP 34.9921 38.2460 44.5934 46.1936 153.9748 157.1752  $ Weld Post Slot Y Absorber
366  RPP 34.9921 38.2460 44.5934 46.1936 179.3748 182.5752  $ Weld Post Slot Y Absorber
367  RPP 34.9921 38.2460 44.5934 46.1936 204.7748 207.9752  $ Weld Post Slot Y Absorber
368  RPP 34.9921 38.2460 44.5934 46.1936 230.1748 233.3752  $ Weld Post Slot Y Absorber
369  RPP 34.9921 38.2460 44.5934 46.1936 255.5748 258.7752  $ Weld Post Slot Y Absorber
370  RPP 34.9921 38.2460 44.5934 46.1936 280.9748 284.1752  $ Weld Post Slot Y Absorber
371  RPP 34.9921 38.2460 44.5934 46.1936 306.3748 309.5752  $ Weld Post Slot Y Absorber
372  RPP 34.9921 38.2460 44.5934 46.1936 331.7748 334.9752  $ Weld Post Slot Y Absorber
373  RPP 34.9921 38.2460 44.5934 46.1936 357.1748 360.3752  $ Weld Post Slot Y Absorber
374  RPP 34.9921 38.2460 44.5934 46.1936 382.5748 385.7752  $ Weld Post Slot Y Absorber
375  RPP 34.9921 38.2460 44.5934 46.1936 407.9748 411.1752  $ Weld Post Slot Y Absorber
376  RPP 34.9921 38.2460 44.5934 46.1936 424.4848 427.6852  $ Weld Post Slot Y Absorber
377  RPP 34.9921 38.2460 54.7534 56.3536 10.4648 13.6652  $ Weld Post Slot Y Absorber
378  RPP 34.9921 38.2460 54.7534 56.3536 26.9748 30.1752  $ Weld Post Slot Y Absorber
379  RPP 34.9921 38.2460 54.7534 56.3536 52.3748 55.5752  $ Weld Post Slot Y Absorber
380  RPP 34.9921 38.2460 54.7534 56.3536 77.7748 80.9752  $ Weld Post Slot Y Absorber
381  RPP 34.9921 38.2460 54.7534 56.3536 103.1748 106.3752  $ Weld Post Slot Y Absorber
382  RPP 34.9921 38.2460 54.7534 56.3536 128.5748 131.7752  $ Weld Post Slot Y Absorber
383  RPP 34.9921 38.2460 54.7534 56.3536 153.9748 157.1752  $ Weld Post Slot Y Absorber
384  RPP 34.9921 38.2460 54.7534 56.3536 179.3748 182.5752  $ Weld Post Slot Y Absorber
385  RPP 34.9921 38.2460 54.7534 56.3536 204.7748 207.9752  $ Weld Post Slot Y Absorber
386  RPP 34.9921 38.2460 54.7534 56.3536 230.1748 233.3752  $ Weld Post Slot Y Absorber
387  RPP 34.9921 38.2460 54.7534 56.3536 255.5748 258.7752  $ Weld Post Slot Y Absorber
388  RPP 34.9921 38.2460 54.7534 56.3536 280.9748 284.1752  $ Weld Post Slot Y Absorber
389  RPP 34.9921 38.2460 54.7534 56.3536 306.3748 309.5752  $ Weld Post Slot Y Absorber
390  RPP 34.9921 38.2460 54.7534 56.3536 331.7748 334.9752  $ Weld Post Slot Y Absorber
391  RPP 34.9921 38.2460 54.7534 56.3536 357.1748 360.3752  $ Weld Post Slot Y Absorber
392  RPP 34.9921 38.2460 54.7534 56.3536 382.5748 385.7752  $ Weld Post Slot Y Absorber
393  RPP 34.9921 38.2460 54.7534 56.3536 407.9748 411.1752  $ Weld Post Slot Y Absorber
394  RPP 34.9921 38.2460 54.7534 56.3536 424.4848 427.6852  $ Weld Post Slot Y Absorber
395  C/X 55.5535 12.0650 0.4191     $ Weld Post Hole Y
396  C/X 55.5535 28.5750 0.4191     $ Weld Post Hole Y
397  C/X 55.5535 53.9750 0.4191     $ Weld Post Hole Y
398  C/X 55.5535 79.3750 0.4191     $ Weld Post Hole Y
399  C/X 55.5535 104.7750 0.4191     $ Weld Post Hole Y
400  C/X 55.5535 130.1750 0.4191     $ Weld Post Hole Y
401  C/X 55.5535 155.5750 0.4191     $ Weld Post Hole Y
402  C/X 55.5535 180.9750 0.4191     $ Weld Post Hole Y
403  C/X 55.5535 206.3750 0.4191     $ Weld Post Hole Y
404  C/X 55.5535 231.7750 0.4191     $ Weld Post Hole Y
405  C/X 55.5535 257.1750 0.4191     $ Weld Post Hole Y
406  C/X 55.5535 282.5750 0.4191     $ Weld Post Hole Y
407  C/X 55.5535 307.9750 0.4191     $ Weld Post Hole Y
408  C/X 55.5535 333.3750 0.4191     $ Weld Post Hole Y
409  C/X 55.5535 358.7750 0.4191     $ Weld Post Hole Y
410  C/X 55.5535 384.1750 0.4191     $ Weld Post Hole Y
411  C/X 55.5535 409.5750 0.4191     $ Weld Post Hole Y
412  C/X 55.5535 426.0850 0.4191     $ Weld Post Hole Y
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
C/X 45.3935 12.0650 0.4191     $ Weld Post Hole Y
C/X 45.3935 28.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 53.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 79.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 104.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 130.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 155.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 180.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 206.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 231.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 257.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 282.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 307.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 333.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 358.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 384.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 409.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 426.0850 0.4191     $ Weld Post Hole Y
C/X 55.5535 12.0650 0.3175     $ Weld Post Y
C/X 55.5535 28.5750 0.3175     $ Weld Post Y
C/X 55.5535 53.9750 0.3175     $ Weld Post Y
C/X 55.5535 79.3750 0.3175     $ Weld Post Y
C/X 55.5535 104.7750 0.3175     $ Weld Post Y
C/X 55.5535 130.1750 0.3175     $ Weld Post Y
C/X 55.5535 155.5750 0.3175     $ Weld Post Y
C/X 55.5535 180.9750 0.3175     $ Weld Post Y
C/X 55.5535 206.3750 0.3175     $ Weld Post Y
C/X 55.5535 231.7750 0.3175     $ Weld Post Y
C/X 55.5535 257.1750 0.3175     $ Weld Post Y
C/X 55.5535 282.5750 0.3175     $ Weld Post Y
C/X 55.5535 307.9750 0.3175     $ Weld Post Y
C/X 55.5535 333.3750 0.3175     $ Weld Post Y
C/X 55.5535 358.7750 0.3175     $ Weld Post Y
C/X 55.5535 384.1750 0.3175     $ Weld Post Y
C/X 55.5535 409.5750 0.3175     $ Weld Post Y
C/X 55.5535 426.0850 0.3175     $ Weld Post Y
C/X 45.3935 12.0650 0.3175     $ Weld Post Y
C/X 45.3935 28.5750 0.3175     $ Weld Post Y
C/X 45.3935 53.9750 0.3175     $ Weld Post Y
C/X 45.3935 79.3750 0.3175     $ Weld Post Y
C/X 45.3935 104.7750 0.3175     $ Weld Post Y
C/X 45.3935 130.1750 0.3175     $ Weld Post Y
C/X 45.3935 155.5750 0.3175     $ Weld Post Y
C/X 45.3935 180.9750 0.3175     $ Weld Post Y
C/X 45.3935 206.3750 0.3175     $ Weld Post Y
C/X 45.3935 231.7750 0.3175     $ Weld Post Y
C/X 45.3935 257.1750 0.3175     $ Weld Post Y
C/X 45.3935 282.5750 0.3175     $ Weld Post Y
C/X 45.3935 307.9750 0.3175     $ Weld Post Y
C/X 45.3935 333.3750 0.3175     $ Weld Post Y
C/X 45.3935 358.7750 0.3175     $ Weld Post Y
C/X 45.3935 384.1750 0.3175     $ Weld Post Y
C/X 45.3935 409.5750 0.3175     $ Weld Post Y
C/X 45.3935 426.0850 0.3175     $ Weld Post Y
c Surface Cards - Plates, Absorber, and Retainer in X direction
RPP 37.8496 82.6046 34.9921 37.8497 7.6200 430.5300  $ DFC Inner Formed Plt
RPP 39.4372 61.5098 37.8497 38.2078 8.8900 428.6250  $ DFC Absorber Clad
RPP 39.4372 61.5098 37.9018 38.1558 8.8900 428.6250  $ DFC Absorber
RPP 39.2340 61.7130 38.2078 38.2460 8.8900 428.6250  $ DFC Retainer
RPP 63.1100 65.0150 37.8497 42.8497 7.6200 430.5300  $ Plate Outer Part
C/Y 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
C/Y 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
RPP 44.5934 46.1936 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
RPP 44.5934 46.1936 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
C/Y 55.5535 12.0650 0.4191     $ Weld Post Hole X
C/Y 55.5535 28.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 53.9750 0.4191     $ Weld Post Hole X
C/Y 55.5535 79.3750 0.4191     $ Weld Post Hole X
C/Y 55.5535 104.7750 0.4191     $ Weld Post Hole X
C/Y 55.5535 130.1750 0.4191     $ Weld Post Hole X
C/Y 55.5535 155.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 180.9750 0.4191     $ Weld Post Hole X
C/Y 55.5535 206.3750 0.4191     $ Weld Post Hole X
C/Y 55.5535 231.7750 0.4191     $ Weld Post Hole X
C/Y 55.5535 257.1750 0.4191     $ Weld Post Hole X
C/Y 55.5535 282.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 307.9750 0.4191     $ Weld Post Hole X
C/Y 55.5535 333.3750 0.4191     $ Weld Post Hole X
C/Y 55.5535 358.7750 0.4191     $ Weld Post Hole X
C/Y 55.5535 384.1750 0.4191     $ Weld Post Hole X
C/Y 55.5535 409.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 426.0850 0.4191     $ Weld Post Hole X
C/Y 45.3935 12.0650 0.4191     $ Weld Post Hole X
C/Y 45.3935 28.5750 0.4191     $ Weld Post Hole X
C/Y 45.3935 53.9750 0.4191     $ Weld Post Hole X
C/Y 45.3935 79.3750 0.4191     $ Weld Post Hole X
C/Y 45.3935 104.7750 0.4191     $ Weld Post Hole X
C/Y 45.3935 130.1750 0.4191     $ Weld Post Hole X
C/Y 45.3935 155.5750 0.4191     $ Weld Post Hole X
C/Y 45.3935 180.9750 0.4191     $ Weld Post Hole X
C/Y 45.3935 206.3750 0.4191     $ Weld Post Hole X
C/Y 45.3935 231.7750 0.4191     $ Weld Post Hole X
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
542  C/Y 45.3935 257.1750 0.4191     $ Weld Post Hole X
543  C/Y 45.3935 282.5750 0.4191     $ Weld Post Hole X
544  C/Y 45.3935 307.9750 0.4191     $ Weld Post Hole X
545  C/Y 45.3935 333.3750 0.4191     $ Weld Post Hole X
546  C/Y 45.3935 358.7750 0.4191     $ Weld Post Hole X
547  C/Y 45.3935 384.1750 0.4191     $ Weld Post Hole X
548  C/Y 45.3935 409.5750 0.4191     $ Weld Post Hole X
549  C/Y 45.3935 426.0850 0.4191     $ Weld Post Hole X
550  C/Y 55.5535 12.0650 0.3175     $ Weld Post X
551  C/Y 55.5535 28.5750 0.3175     $ Weld Post X
552  C/Y 55.5535 53.9750 0.3175     $ Weld Post X
553  C/Y 55.5535 79.3750 0.3175     $ Weld Post X
554  C/Y 55.5535 104.7750 0.3175     $ Weld Post X
555  C/Y 55.5535 130.1750 0.3175     $ Weld Post X
556  C/Y 55.5535 155.5750 0.3175     $ Weld Post X
557  C/Y 55.5535 180.9750 0.3175     $ Weld Post X
558  C/Y 55.5535 206.3750 0.3175     $ Weld Post X
559  C/Y 55.5535 231.7750 0.3175     $ Weld Post X
560  C/Y 55.5535 257.1750 0.3175     $ Weld Post X
561  C/Y 55.5535 282.5750 0.3175     $ Weld Post X
562  C/Y 55.5535 307.9750 0.3175     $ Weld Post X
563  C/Y 55.5535 333.3750 0.3175     $ Weld Post X
564  C/Y 55.5535 358.7750 0.3175     $ Weld Post X
565  C/Y 55.5535 384.1750 0.3175     $ Weld Post X
566  C/Y 55.5535 409.5750 0.3175     $ Weld Post X
567  C/Y 55.5535 426.0850 0.3175     $ Weld Post X
568  C/Y 45.3935 12.0650 0.3175     $ Weld Post X
569  C/Y 45.3935 28.5750 0.3175     $ Weld Post X
570  C/Y 45.3935 53.9750 0.3175     $ Weld Post X
571  C/Y 45.3935 79.3750 0.3175     $ Weld Post X
572  C/Y 45.3935 104.7750 0.3175     $ Weld Post X
573  C/Y 45.3935 130.1750 0.3175     $ Weld Post X
574  C/Y 45.3935 155.5750 0.3175     $ Weld Post X
575  C/Y 45.3935 180.9750 0.3175     $ Weld Post X
576  C/Y 45.3935 206.3750 0.3175     $ Weld Post X
577  C/Y 45.3935 231.7750 0.3175     $ Weld Post X
578  C/Y 45.3935 257.1750 0.3175     $ Weld Post X
579  C/Y 45.3935 282.5750 0.3175     $ Weld Post X
580  C/Y 45.3935 307.9750 0.3175     $ Weld Post X
581  C/Y 45.3935 333.3750 0.3175     $ Weld Post X
582  C/Y 45.3935 358.7750 0.3175     $ Weld Post X
583  C/Y 45.3935 384.1750 0.3175     $ Weld Post X
584  C/Y 45.3935 409.5750 0.3175     $ Weld Post X
585  C/Y 45.3935 426.0850 0.3175     $ Weld Post X
C Surfaces - Basket
601  RPP -12.3698 12.3698 -12.3698 12.3698 0.0000 440.6900  $ Tube Cavity Height
602 1 RPP -16.6116 16.6116 -16.6116 16.6116 0.0000 440.6900  $ Tube Corner Cuts
603  RPP -33.9471 33.9471 -83.6409 83.6409 7.6200 430.5300  $ Outer Surface Side Weld.
604  RPP -33.9471 33.9471 -81.7359 81.7359 7.6200 430.5300  $ Inner Surface Side Weld.
605  RPP -83.6409 83.6409 -33.9471 33.9471 7.6200 430.5300  $ Outer Surface Side Weld.
606  RPP -81.7359 81.7359 -33.9471 33.9471 7.6200 430.5300  $ Inner Surface Side Weld.
607  RPP -38.2459 -34.9922 38.2459 82.6045 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
608  RPP -82.5918 -34.9922 34.9922 38.2459 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
609  RPP -65.0150 -38.2459 63.1100 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
610  RPP -65.0150 -63.1100 38.2459 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
611  RPP 34.9922 38.2459 34.9922 82.5918 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
612  RPP 38.2459 82.6045 34.9922 38.2459 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
613  RPP 38.2459 65.0150 63.1100 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
614  RPP 63.1100 65.0150 38.2459 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
615  RPP -38.2459 -34.9922 -82.5918 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
616  RPP -82.6045 -38.2459 -38.2459 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
617  RPP -65.0150 -38.2459 -65.0150 -63.1100 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
618  RPP -65.0150 -63.1100 -65.0150 -38.2459 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
619  RPP 34.9922 38.2459 -82.6045 -38.2459 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
620  RPP 34.9922 82.5918 -38.2459 -34.9922 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
621  RPP 38.2459 65.0150 -65.0150 -63.1100 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
622  RPP 63.1100 65.0150 -65.0150 -38.2459 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
623  PY 0.0000       $ Cut Plane for Remaining Area
c Surface Cards - Canister
701 RCC 0.0000 0.0000  0.0000 0.0000 0.0000 440.6900  90.1700 $ Canister cavity
702 RCC 0.0000 0.0000  -6.9850 0.0000 0.0000 469.2650  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
801 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
802 CZ 92.7100        $ Cask cavity radius
803 CZ 94.6150        $ Inner shell OR
804 CZ 102.7430        $ Lead shell OR
805 CZ 108.5850        $ Outer shell IR
806 PZ 30.4800        $ Top of bottom plate
807 PZ 453.3900        $ Bottom of top plate
808 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
809 PY 97.0026        $ Inside rail surface
810 PY -97.0026        $ Inside rail surface
811 PY 96.52        $ Door surface
812 PY -96.52        $ Door surface
813 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*814 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
c Fuel Pellet Material  4.60%  Weight UO2 [amu]  269.9115
m1    92235.66c -4.055E-02 92238.66c -8.409E-01  8016.62c -1.186E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.105E-01  8016.62c -8.767E-01
       1001.62c -6.288E-04  8016.62c -9.979E-03  5010.66c -3.977E-04
                                                 5011.66c -1.852E-03
mt3  lwtr.01t
c Lower Nozzle Material
m4
       1001.62c -1.208E-02  8016.62c -9.589E-02
       1001.62c -6.877E-05  8016.62c -1.091E-03  5010.66c -4.350E-05
                                                 5011.66c -2.026E-04
      24050.62c -7.071E-03 26054.62c -3.498E-02 28058.62c -5.686E-02
      24052.62c -1.416E-01 26056.62c -5.688E-01 28060.62c -2.265E-02
      24053.62c -1.637E-02 26057.62c -1.338E-02 28061.62c -1.001E-03
      24054.62c -4.143E-03 26058.62c -1.798E-03 28062.62c -3.241E-03
                                                28064.62c -8.570E-04
      25055.62c -1.781E-02
mt4  lwtr.01t
c Upper Nozzle Material
m5
       1001.62c -5.445E-02  8016.62c -4.321E-01
       1001.62c -3.099E-04  8016.62c -4.919E-03  5010.66c -1.960E-04
                                                 5011.66c -9.129E-04
      24050.62c -4.026E-03 26054.62c -1.991E-02 28058.62c -3.238E-02
      24052.62c -8.065E-02 26056.62c -3.239E-01 28060.62c -1.290E-02
      24053.62c -9.320E-03 26057.62c -7.618E-03 28061.62c -5.702E-04
      24054.62c -2.359E-03 26058.62c -1.024E-03 28062.62c -1.845E-03
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
                                                  28064.62c -4.880E-04
      25055.62c -1.014E-02
mt5  lwtr.01t
c SS304
m6    24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                  28064.62c -9.623E-04
      25055.62c -2.000E-02
c Aluminum
m7    13027.62c -1.000E+00
c Carbon Steel
m8    26054.62c -5.594E-02  6000.66c -1.000E-02
      26056.62c -9.098E-01
      26057.62c -2.140E-02
      26058.62c -2.876E-03
c Lead
m9    82206.66c -2.534E-01
      82207.66c -2.207E-01
      82208.66c -5.259E-01
c NS-F-FR
m10    5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
       5011.66c -3.772E-03  7015.66c -7.852E-05
      13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11   26054.62c -7.911E-04 14000.60c -3.370E-01
      26056.62c -1.287E-02
      26057.62c -3.026E-04
      26058.62c -4.067E-05
       1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
       8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12    5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
       5011.66c -2.799E-01
c Water Exterior
m13    1001.62c 2.0
       8016.62c 1.0
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c DFC fuel mixture material (if applicable)    Mix Height=428.8473in
m24   92235.66c -3.185E-02 92238.66c -6.605E-01  8016.62c -9.312E-02
       1001.62c -2.401E-02  8016.62c -1.905E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
*TR3 0.0 0.0 0.0 90 180 90 0 90 90 90 90 0  $ z-rotation 90 degrees
*TR4 0.0 0.0 0.0 180 270 90 90 180 90 90 90 0  $ z-rotation 180 degrees
*TR5 0.0 0.0 0.0 -90 0 90 -180 -90 90 90 90 0  $ z-rotation -90 degrees
c
c Cell Importances
c
mode n
imp:n 1 263r 0
c
c
c Criticality Controls
c
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= D2
      ERG= D1
      POS= 0.0000 0.00 11.5888
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          l        d
      801:701:17:13:-1 1
      801:702:17:13:-1 1
      801:703:40:35:-30 1
      801:704:17:13:-1 1
      801:703:40:35:-30 1
      801:706:17:13:-1 1
      801:707:17:13:-1 1
      801:708:17:13:-1 1
      801:709:17:13:-1 1
      801:710:17:13:-1 1
      801:711:17:13:-1 1
      801:712:17:13:-1 1
      801:713:17:13:-1 1
      801:714:17:13:-1 1
      801:715:17:13:-1 1
      801:716:17:13:-1 1
      801:703:40:35:-30 1
      801:718:17:13:-1 1
      801:703:40:35:-30 1
      801:720:17:13:-1 1
      801:721:17:13:-1 1
      801:722:17:13:-1 1
      801:723:17:13:-1 1
      801:724:17:13:-1 1
      801:725:17:13:-1 1
      801:726:17:13:-1 1
      801:727:17:13:-1 1
      801:728:17:13:-1 1
      801:729:17:13:-1 1
      801:730:17:13:-1 1
      801:731:17:13:-1 1
      801:732:17:13:-1 1
      801:733:17:13:-1 1
      801:734:17:13:-1 1
      801:735:17:13:-1 1
```

Figure 6.7.8-3 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Unclad Rod Array

```
      801:736:17:13:-1 1
      801:737:17:13:-1 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.4753 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      365.76 1.0
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
Transfer Cask Model - WE17H2
c
c  MAGNASTOR Canister Class 1
c   Neutron Poison Loading -  90 %
c   Nominal Fuel Characteristics
c   Insert Configuration - No
c
c   Boron Content in Water - 2500 ppm
c   Cavity Water Density 1.0025 g/cc
c
c   Fuel to Clad Gap - Wet-UnBorated
c   Exterior Water Density 0.0001 g/cc
c
c   Selected Partial Flood - Yes
c
c   Damaged Fuel Can Option - Yes
c   Damaged Fuel Can Configuration - MIX
c   Mixture Height - 87% Can Cavity Height      DFC Moderator: 0.9982 g/cc
c
c
c   Model Revision 4.90
c
c Cells- Partial Flood Fill
1 0          +1   u=17 $ Above Active Fuel
2 3 -1.0025 -1   u=17 $ Below Active Fuel
c Cells - Fuel Rod - WE17H2 - WE Core - 17x17
3 1 -1.0522E+01 -3   u=16 $ Fuel
4 13 -0.9982 -4 +3 fill=17 ( 0 0 -5.0984 ) u=16 $ Plenum + Fuel to Clad Gap
5 2 -6.56 -5 +4  u=16 $ Clad + End Plugs
6 3 -1.0025 +5  fill=17 ( 0 0 -5.0984 ) u=16 $ Outside Fuel Rod
c Cells - Guide Tube - WE17H2 - WE Core - 17x17
7 3 -1.0025 -7      fill=17 ( 0 0 -5.0984 ) u=15 $ Inside Guide Tube
8 2 -6.56 -8 +7      u=15 $ Guide Tube
9 3 -1.0025 +8      fill=17 ( 0 0 -5.0984 ) u=15 $ Outside Guide Tube
c Cell Cards Instrument Tube - WE17H2 - WE Core - 17x17
10 3 -1.0025 -10      fill=17 ( 0 0 -5.0984 ) u=14 $ Inside Inst. Tube
11 2 -6.56 -11 +10      u=14 $ Inst. Tube
12 3 -1.0025 +11      fill=17 ( 0 0 -5.0984 ) u=14 $ Outside Inst. Tube
c Array_17x17_264
15 3 -1.0025 -15 +16 -17 +18
      trcl=(0 0 6.919)   lat=1 u=13 fill=-8:8 -8:8 0:0
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 16 16 15 16 16 15 16 16 15 16 16 16 16 16
      16 16 16 15 16 16 16 16 16 16 16 16 16 15 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 15 16 16 15 16 16 15 16 16 15 16 16 15 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 15 16 16 15 16 16 14 16 16 15 16 16 15 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 15 16 16 15 16 16 15 16 16 15 16 16 15 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 15 16 16 16 16 16 16 16 16 16 15 16 16 16
      16 16 16 16 16 15 16 16 15 16 16 15 16 16 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
      16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
c Cells - Fuel Assembly Array Inserted Into Assembly - cellPWRAssy
19 3 -1.0025 -19      fill=13 u=12 $ Array
20 3 -1.0025 -20 +19 -19.6 -19.5 fill=17 ( 0.0000 0.0000 1.8206 )   u=12 $ Fuel Width
Envelope
21 4 -2.6182 -20  +19.6     u=12 $ Lower Nozzle
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
22 5 -1.8805 -20   +19.5    u=12 $ Upper Nozzle
23 3 -1.0025 +20    fill=17 ( 0.0000 0.0000 1.8206 )   u=12 $ Remaining Space
c Cells - DFC Content
52 24 -2.775 -52             u=11 $ Fuel / Moderator Mixture
53 3 -0.9982 +52  fill=17 ( 0.0000 0.0000 -6.9494 )           u=11 $ Canister Moderator
c Cell Cards - DFC
60 3 -1.0025 -60   fill=17 ( 0.0000 0.0000 3.4081 )   u=10 $ DFC Cavity
61 6 -7.94 -61 +60     u=10 $ DFC Body
62 3 -1.0025 +61   fill=17 ( 0.0000 0.0000 3.4081 )   u=10 $ Exterior Space
c Cell Cards - Tube, Absorber and Retainer
101 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber -Y
102 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  -Y
103 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber +Y
104 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=9 $ Absorber Clad  +Y
105 6 -7.940 -105 +215 +216   u=9 $ Retainer -Y
106 6 -7.940 -106 +215 +216   u=9 $ Retainer+Y
107 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber -Y
108 3 -1.0025 -102 #101  #102  #107  fill=17 ( 0.0000 0.0000 6.9190 ) u=9 $ Gap Weld Post
to Absorber -Y
109 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=9 $ Weld Post in Absorber +Y
110 3 -1.0025 -104 #103  #104  #109  fill=17 ( 0.0000 0.0000 6.9190 ) u=9 $ Gap Weld Post
to Absorber +Y
111 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber -X
112 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  -X
113 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber +X
114 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=9 $ Absorber Clad  +X
115 6 -7.940 -221 +331 +332   u=9 $ Retainer -X
116 6 -7.940 -222 +331 +332   u=9 $ Retainer+X
117 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber -X
118 3 -1.0025 -218 #111  #112  #117  fill=17 ( 0.0000 0.0000 6.9190 ) u=9 $ Gap Weld Post
to Absorber -X
119 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=9 $ Weld Post in Absorber
120 3 -1.0025 -220 #113  #114  #119  fill=17 ( 0.0000 0.0000 6.9190 ) u=9 $ Gap Weld Post
to Absorber +X
121 3 -1.0025 -333
       +102 +104 #105 #106
       +218 +220 #115 #116  fill=17 ( 0.0000 0.0000 6.9190 )    u=9 $ Space in Tube
122 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=9 $ Fuel
Tube
123 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=9 $ Fuel Tube Weld Posts
124 3 -1.0025 -334 +333  #122  #123
           fill=17 ( 0.0000 0.0000 6.9190 )  u=9 $ Space Around Weld Posts
125 3 -1.0025 +333 +334  fill=17 ( 0.0000 0.0000 6.9190 )  u=9 $ Exterior Space
c Cell Cards - Q1 Peripheral Tube, Absorber and Retainer
126 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber -Y
127 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  -Y
128 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber +Y
129 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=8 $ Absorber Clad  +Y
130 6 -7.940 -105 +215 +216   u=8 $ Retainer -Y
131 6 -7.9400 -106 +215 +216   u=8 $ Retainer+Y
132 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber -Y
133 3 -1.0025 -102 #126  #127  #132  fill=17 ( 0.0000 0.0000 6.9190 ) u=8 $ Gap Weld Post
to Absorber -Y
134 6 -7.9400 -104
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=8 $ Weld Post in Absorber +Y
135 3 -1.0025 -104 #128  #129  #134  fill=17 ( 0.0000 0.0000 6.9190 ) u=8 $ Gap Weld Post
to Absorber +Y
136 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber -X
137 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  -X
138 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber +X
139 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=8 $ Absorber Clad  +X
140 6 -7.940 -221 +331 +332   u=8 $ Retainer -X
141 6 -7.9400 -222 +331 +332   u=8 $ Retainer+X
142 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate-X
143 3 -1.0025 -218 #136  #137  #142  fill=17 ( 0.0000 0.0000 6.9190 ) u=8 $ Gap Weld Post
to Plate -X
144 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=8 $ Weld Post in Plate +X
145 3 -1.0025 -220 #138  #139  #144  fill=17 ( 0.0000 0.0000 6.9190 ) u=8 $ Gap Weld Post
to Plate +X
146 3 -1.0025 -333
       +102 +104 #105 #106
       +218 +220 #115 #116  fill=17 ( 0.0000 0.0000 6.9190 )    u=8 $ Space in Tube
147 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=8 $ Fuel
Tube
148 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=8 $ Fuel Tube Weld Posts
149 3 -1.0025 -334 +333  #147  #148
          fill=17 ( 0.0000 0.0000 6.9190 )  u=8 $ Space Around Weld Posts
150 3 -1.0025 +333 +334  fill=17 ( 0.0000 0.0000 6.9190 )  u=8 $ Exterior Space
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
c Cell Cards - Q2 Peripheral Tube, Absorber and Retainer
151 12 -2.358 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber -Y
152 7 -2.702 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  -Y
153 7 -2.7020 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber +Y
154 7 -2.7020 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=7 $ Absorber Clad  +Y
155 6 -7.940 -105 +215 +216   u=7 $ Retainer -Y
156 6 -7.9400 -106 +215 +216   u=7 $ Retainer+Y
157 6 -7.940 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber -Y
158 3 -1.0025 -102 #151  #152  #157  fill=17 ( 0.0000 0.0000 6.9190 ) u=7 $ Gap Weld Post
to Absorber -Y
159 6 -7.9400 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=7 $ Weld Post in Absorber +Y
160 3 -1.0025 -104 #153  #154  #159  fill=17 ( 0.0000 0.0000 6.9190 ) u=7 $ Gap Weld Post
to Absorber +Y
161 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber -X
162 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  -X
163 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber +X
164 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=7 $ Absorber Clad  +X
165 6 -7.9400 -221 +331 +332   u=7 $ Retainer -X
166 6 -7.940 -222 +331 +332   u=7 $ Retainer+X
167 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate-X
168 3 -1.0025 -218 #161  #162  #167  fill=17 ( 0.0000 0.0000 6.9190 ) u=7 $ Gap Weld Post
to Plate -X
169 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=7 $ Weld Post in Plate +X
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
170 3 -1.0025 -220 #163  #164  #169  fill=17 ( 0.0000 0.0000 6.9190 ) u=7 $ Gap Weld Post
to Plate +X
171 3 -1.0025 -333
       +102 +104 #105 #106
       +218 +220 #115 #116  fill=17 ( 0.0000 0.0000 6.9190 )    u=7 $ Space in Tube
172 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=7 $ Fuel
Tube
173 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=7 $ Fuel Tube Weld Posts
174 3 -1.0025 -334 +333  #172  #173
            fill=17 ( 0.0000 0.0000 6.9190 )  u=7 $ Space Around Weld Posts
175 3 -1.0025 +333 +334  fill=17 ( 0.0000 0.0000 6.9190 )  u=7 $ Exterior Space
c Cell Cards - Q3 Peripheral Tube, Absorber and Retainer
176 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber -Y
177 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  -Y
178 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber +Y
179 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=6 $ Absorber Clad  +Y
180 6 -7.9400 -105 +215 +216   u=6 $ Retainer -Y
181 6 -7.940 -106 +215 +216   u=6 $ Retainer+Y
182 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber -Y
183 3 -1.0025 -102 #176  #177  #182  fill=17 ( 0.0000 0.0000 6.9190 ) u=6 $ Gap Weld Post
to Absorber -Y
184 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=6 $ Weld Post in Absorber +Y
185 3 -1.0025 -104 #178  #179  #184  fill=17 ( 0.0000 0.0000 6.9190 ) u=6 $ Gap Weld Post
to Absorber +Y
186 7 -2.7020 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber -X
187 7 -2.7020 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  -X
188 12 -2.358 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber +X
189 7 -2.702 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=6 $ Absorber Clad  +X
190 6 -7.9400 -221 +331 +332   u=6 $ Retainer -X
191 6 -7.940 -222 +331 +332   u=6 $ Retainer+X
192 6 -7.9400 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate-X
193 3 -1.0025 -218 #186  #187  #192  fill=17 ( 0.0000 0.0000 6.9190 ) u=6 $ Gap Weld Post
to Plate -X
194 6 -7.940 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=6 $ Weld Post in Plate +X
195 3 -1.0025 -220 #188  #189  #194  fill=17 ( 0.0000 0.0000 6.9190 ) u=6 $ Gap Weld Post
to Plate +X
196 3 -1.0025 -333
       +102 +104 #105 #106
       +218 +220 #115 #116  fill=17 ( 0.0000 0.0000 6.9190 )    u=6 $ Space in Tube
197 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
       +170 +171 +172 +173 +174 +175 +176 +177 +178
       +259 +260 +261 +262 +263 +264 +265 +266 +267
       +268 +269 +270 +271 +272 +273 +274 +275 +276
       +277 +278 +279 +280 +281 +282 +283 +284 +285
       +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=6 $ Fuel
Tube
198 6 -7.940 -334 +333
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214:
       -295:-296:-297:-298:-299:-300:-301:-302:-303:
       -304:-305:-306:-307:-308:-309:-310:-311:-312:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=6 $ Fuel Tube Weld Posts
199 3 -1.0025 -334 +333  #197  #198
          fill=17 ( 0.0000 0.0000 6.9190 )  u=6 $ Space Around Weld Posts
200 3 -1.0025 +333 +334  fill=17 ( 0.0000 0.0000 6.9190 )  u=6 $ Exterior Space
c Cell Cards - Q4 Peripheral Tube, Absorber and Retainer
201 7 -2.7020 -101  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber -Y
202 7 -2.7020 -102 +101 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  -Y
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
203 12 -2.358 -103  +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber +Y
204 7 -2.702 -104 +103 +107 +108 +109 +110 +111 +112 +113 +114 +115
          +116 +117 +118 +119 +120 +121 +122 +123 +124
          +125 +126 +127 +128 +129 +130 +131 +132 +133
          +134 +135 +136 +137 +138 +139 +140 +141 +142  +215 +216 u=5 $ Absorber Clad  +Y
205 6 -7.9400 -105 +215 +216   u=5 $ Retainer -Y
206 6 -7.940 -106 +215 +216   u=5 $ Retainer+Y
207 6 -7.9400 -102
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber -Y
208 3 -1.0025 -102 #201  #202  #207  fill=17 ( 0.0000 0.0000 6.9190 ) u=5 $ Gap Weld Post
to Absorber -Y
209 6 -7.940 -104
       (-179:-180:-181:-182:-183:-184:-185:-186:-187:
       -188:-189:-190:-191:-192:-193:-194:-195:-196:
       -197:-198:-199:-200:-201:-202:-203:-204:-205:
       -206:-207:-208:-209:-210:-211:-212:-213:-214)      u=5 $ Weld Post in Absorber +Y
210 3 -1.0025 -104 #203  #204  #209  fill=17 ( 0.0000 0.0000 6.9190 ) u=5 $ Gap Weld Post
to Absorber +Y
211 12 -2.358 -217  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber -X
212 7 -2.702 -218 +217 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  -X
213 7 -2.7020 -219  +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber +X
214 7 -2.7020 -220 +219 +223 +224 +225 +226 +227 +228 +229 +230 +231
          +232 +233 +234 +235 +236 +237 +238 +239 +240
          +241 +242 +243 +244 +245 +246 +247 +248 +249
          +250 +251 +252 +253 +254 +255 +256 +257 +258  +331 +332 u=5 $ Absorber Clad  +X
215 6 -7.940 -221 +331 +332   u=5 $ Retainer -X
216 6 -7.9400 -222 +331 +332   u=5 $ Retainer+X
217 6 -7.940 -218
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate-X
218 3 -1.0025 -218 #211  #212  #217  fill=17 ( 0.0000 0.0000 6.9190 ) u=5 $ Gap Weld Post
to Plate -X
219 6 -7.9400 -220
       (-295:-296:-297:-298:-299:-300:-301:-302:-303:
       -313:-314:-315:-316:-317:-318:-319:-320:-321:
       -322:-323:-324:-325:-326:-327:-328:-329:-330:
       -304:-305:-306:-307:-308:-309:-310:-311:-312)      u=5 $ Weld Post in Plate +X
220 3 -1.0025 -220 #213  #214  #219  fill=17 ( 0.0000 0.0000 6.9190 ) u=5 $ Gap Weld Post
to Plate +X
221 3 -1.0025 -333
       +102 +104 #105 #106
       +218 +220 #115 #116  fill=17 ( 0.0000 0.0000 6.9190 )    u=5 $ Space in Tube
222 8 -7.821 -334 +333
       +143 +144 +145 +146 +147 +148 +149 +150 +151
       +152 +153 +154 +155 +156 +157 +158 +159 +160
       +161 +162 +163 +164 +165 +166 +167 +168 +169
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
        +170 +171 +172 +173 +174 +175 +176 +177 +178
        +259 +260 +261 +262 +263 +264 +265 +266 +267
        +268 +269 +270 +271 +272 +273 +274 +275 +276
        +277 +278 +279 +280 +281 +282 +283 +284 +285
        +286 +287 +288 +289 +290 +291 +292 +293 +294     +215 +216 +331 +332 u=5 $ Fuel
Tube
223 6 -7.940 -334 +333
        (-179:-180:-181:-182:-183:-184:-185:-186:-187:
        -188:-189:-190:-191:-192:-193:-194:-195:-196:
        -197:-198:-199:-200:-201:-202:-203:-204:-205:
        -206:-207:-208:-209:-210:-211:-212:-213:-214:
        -295:-296:-297:-298:-299:-300:-301:-302:-303:
        -304:-305:-306:-307:-308:-309:-310:-311:-312:
        -313:-314:-315:-316:-317:-318:-319:-320:-321:
        -322:-323:-324:-325:-326:-327:-328:-329:-330)      u=5 $ Fuel Tube Weld Posts
224 3 -1.0025 -334 +333  #222  #223
            fill=17 ( 0.0000 0.0000 6.9190 )  u=5 $ Space Around Weld Posts
225 3 -1.0025 +333 +334  fill=17 ( 0.0000 0.0000 6.9190 )  u=5 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in Y direction
351 8 -7.821 -351 +357 +358  +395 +396 +397 +398 +399 +400
         +401 +402 +403 +404 +405 +406 +407 +408 +409 +410
         +411 +412 +413 +414 +415 +416 +417 +418 +419 +420
         +421 +422 +423 +424 +425 +426 +427 +428 +429 +430      u=4 $ DFC Inner Formed Plt
352 12 -2.358 -353 +351 +357 +358  +359 +360 +361 +362 +363 +364
         +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
         +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
         +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $  Absorber
353 7 -2.702 -352 +353 +357 +358  +359 +360 +361 +362 +363 +364
         +365 +366 +367 +368 +369 +370 +371 +372 +373 +374
         +375 +376 +377 +378 +379 +380 +381 +382 +383 +384
         +385 +386 +387 +388 +389 +390 +391 +392 +393 +394      u=4 $ Absorber Clad
354 6 -7.940 -354 +357 +358     u=4 $ Retainer +Y
355 6 -7.940 -352
        (-431:-432:-433:-434:-435:-436:-437:-438:-439:
        -440:-441:-442:-443:-444:-445:-446:-447:-448:
        -449:-450:-451:-452:-453:-454:-455:-456:-457:
        -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Post in Absorber +Y
356 3 -1.001 -352 #352  #353  #355  fill=17 ( 0.0000 0.0000 6.9190 )  u=4 $ Gap Weld Post
to Absorber +Y
357 6 -7.940 -351
        (-431:-432:-433:-434:-435:-436:-437:-438:-439:
        -440:-441:-442:-443:-444:-445:-446:-447:-448:
        -449:-450:-451:-452:-453:-454:-455:-456:-457:
        -458:-459:-460:-461:-462:-463:-464:-465:-466)       u=4 $ Weld Posts in Plate +Y
358 3 -1.0025 -351 #351  #357   fill=17 ( 0.0000 0.0000 6.9190 )  u=4 $ Space Around Weld
Posts+Y
359 3 -1.0025 -354 #354    fill=17 ( 0.0000 0.0000 6.9190 )  u=4 $ Space Inside Retainer
+Y
360 8 -7.821 -355      u=4 $ Outer Plate Part +Y
361 8 -7.821 -356 +351     u=4 $ Inner Plate Part +Y
362 3 -1.0025 +351 +352 +353 +354 +355 +356 +357 +358
            fill=17 ( 0.0000 0.0000 6.9190 )     u=4 $ Exterior Space
c Cell Cards - Plates, Absorber, and Retainer in X direction
471 8 -7.821 -471 +476 +477  +514 +515 +516 +517 +518 +519
         +520 +521 +522 +523 +524 +525 +526 +527 +528 +529
         +530 +531 +532 +533 +534 +535 +536 +537 +538 +539
         +540 +541 +542 +543 +544 +545 +546 +547 +548 +549      u=3 $ DFC Inner Formed Plt
472 12 -2.358 -473  +476 +477  +478 +479 +480 +481 +482 +483
         +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
         +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
         +508 +509 +510 +511 +512 +513      u=3 $ Absorber
473 7 -2.702 -472 +473 +476 +477  +478 +479 +480 +481 +482 +483
         +484 +485 +486 +487 +488 +489 +490 +491 +492 +493 +494 +495
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
        +496 +497 +498 +499 +500 +501 +502 +503 +504 +505 +506 +507
        +508 +509 +510 +511 +512 +513      u=3 $ Absorber Clad
474 6 -7.940 -474 +476 +477     u=3 $Retainer +X
475 6 -7.940 -472
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
       -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Post in Absorber +X
476 3 -1.0025 -472  #472  #473  #475  fill=17 ( 0.0000 0.0000 6.9190 ) u=3 $ Gap Weld
Post to Absorber +X
477 6 -7.940 -471
       (-550:-551:-552:-553:-554:-555:-556:-557:-558:
       -559:-560:-561:-562:-563:-564:-565:-566:-567:
       -568:-569:-570:-571:-572:-573:-574:-575:-576:
       -577:-578:-579:-580:-581:-582:-583:-584:-585)       u=3 $ Weld Posts in Plate +X
478 3 -1.0025 -471 #471   #477  fill=17 ( 0.0000 0.0000 6.9190 )  u=3 $ Space Around Weld
Posts +X
479 3 -1.0025 -474 #474    fill=17 ( 0.0000 0.0000 6.9190 )  u=3 $ Space Inside Retainer
+X
480 8 -7.821 -475      u=3 $ Outer Plate Part +X
481 3 -1.0025 +471 +472 +473 +474 +475 +476 +477
            fill=17 ( 0.0000 0.0000 6.9190 )  u=3 $ Exterior Space
C Cells - Basket
601 3 -1.0025 -601 -602 fill=7 *trcl=( -23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 1
602 like 601 but     fill=8 *trcl=( 23.4925 70.4774 0.0000 )   u=2 $ Tube Loc 2
603 like 601 but     fill=9 *trcl=( 0.0000 46.9849 0.0000 )   u=2 $ Tube Loc 4
604 like 601 but     fill=7 *trcl=( -70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 6
605 like 601 but     fill=9 *trcl=( -23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 7
606 like 601 but     fill=9 *trcl=( 23.4925 23.4925 0.0000 )   u=2 $ Tube Loc 8
607 like 601 but     fill=8 *trcl=( 70.4774 23.4925 0.0000 )   u=2 $ Tube Loc 9
608 like 601 but     fill=9 *trcl=( -46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 10
609 like 601 but     fill=9 *trcl=( 0.0000 0.0000 0.0000 )   u=2 $ Tube Loc 11
610 like 601 but     fill=9 *trcl=( 46.9849 0.0000 0.0000 )   u=2 $ Tube Loc 12
611 like 601 but     fill=6 *trcl=( -70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 13
612 like 601 but     fill=9 *trcl=( -23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 14
613 like 601 but     fill=9 *trcl=( 23.4925 -23.4925 0.0000 )   u=2 $ Tube Loc 15
614 like 601 but     fill=5 *trcl=( 70.4774 -23.4925 0.0000 )   u=2 $ Tube Loc 16
615 like 601 but     fill=9 *trcl=( 0.0000 -46.9849 0.0000 )   u=2 $ Tube Loc 18
616 like 601 but     fill=6 *trcl=( -23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 20
617 like 601 but     fill=5 *trcl=( 23.4925 -70.4774 0.0000 )   u=2 $ Tube Loc 21
618 3 -1.0025 -61  fill=10 *trcl=( -49.4170 49.4170 13.8684 )   u=2 $ Empty DFC Loc 3
619 like 618 but      *trcl=( 49.4170 49.4170 13.8684 )   u=2 $ Empty DFC Loc 5
620 like 618 but      *trcl=( -49.4170 -49.4170 13.8684 )   u=2 $ Empty DFC Loc 17
621 like 618 but      *trcl=( 49.4170 -49.4170 13.8684 )   u=2 $ Empty DFC Loc 19
622 8 -7.821 -603 +604
               #601  #602  #616  #617    u=2 $ Side Weldment Y
623 8 -7.821 -605 +606
               #604  #611  #607  #614    u=2 $ Side Weldment X
624 8 -7.821 -607 #601  #604 #605    fill=3 (5) u=2 $ Loc 3 DFC In Formed Plt
625 8 -7.821 -608 #601  #604 #605    fill=4 (5) u=2 $ Loc 3 DFC In Formed Plt
626 8 -7.821 -609 +610 #601  #604 #605    u=2 $ Loc 3 DFC Out Formed Pl
627 8 -7.821 -610 #601  #604 #605     u=2 $ Loc 3 DFC Out Formed Pl
628 8 -7.821 -611 #602  #606 #607    fill=4 u=2 $ Loc 5 DFC In Formed Plt
629 8 -7.821 -612 #602  #606 #607  +611  fill=3 u=2 $ Loc 5 DFC In Formed Plt
630 8 -7.821 -613 +614 #602  #606 #607    u=2 $ Loc 5 DFC Out Formed Pl
631 8 -7.821 -614 #602  #606 #607     u=2 $ Loc 5 DFC Out Formed Pl
632 8 -7.821 -615 #616  #611 #612    fill=4 (4) u=2 $ Loc 17 DFC In Formed Plt
633 8 -7.821 -616 #616  #611 #612    fill=3 (4) u=2 $ Loc 17 DFC In Formed Plt
634 8 -7.821 -617 +618 #616  #611 #612    u=2 $ Loc 17 DFC Out Formed Pl
635 8 -7.821 -618 #616  #611 #612     u=2 $ Loc 17 DFC Out Formed Pl
636 8 -7.821 -619 #617  #613 #614    fill=3 (3) u=2 $ Loc 19 DFC In Formed Plt
637 8 -7.821 -620 #617  #613 #614    fill=4 (3) u=2 $ Loc 19 DFC In Formed Plt
638 8 -7.821 -621 +622 #617  #613 #614    u=2 $ Loc 19 DFC Out Formed Pl
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
639 8 -7.821 -622 #617  #613 #614     u=2 $ Loc 19 DFC Out Formed Pl
640 3 -1.0025 #601 #602 #603 #604 #605 #606 #607 #608 #609 #610
      +607 +608 +609 +610 +611 +612 +613 +614
      #622  #623  #618  #619  +623 -2   u=2 $ Space Below Flood Plane
641 3 -1.0025 #608 #609 #610 #611 #612 #613 #614 #615 #616 #617
      +615 +616 +617 +618 +619 +620 +621 +622
      #622  #623  #620 #621   -623 -2   u=2 $ Space Below Flood Plane
642 0         #601 #602 #603 #604 #605 #606 #607 #608 #609 #610
      +607 +608 +609 +610 +611 +612 +613 +614
      #622  #623  +623 +2 #618 #619     u=2  $ Space Above Flood Plane
643 0         #608 #609 #610 #611 #612 #613 #614 #615 #616 #617
      +615 +616 +617 +618 +619 +620 +621 +622
      #622  #623  -623 +2 #620 #621     u=2  $ Space Above Flood Plane
c Cell Cards - Canister
701 3 -1.0025 -20  fill=12 *trcl=( -23.0901 70.0750 5.0984 )    u=1 $ Assy loc 1
702 like 701 but      *trcl=( 23.0901 70.0750 5.0984 )    u=1 $ Assy loc 2
703 3 -1.0025 -60  fill=11 *trcl=( -49.4170 49.4170 13.8684 )    u=1 $ Assy loc 3 DFC
704 like 701 but      *trcl=( 0.0000 46.5825 5.0984 )    u=1 $ Assy loc 4
705 3 -1.0025 -60  fill=11 *trcl=( 49.4170 49.4170 13.8684 )    u=1 $ Assy loc 5 DFC
706 like 701 but      *trcl=( -70.0750 23.0901 5.0984 )    u=1 $ Assy loc 6
707 like 701 but      *trcl=( -23.0901 23.0901 5.0984 )    u=1 $ Assy loc 7
708 like 701 but      *trcl=( 23.0901 23.0901 5.0984 )    u=1 $ Assy loc 8
709 like 701 but      *trcl=( 70.0750 23.0901 5.0984 )    u=1 $ Assy loc 9
710 like 701 but      *trcl=( -46.5825 0.0000 5.0984 )    u=1 $ Assy loc 10
711 like 701 but      *trcl=( 0.0000 0.0000 5.0984 )    u=1 $ Assy loc 11
712 like 701 but      *trcl=( 46.5825 0.0000 5.0984 )    u=1 $ Assy loc 12
713 like 701 but      *trcl=( -70.0750 -23.0901 5.0984 )    u=1 $ Assy loc 13
714 like 701 but      *trcl=( -23.0901 -23.0901 5.0984 )    u=1 $ Assy loc 14
715 like 701 but      *trcl=( 23.0901 -23.0901 5.0984 )    u=1 $ Assy loc 15
716 like 701 but      *trcl=( 70.0750 -23.0901 5.0984 )    u=1 $ Assy loc 16
717 3 -1.0025 -60  fill=11 *trcl=( -49.4170 -49.4170 13.8684 )    u=1 $ Assy loc 17 DFC
718 like 701 but      *trcl=( 0.0000 -46.5825 5.0984 )    u=1 $ Assy loc 18
719 3 -1.0025 -60  fill=11 *trcl=( 49.4170 -49.4170 13.8684 )    u=1 $ Assy loc 19 DFC
720 like 701 but      *trcl=( -23.0901 -70.0750 5.0984 )    u=1 $ Assy loc 20
721 like 701 but      *trcl=( 23.0901 -70.0750 5.0984 )    u=1 $ Assy loc 21
722 like 701 but      *trcl=( 0.0000 70.0560 5.0984 )    u=1 $ Assy loc 22
723 like 701 but      *trcl=( -23.0711 46.5636 5.0984 )    u=1 $ Assy loc 23
724 like 701 but      *trcl=( 23.0711 46.5636 5.0984 )    u=1 $ Assy loc 24
725 like 701 but      *trcl=( -46.5636 23.0711 5.0984 )    u=1 $ Assy loc 25
726 like 701 but      *trcl=( 0.0000 23.0711 5.0984 )    u=1 $ Assy loc 26
727 like 701 but      *trcl=( 46.5636 23.0711 5.0984 )    u=1 $ Assy loc 27
728 like 701 but      *trcl=( -70.0560 0.0000 5.0984 )    u=1 $ Assy loc 28
729 like 701 but      *trcl=( -23.0711 0.0000 5.0984 )    u=1 $ Assy loc 29
730 like 701 but      *trcl=( 23.0711 0.0000 5.0984 )    u=1 $ Assy loc 30
731 like 701 but      *trcl=( 70.0560 0.0000 5.0984 )    u=1 $ Assy loc 31
732 like 701 but      *trcl=( -46.5636 -23.0711 5.0984 )    u=1 $ Assy loc 32
733 like 701 but      *trcl=( 0.0000 -23.0711 5.0984 )    u=1 $ Assy loc 33
734 like 701 but      *trcl=( 46.5636 -23.0711 5.0984 )    u=1 $ Assy loc 34
735 like 701 but      *trcl=( -23.0711 -46.5636 5.0984 )    u=1 $ Assy loc 35
736 like 701 but      *trcl=( 23.0711 -46.5636 5.0984 )    u=1 $ Assy loc 36
737 like 701 but      *trcl=( 0.0000 -70.0560 5.0984 )    u=1 $ Assy loc 37
738 3 -1.0025 -701
                #701 #702 #703 #704 #705 #706 #707 #708 #709 #710
                #711 #712 #713 #714 #715 #716 #717 #718 #719 #720
                #721 #722 #723 #724 #725 #726 #727 #728 #729 #730
                #731 #732 #733 #734 #735 #736 #737       fill=2 u=1 $ Cavity
739 6 -7.940 -702  +701     u=1 $ Canister Shell / Lid / Bottom
740 13 -0.0001 +702       u=1 $ Remaining Space
c Cell Cards - Transfer Cask Geometry
801 13 -0.0001 -801 -802  fill=1 ( 0.0000 0.0000 6.9850 )   $ Cask cavity
802 8 -7.821 -801 +802 -806     $ Bottom plate
803 8 -7.821 -803 +802 +806 -807    $ Inner shell
804 9 -11.344 -804 +803 +806 -807    $ Lead shell
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
805 10 -1.632 -805 +804 +806 -807    $ NS-4-FR
806 8 -7.821 -801 +805 +806 -807    $ Outer shell
807 8 -7.821 -801 +802 +807     $ Top plate
808 8 -7.821 -808 +809  -814    $ Door rail
809 8 -7.821 -808 -810  -814    $ Door rail
810 8 -7.821 -813 -811 +812 -814    $ Door steel
811 13 -0.0001 -814 +801 #808 #809 #810      $ Exterior space to Reflector
812 0         +814       $ Exterior space

c Surfaces - Partial Flood Plane
1 PZ 374.2969       $ Flood plane -  fuel lattice
2 PZ 381.2159       $ Flood plane - assembly
c Surfaces - Fuel Rod - WE17H2 - WE Core - 17x17
3 RCC 0.0000 0.0000 3.4385 0.0000 0.0000 365.7600 0.3922 $ Fuel pellet stack
4 RCC 0.0000 0.0000 3.4385 0.0000 0.0000 382.5876 0.4000 $ Annulus + Plenum
5 RCC 0.0000 0.0000 1.4224 0.0000 0.0000 386.2261 0.4572 $ Clad + End-Caps
c Surfaces - Guide Tube - WE17H2 - WE Core - 17x17
7 CZ 0.5715       $ Guide tube inner surface
8 CZ 0.6096       $ Guide tube outer surface
c Surfaces - Instrument Tube - WE17H2 - WE Core - 17x17
10 CZ 0.5715       $ Inst tube inner surface
11 CZ 0.6096       $ Inst tube outer surface
c Surfaces - Pitch - WE17H2 - WE Core - 17x17
15 PX 0.6299       $ Lattice Cell Boundaries
16 PX -0.6299
17 PY 0.6299
18 PY -0.6299
c Surfaces - Fuel Assembly Array Inserted Into Assembly - WE17H2 - WE Core - 17x17
19 RPP -10.5356 10.5356 -10.5356 10.5356 6.9190 397.2560  $ Array
20 RPP -10.7010 10.7010 -10.7010 10.7010 0.0000 406.2159  $ Assembly Outer Dims
c Surfaces - DFC Content - Mixture Axial Extent
52 PZ 363.945
c Surface Cards - DFC
60 RPP -11.0490 11.0490 -11.0490 11.0490 1.5875 418.0904 $  Space inside DFC Shell
61 RPP -11.1709 11.1709 -11.1709 11.1709 0.0000 419.8366 $  DFC body
c Surface Cards - Tube, Absorber and Retainer
101 RPP -10.1346 10.1346 -11.4478 -11.1938 8.8900 428.6250 $ Absorber -Y
102 RPP -10.1346 10.1346 -11.4999 -11.1417 8.8900 428.6250 $ Absorber Clad  -Y
103 RPP -10.1346 10.1346 11.1938 11.4478 8.8900 428.6250 $ Absorber +Y
104 RPP -10.1346 10.1346 11.1417 11.4999 8.8900 428.6250 $ Absorber Clad  +Y
105 RPP -10.3378 10.3378 -11.1417 -11.1036 7.6200 430.5300 $ Retainer -Y
106 RPP -10.3378 10.3378 11.1036 11.1417 7.6200 430.5300 $ Retainer  +Y
107 RPP 4.2799 5.8801 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
108 RPP 4.2799 5.8801 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
109 RPP 4.2799 5.8801 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
110 RPP 4.2799 5.8801 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
111 RPP 4.2799 5.8801 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
112 RPP 4.2799 5.8801 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
113 RPP 4.2799 5.8801 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
114 RPP 4.2799 5.8801 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
115 RPP 4.2799 5.8801 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
116 RPP 4.2799 5.8801 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
117 RPP 4.2799 5.8801 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
118 RPP 4.2799 5.8801 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
119 RPP 4.2799 5.8801 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
120 RPP 4.2799 5.8801 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
121 RPP 4.2799 5.8801 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
122 RPP 4.2799 5.8801 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
123 RPP 4.2799 5.8801 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
124 RPP 4.2799 5.8801 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
125 RPP -5.8801 -4.2799 -12.3698 12.3698 10.4648 13.6652 $ Weld Post Slot Y Absorber
126 RPP -5.8801 -4.2799 -12.3698 12.3698 26.9748 30.1752 $ Weld Post Slot Y Absorber
127 RPP -5.8801 -4.2799 -12.3698 12.3698 52.3748 55.5752 $ Weld Post Slot Y Absorber
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
128 RPP -5.8801 -4.2799 -12.3698 12.3698 77.7748 80.9752 $ Weld Post Slot Y Absorber
129 RPP -5.8801 -4.2799 -12.3698 12.3698 103.1748 106.3752 $ Weld Post Slot Y Absorber
130 RPP -5.8801 -4.2799 -12.3698 12.3698 128.5748 131.7752 $ Weld Post Slot Y Absorber
131 RPP -5.8801 -4.2799 -12.3698 12.3698 153.9748 157.1752 $ Weld Post Slot Y Absorber
132 RPP -5.8801 -4.2799 -12.3698 12.3698 179.3748 182.5752 $ Weld Post Slot Y Absorber
133 RPP -5.8801 -4.2799 -12.3698 12.3698 204.7748 207.9752 $ Weld Post Slot Y Absorber
134 RPP -5.8801 -4.2799 -12.3698 12.3698 230.1748 233.3752 $ Weld Post Slot Y Absorber
135 RPP -5.8801 -4.2799 -12.3698 12.3698 255.5748 258.7752 $ Weld Post Slot Y Absorber
136 RPP -5.8801 -4.2799 -12.3698 12.3698 280.9748 284.1752 $ Weld Post Slot Y Absorber
137 RPP -5.8801 -4.2799 -12.3698 12.3698 306.3748 309.5752 $ Weld Post Slot Y Absorber
138 RPP -5.8801 -4.2799 -12.3698 12.3698 331.7748 334.9752 $ Weld Post Slot Y Absorber
139 RPP -5.8801 -4.2799 -12.3698 12.3698 357.1748 360.3752 $ Weld Post Slot Y Absorber
140 RPP -5.8801 -4.2799 -12.3698 12.3698 382.5748 385.7752 $ Weld Post Slot Y Absorber
141 RPP -5.8801 -4.2799 -12.3698 12.3698 407.9748 411.1752 $ Weld Post Slot Y Absorber
142 RPP -5.8801 -4.2799 -12.3698 12.3698 424.4848 427.6852 $ Weld Post Slot Y Absorber
143 C/Y 5.0800 12.0650 0.4191    $ Weld Post Hole Y
144 C/Y 5.0800 28.5750 0.4191    $ Weld Post Hole Y
145 C/Y 5.0800 53.9750 0.4191    $ Weld Post Hole Y
146 C/Y 5.0800 79.3750 0.4191    $ Weld Post Hole Y
147 C/Y 5.0800 104.7750 0.4191    $ Weld Post Hole Y
148 C/Y 5.0800 130.1750 0.4191    $ Weld Post Hole Y
149 C/Y 5.0800 155.5750 0.4191    $ Weld Post Hole Y
150 C/Y 5.0800 180.9750 0.4191    $ Weld Post Hole Y
151 C/Y 5.0800 206.3750 0.4191    $ Weld Post Hole Y
152 C/Y 5.0800 231.7750 0.4191    $ Weld Post Hole Y
153 C/Y 5.0800 257.1750 0.4191    $ Weld Post Hole Y
154 C/Y 5.0800 282.5750 0.4191    $ Weld Post Hole Y
155 C/Y 5.0800 307.9750 0.4191    $ Weld Post Hole Y
156 C/Y 5.0800 333.3750 0.4191    $ Weld Post Hole Y
157 C/Y 5.0800 358.7750 0.4191    $ Weld Post Hole Y
158 C/Y 5.0800 384.1750 0.4191    $ Weld Post Hole Y
159 C/Y 5.0800 409.5750 0.4191    $ Weld Post Hole Y
160 C/Y 5.0800 426.0850 0.4191    $ Weld Post Hole Y
161 C/Y -5.0800 12.0650 0.4191    $ Weld Post Hole Y
162 C/Y -5.0800 28.5750 0.4191    $ Weld Post Hole Y
163 C/Y -5.0800 53.9750 0.4191    $ Weld Post Hole Y
164 C/Y -5.0800 79.3750 0.4191    $ Weld Post Hole Y
165 C/Y -5.0800 104.7750 0.4191    $ Weld Post Hole Y
166 C/Y -5.0800 130.1750 0.4191    $ Weld Post Hole Y
167 C/Y -5.0800 155.5750 0.4191    $ Weld Post Hole Y
168 C/Y -5.0800 180.9750 0.4191    $ Weld Post Hole Y
169 C/Y -5.0800 206.3750 0.4191    $ Weld Post Hole Y
170 C/Y -5.0800 231.7750 0.4191    $ Weld Post Hole Y
171 C/Y -5.0800 257.1750 0.4191    $ Weld Post Hole Y
172 C/Y -5.0800 282.5750 0.4191    $ Weld Post Hole Y
173 C/Y -5.0800 307.9750 0.4191    $ Weld Post Hole Y
174 C/Y -5.0800 333.3750 0.4191    $ Weld Post Hole Y
175 C/Y -5.0800 358.7750 0.4191    $ Weld Post Hole Y
176 C/Y -5.0800 384.1750 0.4191    $ Weld Post Hole Y
177 C/Y -5.0800 409.5750 0.4191    $ Weld Post Hole Y
178 C/Y -5.0800 426.0850 0.4191    $ Weld Post Hole Y
179 C/Y 5.0800 12.0650 0.3175    $ Weld Post Y
180 C/Y 5.0800 28.5750 0.3175    $ Weld Post Y
181 C/Y 5.0800 53.9750 0.3175    $ Weld Post Y
182 C/Y 5.0800 79.3750 0.3175    $ Weld Post Y
183 C/Y 5.0800 104.7750 0.3175    $ Weld Post Y
184 C/Y 5.0800 130.1750 0.3175    $ Weld Post Y
185 C/Y 5.0800 155.5750 0.3175    $ Weld Post Y
186 C/Y 5.0800 180.9750 0.3175    $ Weld Post Y
187 C/Y 5.0800 206.3750 0.3175    $ Weld Post Y
188 C/Y 5.0800 231.7750 0.3175    $ Weld Post Y
189 C/Y 5.0800 257.1750 0.3175    $ Weld Post Y
190 C/Y 5.0800 282.5750 0.3175    $ Weld Post Y
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
191 C/Y 5.0800 307.9750 0.3175    $ Weld Post Y
192 C/Y 5.0800 333.3750 0.3175    $ Weld Post Y
193 C/Y 5.0800 358.7750 0.3175    $ Weld Post Y
194 C/Y 5.0800 384.1750 0.3175    $ Weld Post Y
195 C/Y 5.0800 409.5750 0.3175    $ Weld Post Y
196 C/Y 5.0800 426.0850 0.3175    $ Weld Post Y
197 C/Y -5.0800 12.0650 0.3175    $ Weld Post Y
198 C/Y -5.0800 28.5750 0.3175    $ Weld Post Y
199 C/Y -5.0800 53.9750 0.3175    $ Weld Post Y
200 C/Y -5.0800 79.3750 0.3175    $ Weld Post Y
201 C/Y -5.0800 104.7750 0.3175    $ Weld Post Y
202 C/Y -5.0800 130.1750 0.3175    $ Weld Post Y
203 C/Y -5.0800 155.5750 0.3175    $ Weld Post Y
204 C/Y -5.0800 180.9750 0.3175    $ Weld Post Y
205 C/Y -5.0800 206.3750 0.3175    $ Weld Post Y
206 C/Y -5.0800 231.7750 0.3175    $ Weld Post Y
207 C/Y -5.0800 257.1750 0.3175    $ Weld Post Y
208 C/Y -5.0800 282.5750 0.3175    $ Weld Post Y
209 C/Y -5.0800 307.9750 0.3175    $ Weld Post Y
210 C/Y -5.0800 333.3750 0.3175    $ Weld Post Y
211 C/Y -5.0800 358.7750 0.3175    $ Weld Post Y
212 C/Y -5.0800 384.1750 0.3175    $ Weld Post Y
213 C/Y -5.0800 409.5750 0.3175    $ Weld Post Y
214 C/Y -5.0800 426.0850 0.3175    $ Weld Post Y
215 C/Y 0.0000 415.2900 1.5875    $ Water Circulation Hole Y
216 C/Y 0.0000 22.8600 1.5875    $ Water Circulation Hole Y
217 RPP -11.4478 -11.1938 -10.1346 10.1346 8.8900 428.6250 $ Absorber -X
218 RPP -11.4999 -11.1417 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  -X
219 RPP 11.1938 11.4478 -10.1346 10.1346 8.8900 428.6250 $ Absorber +X
220 RPP 11.1417 11.4999 -10.1346 10.1346 8.8900 428.6250 $ Absorber Clad  +X
221 RPP -11.1417 -11.1036 -10.3378 10.3378 7.6200 430.5300 $ Retainer -X
222 RPP 11.1036 11.1417 -10.3378 10.3378 7.6200 430.5300 $ Retainer  +X
223 RPP -12.3698 12.3698 4.2799 5.8801 10.4648 13.6652 $ Weld Post Slot X Absorber
224 RPP -12.3698 12.3698 4.2799 5.8801 26.9748 30.1752 $ Weld Post Slot X Absorber
225 RPP -12.3698 12.3698 4.2799 5.8801 52.3748 55.5752 $ Weld Post Slot X Absorber
226 RPP -12.3698 12.3698 4.2799 5.8801 77.7748 80.9752 $ Weld Post Slot X Absorber
227 RPP -12.3698 12.3698 4.2799 5.8801 103.1748 106.3752 $ Weld Post Slot X Absorber
228 RPP -12.3698 12.3698 4.2799 5.8801 128.5748 131.7752 $ Weld Post Slot X Absorber
229 RPP -12.3698 12.3698 4.2799 5.8801 153.9748 157.1752 $ Weld Post Slot X Absorber
230 RPP -12.3698 12.3698 4.2799 5.8801 179.3748 182.5752 $ Weld Post Slot X Absorber
231 RPP -12.3698 12.3698 4.2799 5.8801 204.7748 207.9752 $ Weld Post Slot X Absorber
232 RPP -12.3698 12.3698 4.2799 5.8801 230.1748 233.3752 $ Weld Post Slot X Absorber
233 RPP -12.3698 12.3698 4.2799 5.8801 255.5748 258.7752 $ Weld Post Slot X Absorber
234 RPP -12.3698 12.3698 4.2799 5.8801 280.9748 284.1752 $ Weld Post Slot X Absorber
235 RPP -12.3698 12.3698 4.2799 5.8801 306.3748 309.5752 $ Weld Post Slot X Absorber
236 RPP -12.3698 12.3698 4.2799 5.8801 331.7748 334.9752 $ Weld Post Slot X Absorber
237 RPP -12.3698 12.3698 4.2799 5.8801 357.1748 360.3752 $ Weld Post Slot X Absorber
238 RPP -12.3698 12.3698 4.2799 5.8801 382.5748 385.7752 $ Weld Post Slot X Absorber
239 RPP -12.3698 12.3698 4.2799 5.8801 407.9748 411.1752 $ Weld Post Slot X Absorber
240 RPP -12.3698 12.3698 4.2799 5.8801 424.4848 427.6852 $ Weld Post Slot X Absorber
241 RPP -12.3698 12.3698 -5.8801 -4.2799 10.4648 13.6652 $ Weld Post Slot X Absorber
242 RPP -12.3698 12.3698 -5.8801 -4.2799 26.9748 30.1752 $ Weld Post Slot X Absorber
243 RPP -12.3698 12.3698 -5.8801 -4.2799 52.3748 55.5752 $ Weld Post Slot X Absorber
244 RPP -12.3698 12.3698 -5.8801 -4.2799 77.7748 80.9752 $ Weld Post Slot X Absorber
245 RPP -12.3698 12.3698 -5.8801 -4.2799 103.1748 106.3752 $ Weld Post Slot X Absorber
246 RPP -12.3698 12.3698 -5.8801 -4.2799 128.5748 131.7752 $ Weld Post Slot X Absorber
247 RPP -12.3698 12.3698 -5.8801 -4.2799 153.9748 157.1752 $ Weld Post Slot X Absorber
248 RPP -12.3698 12.3698 -5.8801 -4.2799 179.3748 182.5752 $ Weld Post Slot X Absorber
249 RPP -12.3698 12.3698 -5.8801 -4.2799 204.7748 207.9752 $ Weld Post Slot X Absorber
250 RPP -12.3698 12.3698 -5.8801 -4.2799 230.1748 233.3752 $ Weld Post Slot X Absorber
251 RPP -12.3698 12.3698 -5.8801 -4.2799 255.5748 258.7752 $ Weld Post Slot X Absorber
252 RPP -12.3698 12.3698 -5.8801 -4.2799 280.9748 284.1752 $ Weld Post Slot X Absorber
253 RPP -12.3698 12.3698 -5.8801 -4.2799 306.3748 309.5752 $ Weld Post Slot X Absorber
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
254 RPP -12.3698 12.3698 -5.8801 -4.2799 331.7748 334.9752 $ Weld Post Slot X Absorber
255 RPP -12.3698 12.3698 -5.8801 -4.2799 357.1748 360.3752 $ Weld Post Slot X Absorber
256 RPP -12.3698 12.3698 -5.8801 -4.2799 382.5748 385.7752 $ Weld Post Slot X Absorber
257 RPP -12.3698 12.3698 -5.8801 -4.2799 407.9748 411.1752 $ Weld Post Slot X Absorber
258 RPP -12.3698 12.3698 -5.8801 -4.2799 424.4848 427.6852 $ Weld Post Slot X Absorber
259 C/X 5.0800 12.0650 0.4191    $ Weld Post Hole X
260 C/X 5.0800 28.5750 0.4191    $ Weld Post Hole X
261 C/X 5.0800 53.9750 0.4191    $ Weld Post Hole X
262 C/X 5.0800 79.3750 0.4191    $ Weld Post Hole X
263 C/X 5.0800 104.7750 0.4191    $ Weld Post Hole X
264 C/X 5.0800 130.1750 0.4191    $ Weld Post Hole X
265 C/X 5.0800 155.5750 0.4191    $ Weld Post Hole X
266 C/X 5.0800 180.9750 0.4191    $ Weld Post Hole X
267 C/X 5.0800 206.3750 0.4191    $ Weld Post Hole X
268 C/X 5.0800 231.7750 0.4191    $ Weld Post Hole X
269 C/X 5.0800 257.1750 0.4191    $ Weld Post Hole X
270 C/X 5.0800 282.5750 0.4191    $ Weld Post Hole X
271 C/X 5.0800 307.9750 0.4191    $ Weld Post Hole X
272 C/X 5.0800 333.3750 0.4191    $ Weld Post Hole X
273 C/X 5.0800 358.7750 0.4191    $ Weld Post Hole X
274 C/X 5.0800 384.1750 0.4191    $ Weld Post Hole X
275 C/X 5.0800 409.5750 0.4191    $ Weld Post Hole X
276 C/X 5.0800 426.0850 0.4191    $ Weld Post Hole X
277 C/X -5.0800 12.0650 0.4191    $ Weld Post Hole X
278 C/X -5.0800 28.5750 0.4191    $ Weld Post Hole X
279 C/X -5.0800 53.9750 0.4191    $ Weld Post Hole X
280 C/X -5.0800 79.3750 0.4191    $ Weld Post Hole X
281 C/X -5.0800 104.7750 0.4191    $ Weld Post Hole X
282 C/X -5.0800 130.1750 0.4191    $ Weld Post Hole X
283 C/X -5.0800 155.5750 0.4191    $ Weld Post Hole X
284 C/X -5.0800 180.9750 0.4191    $ Weld Post Hole X
285 C/X -5.0800 206.3750 0.4191    $ Weld Post Hole X
286 C/X -5.0800 231.7750 0.4191    $ Weld Post Hole X
287 C/X -5.0800 257.1750 0.4191    $ Weld Post Hole X
288 C/X -5.0800 282.5750 0.4191    $ Weld Post Hole X
289 C/X -5.0800 307.9750 0.4191    $ Weld Post Hole X
290 C/X -5.0800 333.3750 0.4191    $ Weld Post Hole X
291 C/X -5.0800 358.7750 0.4191    $ Weld Post Hole X
292 C/X -5.0800 384.1750 0.4191    $ Weld Post Hole X
293 C/X -5.0800 409.5750 0.4191    $ Weld Post Hole X
294 C/X -5.0800 426.0850 0.4191    $ Weld Post Hole X
295 C/X 5.0800 12.0650 0.3175    $ Weld Post X
296 C/X 5.0800 28.5750 0.3175    $ Weld Post X
297 C/X 5.0800 53.9750 0.3175    $ Weld Post X
298 C/X 5.0800 79.3750 0.3175    $ Weld Post X
299 C/X 5.0800 104.7750 0.3175    $ Weld Post X
300 C/X 5.0800 130.1750 0.3175    $ Weld Post X
301 C/X 5.0800 155.5750 0.3175    $ Weld Post X
302 C/X 5.0800 180.9750 0.3175    $ Weld Post X
303 C/X 5.0800 206.3750 0.3175    $ Weld Post X
304 C/X 5.0800 231.7750 0.3175    $ Weld Post X
305 C/X 5.0800 257.1750 0.3175    $ Weld Post X
306 C/X 5.0800 282.5750 0.3175    $ Weld Post X
307 C/X 5.0800 307.9750 0.3175    $ Weld Post X
308 C/X 5.0800 333.3750 0.3175    $ Weld Post X
309 C/X 5.0800 358.7750 0.3175    $ Weld Post X
310 C/X 5.0800 384.1750 0.3175    $ Weld Post X
311 C/X 5.0800 409.5750 0.3175    $ Weld Post X
312 C/X 5.0800 426.0850 0.3175    $ Weld Post X
313 C/X -5.0800 12.0650 0.3175    $ Weld Post X
314 C/X -5.0800 28.5750 0.3175    $ Weld Post X
315 C/X -5.0800 53.9750 0.3175    $ Weld Post X
316 C/X -5.0800 79.3750 0.3175    $ Weld Post X
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
317 C/X -5.0800 104.7750 0.3175    $ Weld Post X
318 C/X -5.0800 130.1750 0.3175    $ Weld Post X
319 C/X -5.0800 155.5750 0.3175    $ Weld Post X
320 C/X -5.0800 180.9750 0.3175    $ Weld Post X
321 C/X -5.0800 206.3750 0.3175    $ Weld Post X
322 C/X -5.0800 231.7750 0.3175    $ Weld Post X
323 C/X -5.0800 257.1750 0.3175    $ Weld Post X
324 C/X -5.0800 282.5750 0.3175    $ Weld Post X
325 C/X -5.0800 307.9750 0.3175    $ Weld Post X
326 C/X -5.0800 333.3750 0.3175    $ Weld Post X
327 C/X -5.0800 358.7750 0.3175    $ Weld Post X
328 C/X -5.0800 384.1750 0.3175    $ Weld Post X
329 C/X -5.0800 409.5750 0.3175    $ Weld Post X
330 C/X -5.0800 426.0850 0.3175    $ Weld Post X
331 C/X 0.0000 415.2900 1.5875    $ Water Circulation Hole X
332 C/X 0.0000 22.8600 1.5875    $ Water Circulation Hole X
333 RPP -11.4999 11.4999 -11.4999 11.4999 0.0000 440.6900 $  Space inside tube - cavity
extent
334 RPP -12.3698 12.3698 -12.3698 12.3698 7.6200 430.5300 $  Fuel tube
c Surface Cards - Plates, Absorber, and Retainer in Y direction
351  RPP 34.9921 37.8497 34.9921 82.5919 7.6200 430.5300  $ DFC Inner Formed Plt
352  RPP 37.8497 38.2078 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber Clad
353  RPP 37.9018 38.1558 39.4372 61.5098 8.8900 428.6250  $ DFC Absorber
354  RPP 38.2078 38.2460 39.2340 61.7130 8.8900 428.6250  $ DFC Retainer
355  RPP 37.8497 40.8497 63.1100 65.0150 7.6200 430.5300  $ Plate Outer Part
356  RPP 37.8497 40.8497 34.9921 37.8497 7.6200 430.5300  $ Plate Inner Part
357  C/X 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
358  C/X 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
359  RPP 34.9921 38.2460 44.5934 46.1936 10.4648 13.6652  $ Weld Post Slot Y Absorber
360  RPP 34.9921 38.2460 44.5934 46.1936 26.9748 30.1752  $ Weld Post Slot Y Absorber
361  RPP 34.9921 38.2460 44.5934 46.1936 52.3748 55.5752  $ Weld Post Slot Y Absorber
362  RPP 34.9921 38.2460 44.5934 46.1936 77.7748 80.9752  $ Weld Post Slot Y Absorber
363  RPP 34.9921 38.2460 44.5934 46.1936 103.1748 106.3752  $ Weld Post Slot Y Absorber
364  RPP 34.9921 38.2460 44.5934 46.1936 128.5748 131.7752  $ Weld Post Slot Y Absorber
365  RPP 34.9921 38.2460 44.5934 46.1936 153.9748 157.1752  $ Weld Post Slot Y Absorber
366  RPP 34.9921 38.2460 44.5934 46.1936 179.3748 182.5752  $ Weld Post Slot Y Absorber
367  RPP 34.9921 38.2460 44.5934 46.1936 204.7748 207.9752  $ Weld Post Slot Y Absorber
368  RPP 34.9921 38.2460 44.5934 46.1936 230.1748 233.3752  $ Weld Post Slot Y Absorber
369  RPP 34.9921 38.2460 44.5934 46.1936 255.5748 258.7752  $ Weld Post Slot Y Absorber
370  RPP 34.9921 38.2460 44.5934 46.1936 280.9748 284.1752  $ Weld Post Slot Y Absorber
371  RPP 34.9921 38.2460 44.5934 46.1936 306.3748 309.5752  $ Weld Post Slot Y Absorber
372  RPP 34.9921 38.2460 44.5934 46.1936 331.7748 334.9752  $ Weld Post Slot Y Absorber
373  RPP 34.9921 38.2460 44.5934 46.1936 357.1748 360.3752  $ Weld Post Slot Y Absorber
374  RPP 34.9921 38.2460 44.5934 46.1936 382.5748 385.7752  $ Weld Post Slot Y Absorber
375  RPP 34.9921 38.2460 44.5934 46.1936 407.9748 411.1752  $ Weld Post Slot Y Absorber
376  RPP 34.9921 38.2460 44.5934 46.1936 424.4848 427.6852  $ Weld Post Slot Y Absorber
377  RPP 34.9921 38.2460 54.7534 56.3536 10.4648 13.6652  $ Weld Post Slot Y Absorber
378  RPP 34.9921 38.2460 54.7534 56.3536 26.9748 30.1752  $ Weld Post Slot Y Absorber
379  RPP 34.9921 38.2460 54.7534 56.3536 52.3748 55.5752  $ Weld Post Slot Y Absorber
380  RPP 34.9921 38.2460 54.7534 56.3536 77.7748 80.9752  $ Weld Post Slot Y Absorber
381  RPP 34.9921 38.2460 54.7534 56.3536 103.1748 106.3752  $ Weld Post Slot Y Absorber
382  RPP 34.9921 38.2460 54.7534 56.3536 128.5748 131.7752  $ Weld Post Slot Y Absorber
383  RPP 34.9921 38.2460 54.7534 56.3536 153.9748 157.1752  $ Weld Post Slot Y Absorber
384  RPP 34.9921 38.2460 54.7534 56.3536 179.3748 182.5752  $ Weld Post Slot Y Absorber
385  RPP 34.9921 38.2460 54.7534 56.3536 204.7748 207.9752  $ Weld Post Slot Y Absorber
386  RPP 34.9921 38.2460 54.7534 56.3536 230.1748 233.3752  $ Weld Post Slot Y Absorber
387  RPP 34.9921 38.2460 54.7534 56.3536 255.5748 258.7752  $ Weld Post Slot Y Absorber
388  RPP 34.9921 38.2460 54.7534 56.3536 280.9748 284.1752  $ Weld Post Slot Y Absorber
389  RPP 34.9921 38.2460 54.7534 56.3536 306.3748 309.5752  $ Weld Post Slot Y Absorber
390  RPP 34.9921 38.2460 54.7534 56.3536 331.7748 334.9752  $ Weld Post Slot Y Absorber
391  RPP 34.9921 38.2460 54.7534 56.3536 357.1748 360.3752  $ Weld Post Slot Y Absorber
392  RPP 34.9921 38.2460 54.7534 56.3536 382.5748 385.7752  $ Weld Post Slot Y Absorber
393  RPP 34.9921 38.2460 54.7534 56.3536 407.9748 411.1752  $ Weld Post Slot Y Absorber
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
RPP 34.9921 38.2460 54.7534 56.3536 424.4848 427.6852  $ Weld Post Slot Y Absorber
C/X 55.5535 12.0650 0.4191     $ Weld Post Hole Y
C/X 55.5535 28.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 53.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 79.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 104.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 130.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 155.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 180.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 206.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 231.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 257.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 282.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 307.9750 0.4191     $ Weld Post Hole Y
C/X 55.5535 333.3750 0.4191     $ Weld Post Hole Y
C/X 55.5535 358.7750 0.4191     $ Weld Post Hole Y
C/X 55.5535 384.1750 0.4191     $ Weld Post Hole Y
C/X 55.5535 409.5750 0.4191     $ Weld Post Hole Y
C/X 55.5535 426.0850 0.4191     $ Weld Post Hole Y
C/X 45.3935 12.0650 0.4191     $ Weld Post Hole Y
C/X 45.3935 28.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 53.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 79.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 104.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 130.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 155.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 180.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 206.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 231.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 257.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 282.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 307.9750 0.4191     $ Weld Post Hole Y
C/X 45.3935 333.3750 0.4191     $ Weld Post Hole Y
C/X 45.3935 358.7750 0.4191     $ Weld Post Hole Y
C/X 45.3935 384.1750 0.4191     $ Weld Post Hole Y
C/X 45.3935 409.5750 0.4191     $ Weld Post Hole Y
C/X 45.3935 426.0850 0.4191     $ Weld Post Hole Y
C/X 55.5535 12.0650 0.3175     $ Weld Post Y
C/X 55.5535 28.5750 0.3175     $ Weld Post Y
C/X 55.5535 53.9750 0.3175     $ Weld Post Y
C/X 55.5535 79.3750 0.3175     $ Weld Post Y
C/X 55.5535 104.7750 0.3175     $ Weld Post Y
C/X 55.5535 130.1750 0.3175     $ Weld Post Y
C/X 55.5535 155.5750 0.3175     $ Weld Post Y
C/X 55.5535 180.9750 0.3175     $ Weld Post Y
C/X 55.5535 206.3750 0.3175     $ Weld Post Y
C/X 55.5535 231.7750 0.3175     $ Weld Post Y
C/X 55.5535 257.1750 0.3175     $ Weld Post Y
C/X 55.5535 282.5750 0.3175     $ Weld Post Y
C/X 55.5535 307.9750 0.3175     $ Weld Post Y
C/X 55.5535 333.3750 0.3175     $ Weld Post Y
C/X 55.5535 358.7750 0.3175     $ Weld Post Y
C/X 55.5535 384.1750 0.3175     $ Weld Post Y
C/X 55.5535 409.5750 0.3175     $ Weld Post Y
C/X 55.5535 426.0850 0.3175     $ Weld Post Y
C/X 45.3935 12.0650 0.3175     $ Weld Post Y
C/X 45.3935 28.5750 0.3175     $ Weld Post Y
C/X 45.3935 53.9750 0.3175     $ Weld Post Y
C/X 45.3935 79.3750 0.3175     $ Weld Post Y
C/X 45.3935 104.7750 0.3175     $ Weld Post Y
C/X 45.3935 130.1750 0.3175     $ Weld Post Y
C/X 45.3935 155.5750 0.3175     $ Weld Post Y
C/X 45.3935 180.9750 0.3175     $ Weld Post Y
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
C/X 45.3935 206.3750 0.3175     $ Weld Post Y
C/X 45.3935 231.7750 0.3175     $ Weld Post Y
C/X 45.3935 257.1750 0.3175     $ Weld Post Y
C/X 45.3935 282.5750 0.3175     $ Weld Post Y
C/X 45.3935 307.9750 0.3175     $ Weld Post Y
C/X 45.3935 333.3750 0.3175     $ Weld Post Y
C/X 45.3935 358.7750 0.3175     $ Weld Post Y
C/X 45.3935 384.1750 0.3175     $ Weld Post Y
C/X 45.3935 409.5750 0.3175     $ Weld Post Y
C/X 45.3935 426.0850 0.3175     $ Weld Post Y
c Surface Cards - Plates, Absorber, and Retainer in X direction
RPP 37.8496 82.6046 34.9921 37.8497 7.6200 430.5300  $ DFC Inner Formed Plt
RPP 39.4372 61.5098 37.8497 38.2078 8.8900 428.6250  $ DFC Absorber Clad
RPP 39.4372 61.5098 37.9018 38.1558 8.8900 428.6250  $ DFC Absorber
RPP 39.2340 61.7130 38.2078 38.2460 8.8900 428.6250  $ DFC Retainer
RPP 63.1100 65.0150 37.8497 42.8497 7.6200 430.5300  $ Plate Outer Part
C/Y 50.4735 415.2900 1.5875     $ Water Circulation Hole 5
C/Y 50.4735 22.8600 1.5875     $ Water Circulation Hole 5
RPP 44.5934 46.1936 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
RPP 44.5934 46.1936 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 10.4648 13.6652  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 26.9748 30.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 52.3748 55.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 77.7748 80.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 103.1748 106.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 128.5748 131.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 153.9748 157.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 179.3748 182.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 204.7748 207.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 230.1748 233.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 255.5748 258.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 280.9748 284.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 306.3748 309.5752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 331.7748 334.9752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 357.1748 360.3752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 382.5748 385.7752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 407.9748 411.1752  $ Weld Post Slot X Absorber
RPP 54.7534 56.3536 34.9921 38.2460 424.4848 427.6852  $ Weld Post Slot X Absorber
C/Y 55.5535 12.0650 0.4191     $ Weld Post Hole X
C/Y 55.5535 28.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 53.9750 0.4191     $ Weld Post Hole X
C/Y 55.5535 79.3750 0.4191     $ Weld Post Hole X
C/Y 55.5535 104.7750 0.4191     $ Weld Post Hole X
C/Y 55.5535 130.1750 0.4191     $ Weld Post Hole X
C/Y 55.5535 155.5750 0.4191     $ Weld Post Hole X
C/Y 55.5535 180.9750 0.4191     $ Weld Post Hole X
C/Y 55.5535 206.3750 0.4191     $ Weld Post Hole X
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
523  C/Y 55.5535 231.7750 0.4191     $ Weld Post Hole X
524  C/Y 55.5535 257.1750 0.4191     $ Weld Post Hole X
525  C/Y 55.5535 282.5750 0.4191     $ Weld Post Hole X
526  C/Y 55.5535 307.9750 0.4191     $ Weld Post Hole X
527  C/Y 55.5535 333.3750 0.4191     $ Weld Post Hole X
528  C/Y 55.5535 358.7750 0.4191     $ Weld Post Hole X
529  C/Y 55.5535 384.1750 0.4191     $ Weld Post Hole X
530  C/Y 55.5535 409.5750 0.4191     $ Weld Post Hole X
531  C/Y 55.5535 426.0850 0.4191     $ Weld Post Hole X
532  C/Y 45.3935 12.0650 0.4191     $ Weld Post Hole X
533  C/Y 45.3935 28.5750 0.4191     $ Weld Post Hole X
534  C/Y 45.3935 53.9750 0.4191     $ Weld Post Hole X
535  C/Y 45.3935 79.3750 0.4191     $ Weld Post Hole X
536  C/Y 45.3935 104.7750 0.4191     $ Weld Post Hole X
537  C/Y 45.3935 130.1750 0.4191     $ Weld Post Hole X
538  C/Y 45.3935 155.5750 0.4191     $ Weld Post Hole X
539  C/Y 45.3935 180.9750 0.4191     $ Weld Post Hole X
540  C/Y 45.3935 206.3750 0.4191     $ Weld Post Hole X
541  C/Y 45.3935 231.7750 0.4191     $ Weld Post Hole X
542  C/Y 45.3935 257.1750 0.4191     $ Weld Post Hole X
543  C/Y 45.3935 282.5750 0.4191     $ Weld Post Hole X
544  C/Y 45.3935 307.9750 0.4191     $ Weld Post Hole X
545  C/Y 45.3935 333.3750 0.4191     $ Weld Post Hole X
546  C/Y 45.3935 358.7750 0.4191     $ Weld Post Hole X
547  C/Y 45.3935 384.1750 0.4191     $ Weld Post Hole X
548  C/Y 45.3935 409.5750 0.4191     $ Weld Post Hole X
549  C/Y 45.3935 426.0850 0.4191     $ Weld Post Hole X
550  C/Y 55.5535 12.0650 0.3175     $ Weld Post X
551  C/Y 55.5535 28.5750 0.3175     $ Weld Post X
552  C/Y 55.5535 53.9750 0.3175     $ Weld Post X
553  C/Y 55.5535 79.3750 0.3175     $ Weld Post X
554  C/Y 55.5535 104.7750 0.3175     $ Weld Post X
555  C/Y 55.5535 130.1750 0.3175     $ Weld Post X
556  C/Y 55.5535 155.5750 0.3175     $ Weld Post X
557  C/Y 55.5535 180.9750 0.3175     $ Weld Post X
558  C/Y 55.5535 206.3750 0.3175     $ Weld Post X
559  C/Y 55.5535 231.7750 0.3175     $ Weld Post X
560  C/Y 55.5535 257.1750 0.3175     $ Weld Post X
561  C/Y 55.5535 282.5750 0.3175     $ Weld Post X
562  C/Y 55.5535 307.9750 0.3175     $ Weld Post X
563  C/Y 55.5535 333.3750 0.3175     $ Weld Post X
564  C/Y 55.5535 358.7750 0.3175     $ Weld Post X
565  C/Y 55.5535 384.1750 0.3175     $ Weld Post X
566  C/Y 55.5535 409.5750 0.3175     $ Weld Post X
567  C/Y 55.5535 426.0850 0.3175     $ Weld Post X
568  C/Y 45.3935 12.0650 0.3175     $ Weld Post X
569  C/Y 45.3935 28.5750 0.3175     $ Weld Post X
570  C/Y 45.3935 53.9750 0.3175     $ Weld Post X
571  C/Y 45.3935 79.3750 0.3175     $ Weld Post X
572  C/Y 45.3935 104.7750 0.3175     $ Weld Post X
573  C/Y 45.3935 130.1750 0.3175     $ Weld Post X
574  C/Y 45.3935 155.5750 0.3175     $ Weld Post X
575  C/Y 45.3935 180.9750 0.3175     $ Weld Post X
576  C/Y 45.3935 206.3750 0.3175     $ Weld Post X
577  C/Y 45.3935 231.7750 0.3175     $ Weld Post X
578  C/Y 45.3935 257.1750 0.3175     $ Weld Post X
579  C/Y 45.3935 282.5750 0.3175     $ Weld Post X
580  C/Y 45.3935 307.9750 0.3175     $ Weld Post X
581  C/Y 45.3935 333.3750 0.3175     $ Weld Post X
582  C/Y 45.3935 358.7750 0.3175     $ Weld Post X
583  C/Y 45.3935 384.1750 0.3175     $ Weld Post X
584  C/Y 45.3935 409.5750 0.3175     $ Weld Post X
585  C/Y 45.3935 426.0850 0.3175     $ Weld Post X
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
C Surfaces - Basket
601  RPP -12.3698 12.3698 -12.3698 12.3698 0.0000 440.6900  $ Tube Cavity Height
602 1 RPP -16.6116 16.6116 -16.6116 16.6116 0.0000 440.6900  $ Tube Corner Cuts
603  RPP -33.9471 33.9471 -83.6409 83.6409 7.6200 430.5300  $ Outer Surface Side Weld.
604  RPP -33.9471 33.9471 -81.7359 81.7359 7.6200 430.5300  $ Inner Surface Side Weld.
605  RPP -83.6409 83.6409 -33.9471 33.9471 7.6200 430.5300  $ Outer Surface Side Weld.
606  RPP -81.7359 81.7359 -33.9471 33.9471 7.6200 430.5300  $ Inner Surface Side Weld.
607  RPP -38.2459 -34.9922 38.2459 82.6045 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
608  RPP -82.5918 -34.9922 34.9922 38.2459 7.6200 430.5300  $ Loc 3 DFC In. Formed Plt
609  RPP -65.0150 -38.2459 63.1100 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
610  RPP -65.0150 -63.1100 38.2459 65.0150 7.6200 430.5300  $ Loc 3 DFC Out Formed Pl
611  RPP 34.9922 38.2459 34.9922 82.5918 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
612  RPP 38.2459 82.6045 34.9922 38.2459 7.6200 430.5300  $ Loc 5 DFC In. Formed Plt
613  RPP 38.2459 65.0150 63.1100 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
614  RPP 63.1100 65.0150 38.2459 65.0150 7.6200 430.5300  $ Loc 5 DFC Out Formed Pl
615  RPP -38.2459 -34.9922 -82.5918 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
616  RPP -82.6045 -38.2459 -38.2459 -34.9922 7.6200 430.5300  $ Loc 17 DFC In. Formed Plt
617  RPP -65.0150 -38.2459 -65.0150 -63.1100 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
618  RPP -65.0150 -63.1100 -65.0150 -38.2459 7.6200 430.5300  $ Loc 17 DFC Out Formed Pl
619  RPP 34.9922 38.2459 -82.6045 -38.2459 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
620  RPP 34.9922 82.5918 -38.2459 -34.9922 7.6200 430.5300  $ Loc 19 DFC In. Formed Plt
621  RPP 38.2459 65.0150 -65.0150 -63.1100 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
622  RPP 63.1100 65.0150 -65.0150 -38.2459 7.6200 430.5300  $ Loc 19 DFC Out Formed Pl
623  PY 0.0000       $ Cut Plane for Remaining Area
c Surface Cards - Canister
701 RCC 0.0000 0.0000  0.0000 0.0000 0.0000 440.6900  90.1700 $ Canister cavity
702 RCC 0.0000 0.0000  -6.9850 0.0000 0.0000 469.2650  91.4400 $ Canister
c Surface Cards - Transfer Cask Geometry
801 RCC 0.000 0.000 0.000 0.000 0.000 488.9500 111.7600  $ Cask Cylindrical Section
802 CZ 92.7100        $ Cask cavity radius
803 CZ 94.6150        $ Inner shell OR
804 CZ 102.7430        $ Lead shell OR
805 CZ 108.5850        $ Outer shell IR
806 PZ 30.4800        $ Top of bottom plate
807 PZ 453.3900        $ Bottom of top plate
808 RPP -104.3178 104.3178 -111.7600 111.7600 -12.7000 0.0000   $ Door Enclosing Shape
809 PY 97.0026        $ Inside rail surface
810 PY -97.0026        $ Inside rail surface
811 PY 96.52        $ Door surface
812 PY -96.52        $ Door surface
813 RHP 0.0000 0.0000 -12.7000 0.0000 0.0000 12.7000
          108.4699 0.0000 0.0000 89.73736 -73.7172 0.0000
          -89.7374 -73.7172 0.0000      $ Door prism
*814 RCC 0.000 0.000 -32.700 0.000 0.000 541.6500 131.7600  $ Cylinder to Reflect

c
c Materials List
c
c Fuel Pellet Material  5.00%  Weight UO2 [amu]  269.8995
m1    92235.66c -4.407E-02 92238.66c -8.374E-01  8016.62c -1.186E-01
c Clad Material
m2    26054.62c -7.063E-05 24050.62c -4.179E-05  7014.62c -4.980E-04
      26056.62c -1.149E-03 24052.62c -8.370E-04  7015.66c -1.981E-06
      26057.62c -2.702E-05 24053.62c -9.673E-05
      26058.62c -3.631E-06 24054.62c -2.448E-05
      40000.66c -9.823E-01 50000.42c -1.500E-02
c Water
m3     1001.62c -1.103E-01  8016.62c -8.754E-01
       1001.62c -6.986E-04  8016.62c -1.109E-02  5010.66c -4.419E-04
                                                 5011.66c -2.058E-03
mt3  lwtr.01t
c Lower Nozzle Material
m4
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
       1001.62c -3.240E-02  8016.62c -2.571E-01
       1001.62c -2.052E-04  8016.62c -3.257E-03  5010.66c -1.298E-04
                                                 5011.66c -6.045E-04
      24050.62c -5.607E-03 26054.62c -2.774E-02 28058.62c -4.509E-02
      24052.62c -1.123E-01 26056.62c -4.511E-01 28060.62c -1.796E-02
      24053.62c -1.298E-02 26057.62c -1.061E-02 28061.62c -7.940E-04
      24054.62c -3.285E-03 26058.62c -1.426E-03 28062.62c -2.570E-03
                                                28064.62c -6.796E-04
      25055.62c -1.413E-02
mt4  lwtr.01t
c Upper Nozzle Material
m5
      24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                28064.62c -9.623E-04
      25055.62c -2.000E-02
mt5  lwtr.01t
c SS304
m6    24050.62c -7.939E-03 26054.62c -3.927E-02 28058.62c -6.384E-02
      24052.62c -1.590E-01 26056.62c -6.387E-01 28060.62c -2.543E-02
      24053.62c -1.838E-02 26057.62c -1.502E-02 28061.62c -1.124E-03
      24054.62c -4.652E-03 26058.62c -2.019E-03 28062.62c -3.639E-03
                                                28064.62c -9.623E-04
      25055.62c -2.000E-02
c Aluminum
m7    13027.62c -1.000E+00
c Carbon Steel
m8    26054.62c -5.594E-02  6000.66c -1.000E-02
      26056.62c -9.098E-01
      26057.62c -2.140E-02
      26058.62c -2.876E-03
c Lead
m9    82206.66c -2.534E-01
      82207.66c -2.207E-01
      82208.66c -5.259E-01
c NS-F-FR
m10    5010.66c -9.313E-04  7014.62c -1.974E-02  8016.62c -4.250E-01
       5011.66c -3.772E-03  7015.66c -7.852E-05
      13027.62c -2.142E-01  1001.62c -6.001E-02  6000.66c -2.763E-01
c Concrete
m11   26054.62c -7.911E-04 14000.60c -3.370E-01
      26056.62c -1.287E-02
      26057.62c -3.026E-04
      26058.62c -4.067E-05
       1001.62c -1.000E-02 13027.62c -3.400E-02 20000.62c -4.400E-02
       8016.62c -5.320E-01 11023.62c -2.900E-02
c Absorber Material B4C-Al Plate
m12    5010.66c -6.011E-02 13027.62c -5.656E-01  6000.66c -9.430E-02
       5011.66c -2.799E-01
c Water Exterior
m13    1001.62c 2.0
       8016.62c 1.0
mt13  lwtr.01t
c Uranium Blanket  0.711%  Weight UO2 [amu]  270.0284
m14   92235.66c -6.267E-03 92238.66c -8.752E-01  8016.62c -1.185E-01
c Borated SS304
m15   28058.62c -9.072E-02 26054.62c -3.523E-02 24050.62c -7.939E-03
      28060.62c -3.614E-02 26056.62c -5.729E-01 24052.62c -1.590E-01
      28061.62c -1.598E-03 26057.62c -1.348E-02 24053.62c -1.838E-02
      28062.62c -5.171E-03 26058.62c -1.811E-03 24054.62c -4.652E-03
      28064.62c -1.367E-03 25055.62c -2.000E-02 15031.66c -4.500E-04
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
       5010.66c -3.535E-03 14000.60c -1.000E-02  6000.66c -8.000E-04
       5011.66c -1.646E-02 16000.62c -3.000E-04
c B4C
m16    5010.66c -1.384E-01  5011.66c -6.445E-01  6000.66c -2.171E-01
c Pyrex
m17    8016.62c -5.350E-01 14000.60c -3.770E-01 11023.62c -4.100E-02
      13027.62c -1.000E-02  5010.66c -6.540E-03  5011.66c -3.046E-02
c Borated Aluminum  25% B4C
m18    5010.66c -3.460E-02 13027.62c -7.500E-01  6000.66c -5.428E-02
       5011.66c -1.611E-01
c DFC fuel mixture material (if applicable)    Mix Height=362.3575in
m24   92235.66c -3.484E-02 92238.66c -6.620E-01  8016.62c -9.373E-02
       1001.62c -2.344E-02  8016.62c -1.860E-01
c
c Rotation Matrix
*TR1 0.0 0.0 0.0 45 135 90 -45 45 90 90 90 0  $ z-rotation 45 degrees
*TR2 0.0 0.0 0.0 135 225 90 45 135 90 90 90 0  $ z-rotation 135 degrees
*TR3 0.0 0.0 0.0 90 180 90 0 90 90 90 90 0  $ z-rotation 90 degrees
*TR4 0.0 0.0 0.0 180 270 90 90 180 90 90 90 0  $ z-rotation 180 degrees
*TR5 0.0 0.0 0.0 -90 0 90 -180 -90 90 90 90 0  $ z-rotation -90 degrees
c
c Cell Importances
c
mode n
imp:n 1 264r 0
c
c
c Criticality Controls
c
kcode 2000 1.00 30 530
c
c Source Distribution for Initial Generation
SDEF  CEL= D2
      ERG= D1
      POS= 0.0000 0.00 3.4385
      RAD= D3
      AXS= 0.00 0.00 1.00
      EXT= D4
C - Neutron Source Energy Source Distribution
#         SP1
      -3
c Assembly Source Distribution
#    SI2        SP2
          1        d
      801:701:19:15:-3 1
      801:702:19:15:-3 1
      801:703:-52 1
      801:704:19:15:-3 1
      801:703:-52 1
      801:706:19:15:-3 1
      801:707:19:15:-3 1
      801:708:19:15:-3 1
      801:709:19:15:-3 1
      801:710:19:15:-3 1
      801:711:19:15:-3 1
      801:712:19:15:-3 1
      801:713:19:15:-3 1
      801:714:19:15:-3 1
      801:715:19:15:-3 1
      801:716:19:15:-3 1
      801:703:-52 1
      801:718:19:15:-3 1
      801:703:-52 1
```

Figure 6.7.8-4 Transfer Cask Sample Input File – Damaged PWR Fuel TSC – Partially Flooded Mixture

```
      801:720:19:15:-3 1
      801:721:19:15:-3 1
      801:722:19:15:-3 1
      801:723:19:15:-3 1
      801:724:19:15:-3 1
      801:725:19:15:-3 1
      801:726:19:15:-3 1
      801:727:19:15:-3 1
      801:728:19:15:-3 1
      801:729:19:15:-3 1
      801:730:19:15:-3 1
      801:731:19:15:-3 1
      801:732:19:15:-3 1
      801:733:19:15:-3 1
      801:734:19:15:-3 1
      801:735:19:15:-3 1
      801:736:19:15:-3 1
      801:737:19:15:-3 1
C - Uniform Radial Distribution in Fuel Rod
# SI3 SP3
      0.0000 -21
      0.3922 1
C - Axial Source Profile
# SI4 SP4
      0 0.0
      365.76 1.0
c
c Random Number Generator Controls
c
RAND GEN=2 SEED=19073486328125
c
c
c Print Control
c
PRINT
c
```

Figure 6.7.8-5 DFC Fuel Mixture Height versus Reactivity

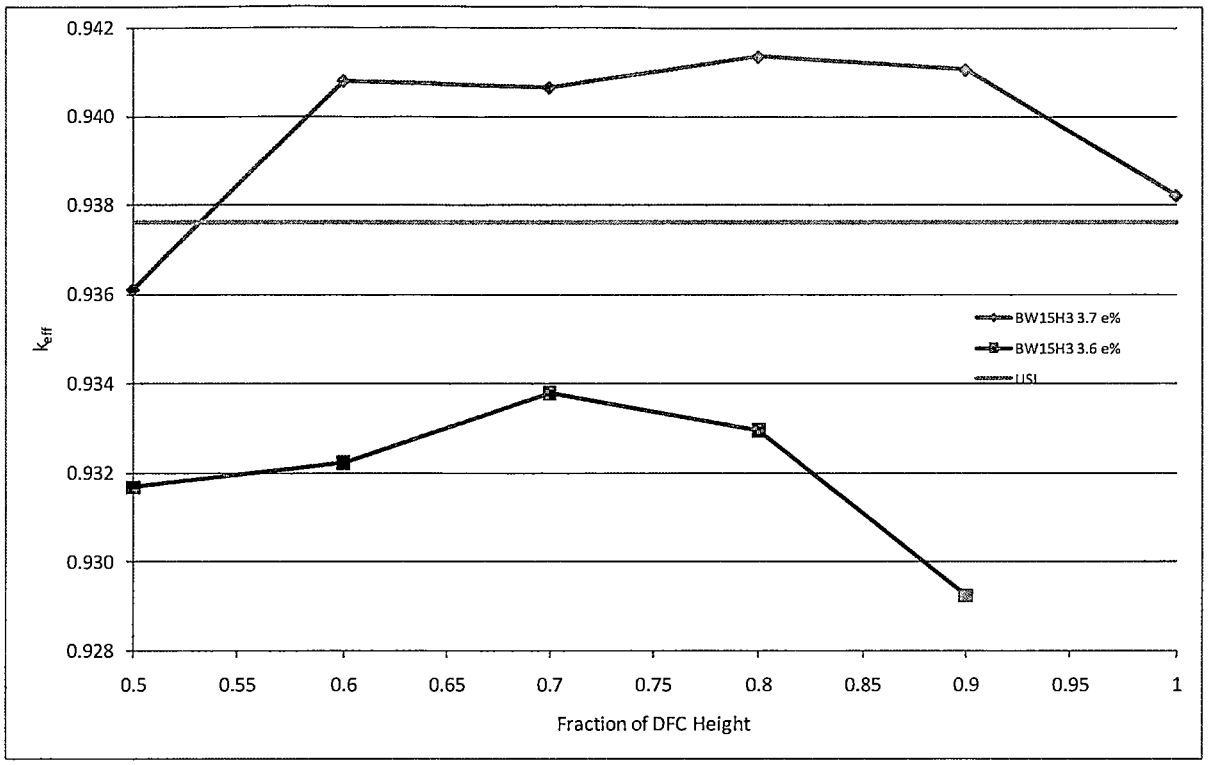


Figure 6.7.8-6 DFC Preferential Flood Analysis

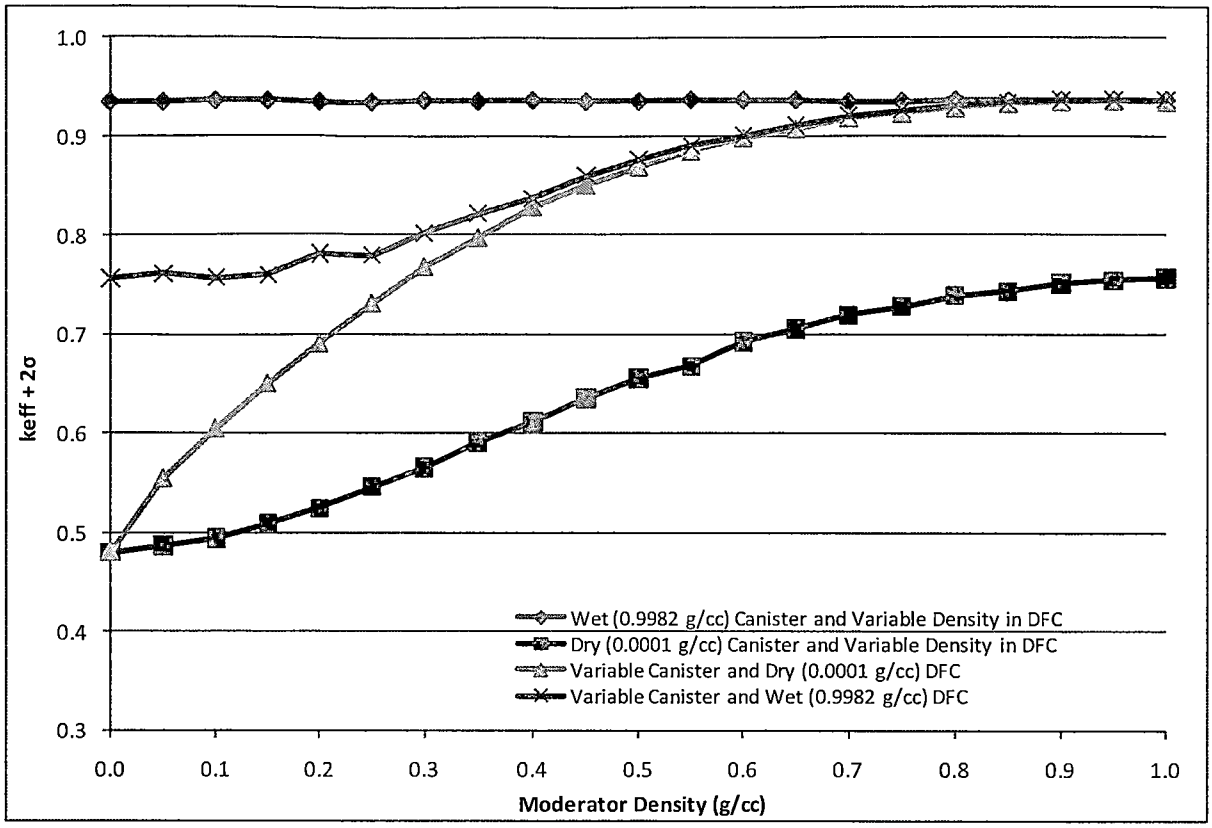


Figure 6.7.8-7 DFC Cask Partial Flooding Study

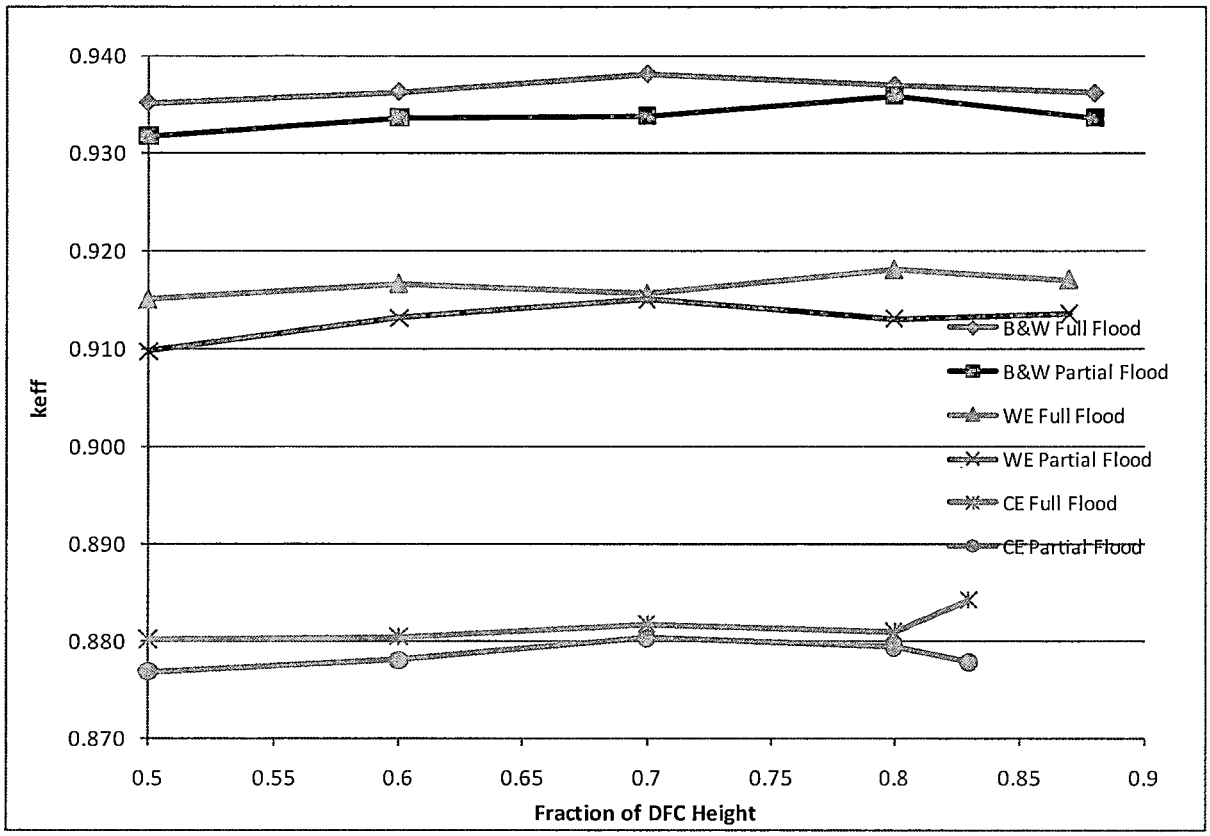


Figure 6.7.8-8 DFC Moderator Density in Fuel/Water Mixture

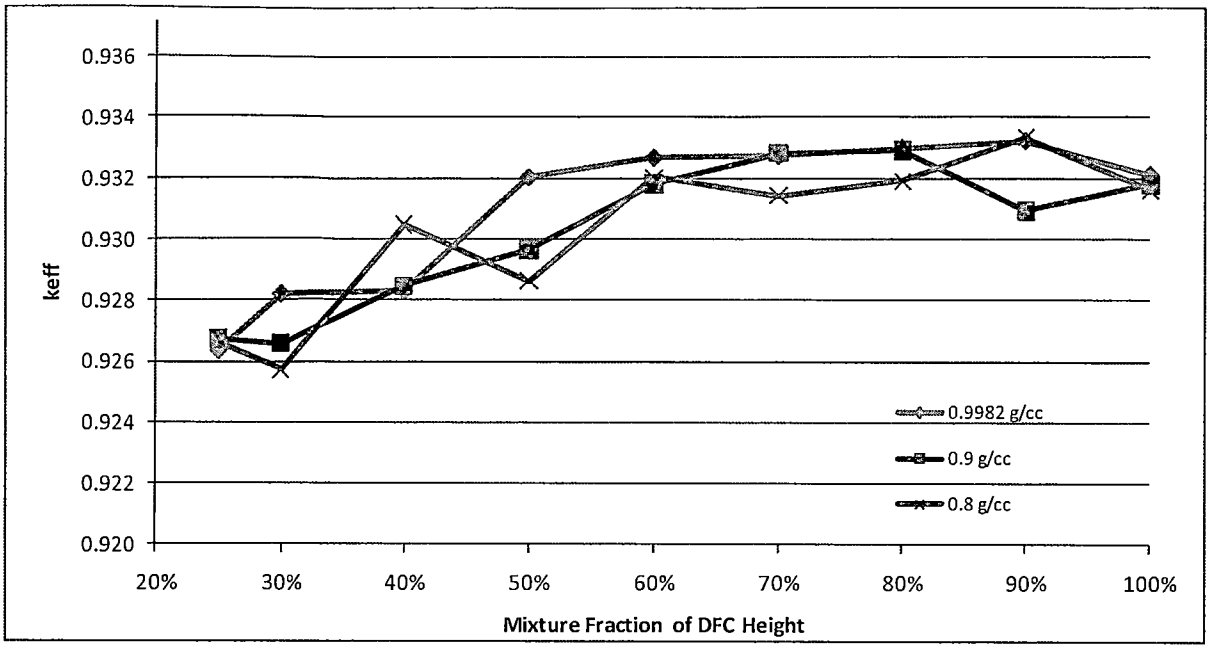


Table 6.7.8-1 Sample Results for Undamaged Fuel in DFC (Damaged Fuel Basket)

Assembly Type	Minimum 1500 ppm B Max. Initial Enrichment	Reactivity			Minimum 2000 ppm B Max. Initial Enrichment	Reactivity			Minimum 2500 ppm B Max. Initial Enrichment	Reactivity		
	(wt% ^{235}U)	σ	$k_{eff} + 2\sigma$	Δk/σ	(wt% ^{235}U)	σ	$k_{eff} + 2\sigma$	Δk/σ	(wt% ^{235}U)	σ	$k_{eff} + 2\sigma$	Δk/σ
BW15H1	3.7%	0.00073	0.92965		4.4%	0.00073	0.93538		5.0%	0.00070	0.93416	
	3.7%	0.00073	0.93240	2.66	4.4%	0.00072	0.93503	-0.34	5.0%	0.00073	0.93594	1.76
BW15H2	3.7%	0.00068	0.93581		4.3%	0.00071	0.93498		4.9%	0.00072	0.93317	
	3.7%	0.00073	0.93607		4.3%	0.00073	0.93763	2.60	4.9%	0.00077	0.93435	
					4.2%	0.00076	0.92842					
BW15H3	3.7%	0.00071	0.93700		4.3%	0.00074	0.93514		4.9%	0.00072	0.93415	
	3.7%	0.00070	0.93818	1.18	4.3%	0.00074	0.93697	1.75	4.9%	0.00074	0.93686	2.62
	3.6%	0.00070	0.93066									
BW15H4	3.8%	0.00071	0.93146		4.5%	0.00073	0.93364		5.0%	0.00073	0.92368	
	3.8%	0.00074	0.93284		4.5%	0.00078	0.93488	1.16	5.0%	0.00075	0.92548	
BW17H1	3.7%	0.00073	0.93296		4.3%	0.00070	0.93382		5.0%	0.00072	0.93716	
	3.7%	0.00071	0.93589	2.88	4.3%	0.00072	0.93432	0.50	5.0%	0.00072	0.94043	3.21
									4.9%	0.00072	0.93171	
CE14H1	4.5%	0.00073	0.93518		5.0%	0.00078	0.91583		5.0%	0.00078	0.87766	
	4.5%	0.00081	0.93353		5.0%	0.00074	0.91808	2.09	5.0%	0.00071	0.87934	
CE16H1	4.4%	0.00075	0.93329		5.0%	0.00077	0.92515		5.0%	0.00080	0.88644	
	4.4%	0.00074	0.93299	-0.28	5.0%	0.00073	0.92359	-1.47	5.0%	0.00079	0.88529	-1.02
WE14H1	4.7%	0.00073	0.93682		5.0%	0.00073	0.90625		5.0%	0.00077	0.86657	
	4.7%	0.00077	0.93520	-1.53	5.0%	0.00075	0.90620	-0.05	5.0%	0.00074	0.86864	1.94
WE15H1	3.8%	0.00072	0.93295		4.5%	0.00078	0.93614		5.0%	0.00074	0.92470	
	3.8%	0.00079	0.93092		4.5%	0.00074	0.93534	-0.74	5.0%	0.00075	0.92747	
WE15H2	4.0%	0.00077	0.93454		4.7%	0.00072	0.93520		5.0%	0.00071	0.91355	
	4.0%	0.00071	0.93602	1.41	4.7%	0.00074	0.93494	-0.25	5.0%	0.00073	0.91313	-0.41
WE17H1	3.7%	0.00074	0.92921		4.4%	0.00076	0.93628		5.0%	0.00070	0.93402	
	3.7%	0.00070	0.93064		4.4%	0.00074	0.93712	0.79	5.0%	0.00073	0.93419	
WE17H2	4.0%	0.00073	0.93415		4.7%	0.00071	0.93342		5.0%	0.00071	0.91309	
	4.0%	0.00076	0.93355	-0.57	4.7%	0.00072	0.93507	1.63	5.0%	0.00070	0.91196	-1.13

Table 6.7.8-2 DFC Unclad Rod Array Pitch Study Results

Assembly	Enrichment	Reactivity with Maximum Pitch		Reactivity with Average Pitch			Reactivity with Nominal Pitch		
	(wt% ^{235}U)	σ	k_{eff} + 2σ	σ	k_{eff} + 2σ	Δk/σ	σ	k_{eff} + 2σ	Δk/σ
BW15H1	4.7%	0.00071	0.93472	0.00072	0.93607	1.34	0.00075	0.93646	1.68
BW15H2	4.6%	0.00073	0.93589	0.00075	0.93641	0.50	0.00076	0.93473	-1.10
BW15H3	4.6%	0.00066	0.93711	0.00073	0.93765	0.55	0.00078	0.93778	0.66
BW15H4	4.8%	0.00071	0.93398	0.00077	0.93390	-0.08	0.00075	0.93433	0.34
BW17H1	4.6%	0.00073	0.93383	0.00072	0.93446	0.61	0.00073	0.93466	0.80
CE14H1	5.0%	0.00079	0.89735	0.00077	0.89484	-2.28	0.00074	0.89522	-1.97
CE16H1	5.0%	0.00075	0.90438	0.00074	0.90395	-0.41	0.00077	0.90557	1.11
WE14H1	5.0%	0.00077	0.88574	0.00078	0.88600	0.24	0.00079	0.88591	0.15
WE15H1	4.8%	0.00074	0.93410	0.00075	0.93307	-0.98	0.00075	0.93368	-0.40
WE15H2	5.0%	0.00079	0.93251	0.00075	0.93201	-0.46	0.00073	0.93239	-0.11
WE17H1	4.7%	0.00073	0.93349	0.00075	0.93626	2.65	0.00074	0.93546	1.90
WE17H2	5.0%	0.00073	0.93227	0.00071	0.93048	-1.76	0.00077	0.93145	-0.77

Table 6.7.8-3 Sample Results for Unclad Rod/Loose Pellet Fuel in DFC (Damaged Fuel Basket)

Assembly Type	Minimum 1500 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity σ	Reactivity $k_{eff} + 2\sigma$	Reactivity Δk/σ	Minimum 2000 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity σ	Reactivity $k_{eff} + 2\sigma$	Reactivity Δk/σ	Minimum 2500 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity σ	Reactivity $k_{eff} + 2\sigma$	Reactivity Δk/σ
BW15H1	3.7%	0.00073	0.92965		4.4%	0.00073	0.93538		5.0%	0.00070	0.93416	
	3.7%	0.00072	0.93127	1.58	4.4%	0.00073	0.93700	1.57	5.0%	0.00075	0.93608	1.87
BW15H2	3.7%	0.00068	0.93581		4.3%	0.00071	0.93498		4.9%	0.00072	0.93317	
	3.7%	0.00070	0.93704	1.26	4.3%	0.00075	0.93589	0.88	4.9%	0.00073	0.93554	2.31
BW15H3	3.7%	0.00071	0.93700		4.3%	0.00074	0.93514		4.9%	0.00072	0.93415	
	3.7%	0.00069	0.93818	1.19	4.3%	0.00069	0.93668	1.52	4.9%	0.00071	0.93579	1.62
	3.6%	0.00072	0.93134									
BW15H4	3.8%	0.00071	0.93146		4.5%	0.00073	0.93364		5.0%	0.00073	0.92368	
	3.8%	0.00072	0.93393	2.44	4.5%	0.00073	0.93438	0.72	5.0%	0.00074	0.92418	0.48
BW17H1	3.7%	0.00073	0.93296		4.3%	0.00070	0.93382		5.0%	0.00072	0.93716	
	3.7%	0.00072	0.93545	2.43	4.3%	0.00071	0.93443	0.61	5.0%	0.00069	0.93818	1.02
									4.9%	0.00072	0.93174	
CE14H1	4.5%	0.00073	0.93518		5.0%	0.00078	0.91583		5.0%	0.00078	0.87766	
	4.5%	0.00077	0.93387	-1.23	5.0%	0.00079	0.91801	1.96	5.0%	0.00081	0.87926	1.42
CE16H1	4.4%	0.00075	0.93329		5.0%	0.00077	0.92515		5.0%	0.00080	0.88644	
	4.4%	0.00076	0.93404	0.70	5.0%	0.00076	0.92362	-1.41	5.0%	0.00073	0.88414	-2.12
WE14H1	4.7%	0.00073	0.93682		5.0%	0.00073	0.90625		5.0%	0.00077	0.86657	
	4.7%	0.00074	0.93777	0.91	5.0%	0.00077	0.90693	0.64	5.0%	0.00074	0.86736	0.74
	4.6%	0.00074	0.93090									
WE15H1	3.8%	0.00072	0.93295		4.5%	0.00078	0.93614		5.0%	0.00074	0.92470	
	3.8%	0.00070	0.93213	-0.82	4.5%	0.00075	0.93689	0.69	5.0%	0.00072	0.92569	0.96
WE15H2	4.0%	0.00077	0.93454		4.7%	0.00072	0.93520		5.0%	0.00071	0.91355	
	4.0%	0.00074	0.93465	0.10	4.7%	0.00070	0.93439	-0.81	5.0%	0.00076	0.91163	-1.85
WE17H1	3.7%	0.00074	0.92921		4.4%	0.00076	0.93628		5.0%	0.00070	0.93402	
	3.7%	0.00075	0.92991	0.66	4.4%	0.00070	0.93500	-1.24	5.0%	0.00072	0.93484	0.82
WE17H2	4.0%	0.00073	0.93415		4.7%	0.00071	0.93342		5.0%	0.00071	0.91309	
	4.0%	0.00072	0.93379	-0.35	4.7%	0.00074	0.93522	1.76	5.0%	0.00072	0.91258	-0.50

Table 6.7.8-4 DFC Missing Rod Study

# Missing Rods	Reactivity			
	k_{eff}	σ	$k_{eff} + 2\sigma$	$\Delta k/\sigma$
0	0.93574	0.00072	0.93718	-
1	0.9357	0.0007	0.93710	-0.08
4	0.93565	0.00075	0.93715	-0.03
8	0.93526	0.00072	0.93670	-0.47
12	0.93574	0.00071	0.93716	-0.02
16	0.93492	0.00075	0.93642	-0.73
20	0.93544	0.0007	0.93684	-0.34
32	0.93535	0.00075	0.93685	-0.32
50	0.93334	0.00067	0.93468	-2.54

Table 6.7.8-5 Sample DFC Fuel Mixture Height Study Results

Assembly Type	Mixture Height Percent DFC Cavity	Minimum 1500 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Minimum 2000 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Minimum 2500 ppm B Max. Initial Enrichment (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$
BW15H1	50	3.7%	0.93203	4.4%	0.93744	5.0%	0.93465
	60	3.7%	0.93267	4.3%	0.93287	4.9%	0.93410
	70	3.7%	0.93273	4.3%	0.93553	4.9%	0.93356
	80	3.7%	0.93300	4.3%	0.93461	4.9%	0.93303
	90	3.7%	0.93323	4.3%	0.93335	4.9%	0.93382
	100	3.7%	0.93212	4.3%	0.93387	4.9%	0.93372
BW17H1	50	3.7%	0.93527	4.3%	0.93451	4.9%	0.93511
	60	3.7%	0.93596	4.3%	0.93658	4.9%	0.93623
	70	3.6%	0.92912	4.3%	0.93688	4.9%	0.93675
	80	3.7%	0.93683	4.2%	0.93055	4.9%	0.93691
	90	3.7%	0.93517	4.2%	0.92919	4.9%	0.93694
	100	3.7%	0.93737	4.3%	0.93706	4.9%	0.93686
CE14H1	50	4.5%	0.93318	5.0%	0.91737	5.0%	0.88014
	60	4.5%	0.93691	5.0%	0.91876	5.0%	0.88041
	70	4.5%	0.93728	5.0%	0.91941	5.0%	0.88169
	80	4.5%	0.93586	5.0%	0.91827	5.0%	0.88088
	90	4.5%	0.93320	5.0%	0.91968	5.0%	0.88176
	100	4.5%	0.93383	5.0%	0.91738	5.0%	0.88101
CE16H1	50	4.4%	0.93480	5.0%	0.92518	5.0%	0.88682
	60	4.4%	0.93399	5.0%	0.92902	5.0%	0.88868
	70	4.4%	0.93472	5.0%	0.92689	5.0%	0.88974
	80	4.4%	0.93575	5.0%	0.92611	5.0%	0.88962
	90	4.4%	0.93515	5.0%	0.92598	5.0%	0.88946
	100	4.4%	0.93395	5.0%	0.92705	5.0%	0.89002
WE14H1	50	4.7%	0.93751	5.0%	0.90583	5.0%	0.86685
	60	4.7%	0.93750	5.0%	0.90787	5.0%	0.87013
	70	4.7%	0.93733	5.0%	0.90738	5.0%	0.87007
	80	4.7%	0.93717	5.0%	0.90915	5.0%	0.86996
	90	4.7%	0.93660	5.0%	0.90841	5.0%	0.86892
	100	4.7%	0.93717	5.0%	0.90721	5.0%	0.86698
WE15H1	50	3.8%	0.93095	4.5%	0.93691	5.0%	0.92753
	60	3.8%	0.93313	4.5%	0.93737	5.0%	0.93028
	70	3.8%	0.93436	4.5%	0.93735	5.0%	0.93016
	80	3.8%	0.93408	4.4%	0.93060	5.0%	0.92991
	90	3.8%	0.93436	4.4%	0.93150	5.0%	0.92964
	100	3.8%	0.93538	4.5%	0.93697	5.0%	0.92849
WE17H2	50	4.0%	0.93462	4.7%	0.93661	5.0%	0.91502
	60	3.9%	0.92899	4.6%	0.93299	5.0%	0.91658
	70	3.9%	0.92934	4.6%	0.93247	5.0%	0.91559
	80	4.0%	0.93563	4.6%	0.93343	5.0%	0.91805
	90	4.0%	0.93669	4.6%	0.93159	5.0%	0.91537
	100	3.9%	0.92870	4.7%	0.93653	5.0%	0.91664

Table 6.7.8-6 DFC Fuel Mixture Maximum Reactivity Height for 0.036 g/cm^2 ^{10}B – No Inserts

Assembly	Parameter	Minimum 1500 ppm	Minimum 1750 ppm	Minimum 2000 ppm	Minimum 2250 ppm	Minimum 2500 ppm
BW15H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%
	$k_{eff}+2\sigma$	0.93323	0.93439	0.93553	0.93571	0.93410
	Configuration	MIX90	MIX70	MIX70	MIX70	MIX60
BW15H2	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%
	$k_{eff}+2\sigma$	0.93147	0.93234	0.93312	0.93368	0.93355
	Configuration	MIX80	MIX80	MIX90	MIX80	MIX70
BW15H3	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%
	$k_{eff}+2\sigma$	0.93380	0.93398	0.93450	0.93518	0.93674
	Configuration	MIX80	MIX100	MIX90	MIX80	MIX80
BW15H4	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%
	$k_{eff}+2\sigma$	0.93650	0.93692	0.93368	0.93302	0.93165
	Configuration	MIX80	MIX90	MIX70	MIX70	MIX70
BW17H1	Enrichment	3.6%	3.9%	4.2%	4.5%	4.9%
	$k_{eff}+2\sigma$	0.92912	0.92805	0.93055	0.93166	0.93694
	Configuration	MIX70	MIX60	MIX80	MIX90	MIX90
CE14H1	Enrichment	4.5%	4.9%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93728	0.93616	0.91968	0.90123	0.88176
	Configuration	MIX70	MIX70	MIX90	MIX60	MIX90
CE16H1	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93575	0.93022	0.92902	0.90938	0.89002
	Configuration	MIX80	MIX70	MIX60	MIX80	MIX100
WE14H1	Enrichment	4.7%	5.0%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93751	0.92989	0.90915	0.88872	0.87013
	Configuration	MIX50	MIX60	MIX80	MIX80	MIX60
WE15H1	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%
	$k_{eff}+2\sigma$	0.93538	0.93541	0.93150	0.93075	0.93028
	Configuration	MIX100	MIX70	MIX90	MIX80	MIX60
WE15H2	Enrichment	3.9%	4.3%	4.6%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93365	0.93581	0.93464	0.93720	0.91729
	Configuration	MIX70	MIX70	MIX70	MIX60	MIX70
WE17H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%
	$k_{eff}+2\sigma$	0.93327	0.93385	0.93517	0.93304	0.93417
	Configuration	MIX80	MIX90	MIX70	MIX90	MIX90
WE17H2	Enrichment	3.9%	4.3%	4.6%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.92934	0.93490	0.93343	0.93722	0.91805
	Configuration	MIX70	MIX70	MIX80	MIX70	MIX80

Table 6.7.8-7 DFC Fuel Mixture Maximum Reactivity Height for 0.036 g/cm^2 ^{10}B – Inserts

Assembly	Parameter	Minimum 1500 ppm	Minimum 1750 ppm	Minimum 2000 ppm	Minimum 2250 ppm	Minimum 2500 ppm
BW15H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%
	$k_{eff}+2\sigma$	0.93185	0.93353	0.93536	0.93570	0.93666
	Configuration	MIX70	MIX90	MIX80	MIX70	MIX100
BW15H2	Enrichment	3.7%	3.9%	4.2%	4.5%	4.8%
	$k_{eff}+2\sigma$	0.93732	0.92857	0.93295	0.93446	0.93579
	Configuration	MIX80	MIX100	MIX80	MIX80	MIX70
BW15H3	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%
	$k_{eff}+2\sigma$	0.92862	0.93150	0.93343	0.93497	0.93723
	Configuration	MIX80	MIX70	MIX80	MIX100	MIX80
BW15H4	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%
	$k_{eff}+2\sigma$	0.93574	0.93435	0.93620	0.93567	0.93522
	Configuration	MIX70	MIX70	MIX80	MIX70	MIX70
BW17H1	Enrichment	3.7%	4.0%	4.3%	4.5%	4.8%
	$k_{eff}+2\sigma$	0.93562	0.93574	0.93608	0.93184	0.93432
	Configuration	MIX70	MIX70	MIX80	MIX80	MIX70
CE14H1	Enrichment	4.4%	4.8%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93160	0.93612	0.92831	0.91230	0.89638
	Configuration	MIX80	MIX70	MIX70	MIX60	MIX80
CE16H1	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93572	0.93177	0.93160	0.91441	0.89748
	Configuration	MIX80	MIX80	MIX70	MIX70	MIX90
WE14H1	Enrichment	4.8%	5.0%	5.0%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93667	0.92601	0.90543	0.88775	0.86940
	Configuration	MIX90	MIX60	MIX80	MIX70	MIX70
WE15H1	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%
	$k_{eff}+2\sigma$	0.93169	0.93364	0.93274	0.93291	0.93317
	Configuration	MIX70	MIX80	MIX70	MIX70	MIX100
WE15H2	Enrichment	4.0%	4.3%	4.6%	4.9%	5.0%
	$k_{eff}+2\sigma$	0.93503	0.93522	0.93350	0.93434	0.92239
	Configuration	MIX90	MIX80	MIX90	MIX80	MIX90
WE17H1	Enrichment	3.8%	4.1%	4.4%	4.7%	4.9%
	$k_{eff}+2\sigma$	0.93430	0.93452	0.93541	0.93710	0.93099
	Configuration	MIX90	MIX70	MIX70	MIX80	MIX90
WE17H2	Enrichment	4.0%	4.3%	4.7%	5.0%	5.0%
	$k_{eff}+2\sigma$	0.93202	0.93278	0.93680	0.93721	0.91961
	Configuration	MIX60	MIX80	MIX80	MIX90	MIX70

Table 6.7.8-8 DFC Partial Flooding Mixture Moderator Density Study (BW Fuel 3.7 wt % ^{235}U, 1500 ppm B)

Mixture Fraction of DFC Cavity	Water Density in Fuel/Water Mixture							
	0.9982 g/cm³		0.9 g/cm³		Δ to 0.9982 g/cm³	0.8 g/cm³		Δ to 0.9982 g/cm³
	$k_{eff}+2\sigma$	σ	$k_{eff}+2\sigma$	σ	$\Delta k/\sigma$	$k_{eff}+2\sigma$	σ	$\Delta k/\sigma$
25%	0.92697	0.00071	0.92642	0.00070	-0.6	0.92611	0.00072	-0.9
30%	0.92726	0.00070	0.92584	0.00074	-1.4	0.92685	0.00071	-0.4
40%	0.92924	0.00074	0.92973	0.00075	0.5	0.92986	0.00074	0.6
50%	0.93155	0.00072	0.93056	0.00070	-1.0	0.92967	0.00071	-1.9
60%	0.93286	0.00073	0.93171	0.00069	-1.1	0.93009	0.00072	-2.7
70%	0.93492	0.00074	0.93173	0.00072	-3.1	0.93192	0.00069	-3.0
80%	0.93351	0.00074	0.93300	0.00072	-0.5	0.93167	0.00073	-1.8
90%	0.93485	0.00071	0.93417	0.00073	-0.7	0.93347	0.00071	-1.4
100%	0.93212	0.00075	0.93181	0.00073	-0.3	0.93161	0.00075	-0.5

Table 6.7.8-9 PWR Damaged Fuel Storage Cask Analyses Results (BW Fuel 5.0 wt % ^{235}U)

Water Density (g/cm³)				0 ppm B	Reactivity
			DFC	Max. Initial	
Interior	Exterior	Inside DFC	Configuration	Enrichment	
				(wt% ^{235}U)	$k_{eff} + 2\sigma$
0.0001	0.0001	0.0001	IAA	5.0%	0.48727
0.0001	0.0001	0.0001	URA	5.0%	0.48578
0.0001	0.0001	0.0001	MIX50	5.0%	0.49142
0.0001	0.0001	0.0001	MIX60	5.0%	0.49042
0.0001	0.0001	0.0001	MIX70	5.0%	0.48882
0.0001	0.0001	0.0001	MIX80	5.0%	0.48578
0.0001	0.0001	0.0001	MIX90	5.0%	0.48614
0.0001	0.0001	0.0001	MIX100	5.0%	0.48210
0.0001	0.9982	0.0001	IAA	5.0%	0.48064
0.0001	0.9982	0.0001	URA	5.0%	0.48140
0.0001	0.9982	0.0001	MIX50	5.0%	0.48211
0.0001	0.9982	0.0001	MIX60	5.0%	0.48014
0.0001	0.9982	0.0001	MIX70	5.0%	0.48015
0.0001	0.9982	0.0001	MIX80	5.0%	0.48030
0.0001	0.9982	0.0001	MIX90	5.0%	0.47815
0.0001	0.9982	0.0001	MIX100	5.0%	0.47796

Notes:
IAA - undamaged assembly
URA - unclad rod array
MIX - fuel mixture cases (in the context of storage analysis various fissle material heights; no moderator)

Table 6.7.8-10 PWR Damaged Fuel Assembly Allowable Loading (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)														
	Absorber[a] 0.036 ^{10}B g/cm^2					Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Chapter 7
Confinement

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7 CONFINEMENT

The MAGNASTOR® TSC provides confinement for its radioactive contents in long-term storage. The confinement boundary provided by the TSC is closed by welding, creating a solid barrier to the release of contents in the design basis normal conditions and off-normal or accident events. The welds are visually inspected and nondestructively examined to verify integrity.

The sealed TSC contains a pressurized inert gas (helium). The confinement boundary retains the helium and also prevents the entry of outside air into the TSC in long-term storage. The exclusion of air precludes fuel rod cladding oxidation failures during storage.

The TSC confinement system meets the requirements of 10 CFR 72.24 [1] for protection of the public from release of radioactive material. The design of the TSC allows the recovery of stored spent fuel should it become necessary per the requirements of 10 CFR 72.122. The TSC meets the requirements of 10 CFR 72.122 (h) for protection of the spent fuel contents in long-term storage such that future handling of the contents would not pose an operational safety concern.

The MAGNASTOR TSC provides an austenitic stainless steel closure design sealed by welding, precluding the need for continuous monitoring. The analysis for normal conditions and off-normal or accident events shows that the integrity of the confinement boundary is maintained in all of the evaluated conditions. Consequently, there is no release of radionuclides from the TSC resulting in site boundary doses in excess of regulatory requirements. Therefore, the confinement design of MAGNASTOR meets the regulatory requirements of 10 CFR 72 and the acceptance criteria defined in NUREG-1536 [2].

7.1 Confinement Boundary

The welded TSC is the confinement vessel for the PWR or BWR spent fuel assembly contents.

The confinement boundary of the TSC consists of the TSC shell, bottom plate, closure lid, inner vent and drain port covers, and the welds that join these components. The redundant closure of the TSC confinement boundary consists of the closure ring, the outer vent and drain port covers, and the welds that join these components to the TSC shell and closure lid. The confinement boundary is shown in Figure 7.1-1. The confinement boundary does not incorporate bolted closures or mechanical seals. The confinement boundary welds are described in Table 7.1-1.

7.1.1 Confinement Vessel

The TSC consists of three principal components: the TSC shell, bottom plate, and closure lid assembly. The TSC shell is a right circular cylinder constructed of rolled Type 304/304L (dual certified) stainless steel plate with the edges of the plate joined by full penetration welds. It is closed at the bottom end by a circular plate joined to the shell by a full penetration weld. The TSC has two lengths to accommodate different fuel lengths. The TSC shell and the composite closure lid stainless steel plate are helium leak tested to leak tight criteria per ANSI N14.5-1997 following fabrication, as described in the Acceptance Test Program of Chapter 10.

After loading, the TSC is closed at the top by a closure lid assembly fabricated from 9-inch thick Type 304 stainless steel (for TSC1 and TSC2), or a composite lid assembly consisting of a 4-inch thick stainless steel plate and a bolted 5-inch thick carbon steel shield plate. The closure lid assembly is joined to the TSC shell using a field-installed groove weld. The closure lid-to-TSC shell weld is analyzed, installed, and examined in accordance with ISG-15 [6] guidance. This closure lid-to-TSC shell weld is a partial penetration weld progressively examined at the root, midplane, and final surface by liquid penetrant (PT) examination. Following NDE of the closure lid-to-TSC shell weld, the TSC cavity is reflooded and the TSC vessel and closure lid assembly are hydrostatically pressure tested as described in the Operating Procedures of Chapter 9 and the Acceptance Test Program of Chapter 10. The acceptance criteria for the test is no leakage from the closure lid to shell weld during the minimum 10-minute test duration.

After successful completion of the hydrostatic pressure test, the Type 304 stainless steel closure ring is installed in the TSC-to-closure lid weld groove, and welded to both the closure lid and the TSC shell. The closure ring welds are inspected by PT examination of the final weld surfaces. The closure ring provides the double weld redundant sealing of the confinement boundary, as required by 10 CFR 72.236(e). At the option of the user, the closure ring installation and

welding can be completed later in the TSC preparation process following final helium back fill operations.

The closure lid assembly incorporates drain and vent penetrations, which provide access to the TSC cavity for canister draining, drying and helium backfilling operations during TSC closure and preparation for placement into storage. The design of the penetrations incorporates features to provide adequate shielding for the operators during these operations and closure welding.

Following final helium backfill and pressurization, the vent and drain port penetrations are closed with Type 304 stainless steel inner port covers that are partial-penetration welded in place. Each inner port cover weld is tested for helium leakage past the port cover to closure lid weld. Each inner port cover weld final surface is then PT examined. A second (outer) port cover is then installed and welded to the closure lid at each of the ports to provide the double weld redundant sealing of the confinement boundary. The outer port cover weld final surfaces are inspected by PT examination.

Prior to sealing, the TSC cavity is backfilled and pressurized with helium. The minimum helium purity level of 99.995% (minimum) specified in the Operating Procedures maintains the quantity of oxidizing contaminants to less than one mole per canister for all loading conditions. Based on the maximum empty canister free volume of 10,400 liters and the design basis helium density (Section 4.4.4), an empty canister would contain approximately 2,000 moles of gases. Conservatively, assuming that all of the impurities in the helium are oxidants, a maximum of 0.1 moles of oxidants could exist in the largest canister during storage. By limiting the amount of oxidants to less than one mole, the recommended limits for preventing cladding degradation found in the PNL-6365 [4] are satisfied.

The thermal analysis of the loaded TSC is based, in part, on heat transfer from the fuel to the TSC shell by convection within the TSC. The provision of a specific density of high-purity helium, which ensures the establishment of internal convection in the TSC, also ensures that a positive pressure exists within the TSC during the design life of the system. The maintenance of a positive helium pressure eliminates any potential for in-leakage of air into the TSC cavity during storage operations.

The closure lid assembly to TSC shell weld completed in the field is not helium leakage tested. Interim Staff Guidance (ISG)-18 [5] provides that an adequate confinement boundary is established for stainless steel spent fuel storage canisters that are closed using a closure weld that meets the guidance of ISG-15 [6]. The TSC closure weld meets the ISG-15 guidance in that the analysis of the weld considers a stress reduction factor of 0.8. The weld is qualified and performed in accordance with the ASME Code, Section IX requirements [7]; and the weld is dye penetrant examined after the root, midplane, and final surface passes. The final surfaces of the

welds joining the closure ring to the closure lid and shell, and joining the redundant port covers to the closure lid are PT examined. The inner port cover welds are helium leakage tested as defined in Chapter 10.

During fabrication, the TSC shell and bottom plate welds are volumetrically inspected and the shell assembly is shop helium leakage tested to the leaktight criteria of 2×10^{-7} cm^3/sec (helium) in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14. 5 [8]. A minimum test sensitivity of 1×10^{-7} cm^3/sec (helium) is required. In addition, the 9-inch stainless steel closure lid assembly (TSC1 and TSC2) are volumetrically inspected in accordance with ASME Code, Section III, Subsection NB-2500 requirements. The 4-inch stainless steel closure lid that is part of the composite closure lid assembly (TSC3 and TSC4) is shop helium leakage tested due to its reduced thickness and shield plate bolt holes. The closure lid is tested in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14.5 [8] to the leak tight criteria of 2×10^{-7} cm^3/sec (helium). A minimum test sensitivity of 1×10^{-7} cm^3/sec (helium) is required.

Based on the shop helium leakage testing of the 4-inch thick closure lid, the TSC shell, bottom plate and the joining welds; the design analyses and qualifications of the closure lid and inner port cover welds; the performance of a TSC field hydrostatic pressure test of the closure lid assembly-to-TSC shell weld; the helium leakage test performed on the inner vent and drain port covers; and the multiple NDE performed on all of the confinement boundary welds, the loaded TSC is considered and analyzed as having no credible leakage.

The confinement boundary details at the top of the TSC are shown in Figure 7.1-1. The closure is welded by qualified welders using weld procedures qualified in accordance with ASME Code, Section IX. Over its 50-year design life, the TSC precludes the release of radioactive contents to the environment and the entry of air or water that could potentially damage the cladding of the stored spent fuel.

7.1.2 Confinement Penetrations

Two penetrations fitted with quick-disconnect fittings are provided in the TSC closure lid for operational functions during system loading and sealing operations. The drain port accesses a drain tube that extends into a sump located in the bottom plate. The vent port extends to the underside of the closure lid and accesses the top of the TSC cavity.

After the completion of the closure lid-to-TSC shell weld, TSC pressure test and cavity draining, the vent and drain penetrations are utilized for drying the TSC internals and contents, and for helium backfilling and pressurizing the TSC. After backfilling to a specific helium density, both

penetrations are closed with redundant port covers welded to the closure lid. As presented for storage, the TSC has no exposed or accessible penetrations, has no mechanical closures, and does not employ seals to maintain confinement.

7.1.3 Seals and Welds

The confinement boundary welds consist of the field-installed welds that close and seal the TSC, and the shop welds that join the bottom plate to the TSC and that join the rolled plates that form the TSC shell. The TSC shell may incorporate both longitudinal and circumferential weld seams in joining the rolled plates. No elastomer or metallic seals are used in the confinement boundary of the TSC. All cutting, machining, welding, and forming of the TSC vessel are performed in accordance with Section III, Article NB-4000 of the ASME Code, unless otherwise specified in the approved fabrication drawings and specifications. Code alternatives are listed in Table 2.1-2.

Weld procedures, welders, and welding machine operators shall be qualified in accordance with ASME Code, Section IX. Refer to Chapter 10 for the acceptance criteria for the TSC weld visual inspections and nondestructive examinations (NDE).

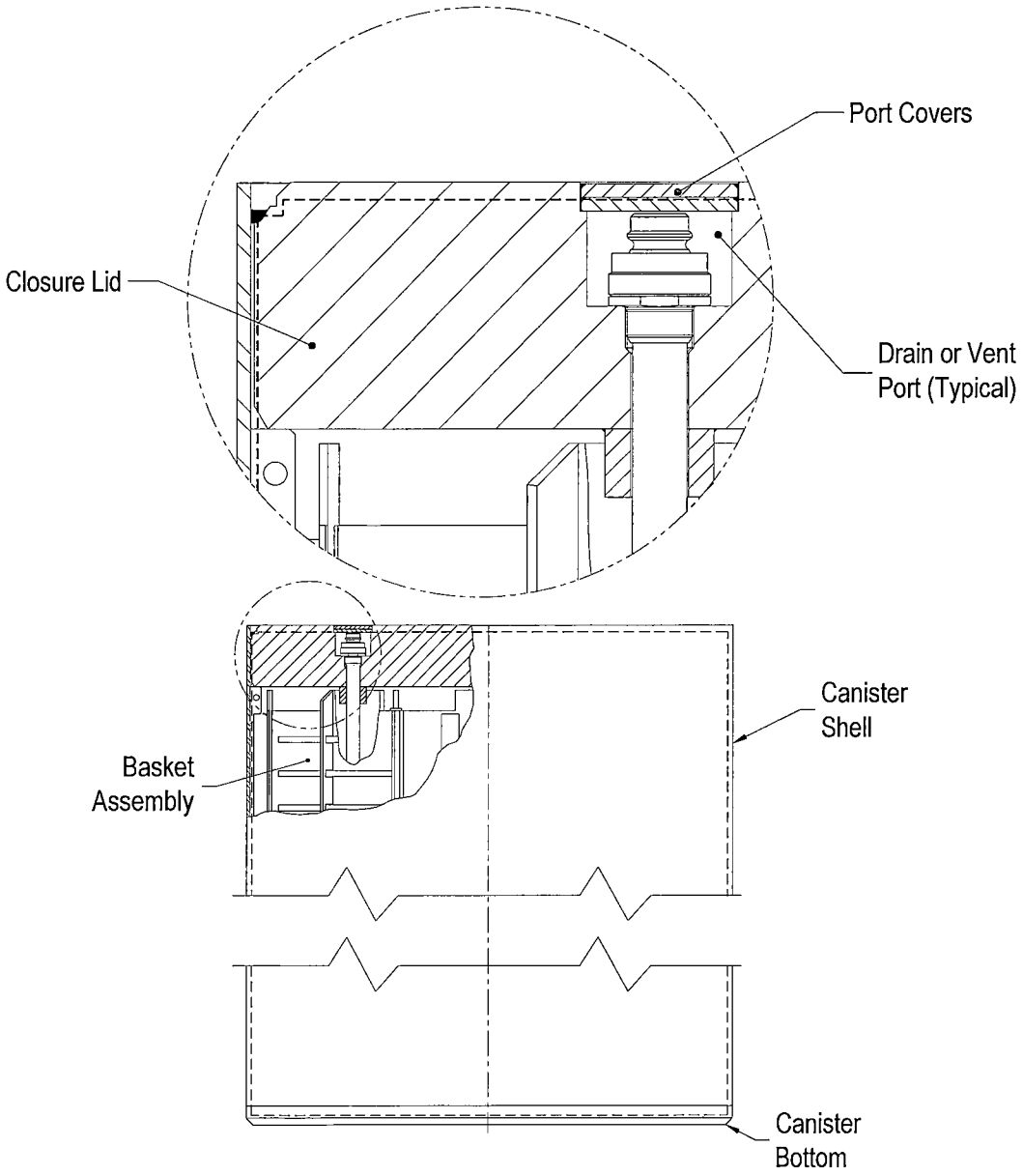
The loaded TSC is closed using field-installed welds. The closure lid to TSC shell weld is liquid penetrant examined at the root, at the midplane level and the final surface. After the completion of TSC hydrostatic pressure testing or helium backfilling, the closure ring is installed and welded to the TSC shell and closure lid. The final surface of each of the closure ring welds is liquid penetrant examined. Following draining, drying, and helium backfilling operations, the vent and drain ports are closed with redundant port covers that are welded in place. The inner port cover welds are helium leakage tested. The final surface of each port cover to closure lid weld is liquid penetrant examined.

Shop and field examinations of TSC confinement boundary welds are performed by personnel qualified in accordance with American Society of Nondestructive Testing Recommended Practice No. SNT-TC-1A [9]. Weld examinations are documented in written reports.

7.1.4 Closure

The closure of the TSC consists of the welded closure lid, the welded closure ring, and the welded redundant vent and drain port covers. There are no bolted closures or mechanical seals in the confinement boundary.

Figure 7.1-1 TSC Confinement Boundary



Note: Illustrated is a single stainless steel plate closure lid. Closure lid may be composed of a stainless steel lid combined with a carbon steel shield plate.

Table 7.1-1 TSC Confinement Boundary Welds

Weld Location	Weld Type	ASME Code Category (Section III, Subsection NB)
Shell longitudinal	Full penetration groove (Shop weld)	A
Shell circumferential (if used)	Full penetration groove (Shop weld)	B
Bottom plate to shell	Full penetration groove (Shop weld)	C
TSC closure lid to shell	Groove (field weld)	C
Inner vent and drain port covers to closure lid	Bevel (field weld)	C

7.2 Requirements for Normal Conditions of Storage

The TSC is transferred to a concrete cask using a transfer cask. Once the TSC is placed inside of the concrete cask, it is effectively protected from direct structural loading due to natural phenomena, such as wind, snow, and ice loading. The principal direct loading for normal operating conditions results from increased internal pressure caused by decay heat, solar insolation, and ambient temperature. Loading due to transient handling may occur during the transfer of the loaded TSC to the concrete cask.

7.2.1 Release of Radioactive Material

The structural analysis of the TSC for normal conditions of storage presented in Chapter 3 demonstrates that the confinement boundary is not breached in any of the normal operating events. Therefore, there is no release of radioactive material during normal storage conditions.

7.2.2 Pressurization of the Confinement Vessel

The TSC cavity is dried and pressurized with helium prior to installing and welding the vent and drain port covers. Under normal conditions, the internal pressure increases due to an increase in temperature of the helium and the postulated normal storage cladding failure of 1% of the stored fuel rods, which is assumed to release 30% of the available fission gases in the rods.

The TSC, closure lid, fittings, and the basket assembly are fabricated from materials that either do not react with ordinary or borated spent fuel pool water to generate gases, or which have an electroless nickel plating to significantly reduce, or eliminate, the potential for interaction with water. Refer to Chapter 8 for a description of the electroless nickel plating and process. The neutron absorber sheets in the fuel baskets, as described in Chapter 8, and the stainless steel covers are held in place by weld posts attached to the fuel tubes. The neutron absorber is a borated aluminum composite, which is protected by an oxide film that forms shortly after fabrication of the plates. This oxide layer effectively precludes further oxidation that could result in the generation of gases in the TSC.

As the TSC is dried and helium backfilled prior to sealing, no significant moisture or other gases, such as air, remain in the TSC. Consequently, there is no potential that radiolytic decomposition could cause an increase in TSC internal pressure or result in a buildup of explosive gases in the TSC. Foreign materials will be excluded from the cavity to ensure that explosive levels of gases due to radiological decomposition will not be generated.

The calculated TSC pressure for normal conditions of storage is presented in Chapter 4 and is less than the pressure evaluated in Chapter 3 for the maximum normal operating pressure. Consequently, there is no adverse consequence due to the internal pressure resulting from normal storage conditions.

As the confinement boundary is closed by welding and does not contain seals or O-rings, and the boundary is not ruptured or otherwise compromised under any normal handling event, the release of contents during normal conditions of storage is precluded.

7.3 Confinement Requirements for Hypothetical Accident Conditions

The results of the structural analyses of the TSC for off-normal and accident events of storage, presented in Chapter 12, show that the TSC is not breached in any of the evaluated events. Consequently, based on the welded closure TSC confinement boundary and the leakage tests described in Section 10.1.3, the TSC has no credible leakage and, therefore, there is no release of radioactive material during off-normal or accident events of storage.

A hypothetical accident condition assumes the cladding failure of all the fuel rods stored in the TSC. This postulated event results in an increase in TSC internal pressure due to the release of the fission product and fuel rod charge gases. The accident condition internal pressures for the PWR and BWR configurations are calculated in Chapter 4 and are shown to be less than the design pressure. Consequently, the integrity of the TSC confinement boundary is maintained and there is no release of radioactive material under off-normal or accident events of storage.

Since no release occurs as the result of accident events, the resulting site boundary dose due to a hypothetical accident is less than the 5 rem whole body or organ (including skin) dose at the 100 meter minimum boundary specified by 10 CFR 72.106 (b) for accident exposures.

7.4 References

1. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste," US Nuclear Regulatory Commission, Washington, DC.
2. NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," Nuclear Regulatory Commission, Washington, DC, January 1997.
3. Deleted
4. PNL-6365, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel," Pacific Northwest Laboratory, Richland, Washington, November, 1987.
5. ISG-18, "The Design/Qualification of Final Closure Welds on Austenitic Stainless Steel Canisters as Confinement Boundary for Spent Fuel Storage and Containment Boundary for Spent Fuel Transportation," US Nuclear Regulatory Commission, Washington, DC, May 2003.
6. ISG-15, "Materials Evaluation," US Nuclear Regulatory Commission, Washington, DC, Revision 0, January 10, 2001.
7. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
8. ANSI N14.5-1997. "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," American National Standards Institute, Washington, DC, 1997.
9. Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing," The American Society for Nondestructive Testing, Inc., Columbus, OH, edition as invoked by the applicable ASME Code.

Chapter 8
Materials Evaluation

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8 MATERIALS EVALUATION

This chapter provides the detailed descriptions of the materials selected for use in the components of MAGNASTOR®. The component materials are specified in the license drawings. The significant physical, chemical, mechanical, and thermal properties of materials used in components of MAGNASTOR are defined, and the material specifications, tests and acceptance conditions important to material use are identified in this chapter. The MAGNASTOR materials are consistent with the application of the accepted design criteria, codes, standards, and specifications described in Chapter 2.

8.1 Material Selection

Type 304 stainless steel is used in the TSC, except for the shield plate and shield plate bolts of the composite closure lid assembly. It is selected for this use because of its high strength, ductility, resistance to corrosion and brittle fracture, and metallurgical stability for long-term storage. The steels used in the fabrication of the TSC are as follows.

Shell	ASME SA240, Type 304/304L dual-certified, stainless steel
Bottom	ASME SA240, Type 304/304L dual-certified, stainless steel
Closure Lid	ASME SA240, Type 304 stainless steel
Closure Ring	ASME SA479/SA240, Type 304/304L dual-certified, stainless steel
Port Covers	ASME SA240, Type 304/304L dual-certified, stainless steel
Shield Plate	ASTM A36 carbon steel
Shield Plate Bolts	ASME SA193, Grade B6 high alloy bolting steel
Lifting Lug – PWR/BWR	ASTM A240/A276, Type 304/304L dual-certified stainless steel
Lifting Lug – PWR Damaged Fuel	ASTM A240/276, Type 347 stainless steel

Note: SA182/SA336, Type F304/F304L and SA240, Type 304L stainless steel may be substituted for SA240, Type 304 stainless steel for the closure lid, provided that their material yield and ultimate strengths are greater than, or equal to, those of SA240, Type 304 stainless steel.

The carbon steels used in the fuel baskets are selected based on their strength and thermal conductivity. After fabrication, the basket components are electroless nickel-coated to improve resistance to corrosion and to significantly reduce the potential for the formation of flammable gases during in-pool loading. The materials used in the fabrication of the fuel baskets are:

Basket Supports, Plates and Gussets	ASME SA537, Class 1, carbon steel
Corner Support Bars	ASME SA695, Type B, Grade 40, SA696, Grade C or SA516, Grade 70 carbon steel
Fuel Tubes	ASME SA537, Class 1, carbon steel
Pins	SA696, Grade C or ASME SA36 carbon steel (PWR only)
Mounting Bolts	ASME SA193, Grade B6 stainless steel
Neutron Absorber	Borated Metal Matrix Composite, borated aluminum alloy or Boral

The materials used in the concrete cask fabrication are:

Shell	ASTM A36 Carbon Steel
Pedestal Plate	ASTM A36 Carbon Steel
Base and Top Plates	ASTM A537, Class 2, Carbon Steel
Lift Lugs and Anchors	ASTM A537, Class 2, Carbon Steel
Lift Lug Bolts	ASME SB637, Grade NO7718 nickel alloy
Reinforcing bar	ASTM A615/A615M Carbon Steel
Concrete	ASTM C150 Type II Portland Cement

The materials used in the MTC1 transfer cask fabrication are:

Inner Shell	ASTM A588 low alloy steel
Outer Shell	ASTM A588 low alloy steel
Bottom Forging	ASTM A516, Grade 70
Top Forging	ASTM A516, Grade 70
Trunnions	ASTM A350, LF2 low alloy steel
Shield Doors and Rails	ASTM A350, LF2 low alloy steel
Retaining Block Pins	ASTM A516, Grade 70
Retaining Block	ASTM A693/A564 17-4 PH stainless steel
Gamma Shield Brick	ASTM B29 Lead-Chemical Copper Grade
Neutron Shield	NS-4-FR

The materials used in the MTC2 transfer cask fabrication are:

Inner Shell	ASTM A240, Type 304 stainless steel
Outer Shell	ASTM A240, Type 304 stainless steel
Bottom Forging	ASTM A182, Type F304 stainless steel
Top Forging	ASTM A182, Type F304 stainless steel
Trunnions	ASTM A182, Type F304 stainless steel
Shield Doors and Rails	ASTM A182, Type F304 stainless steel
Retaining Ring Bolts	ASTM A193 Grade B8 bolting steel
Retaining Ring	ASTM A240, Type 304 stainless steel
Gamma Shield Brick	ASTM B29 Lead-Chemical Copper Grade
Neutron Shield	NS-4-FR

8.1.1 Fracture Toughness

The TSC structural material is austenitic stainless steel, except for the shield plate and shield plate bolts of the composite closure lid assembly. In accordance with ASME Code, Section III, Subsection NB, Paragraph NB-2311, these materials do not require testing for fracture toughness. The carbon steel shield plate and bolts of the composite closure lid assembly do not perform a pressure-retaining function and are not in the canister support load path and, therefore, are considered a nonstructural attachment. In accordance with ASME Code, Section III, Subsection NB, Subsubarticle NB-1130, the shield plate and bolts may be classified as an internal structure with material and design requirements outside code jurisdiction. Consistent with the discussion of bolting design considerations provided in Section 5 of NUREG/CR-1815 [41], impact testing of the attachment bolts is deemed not required due to the multiple load paths and redundancy in the bolted design. Consistent with ASME Code, Section III, Subsection NF, Paragraph NF-2311, the carbon steel shield plate of the composite closure lid assembly does not require impact testing since the maximum stress does not exceed 6,000 psi tension.

The fuel basket is comprised of welded tubes and supports primarily fabricated from ASME Code SA537, Class 1, carbon steel. Fuel basket materials will meet ASME Code, Section III, Subsection NG, Subarticle NG-2300 requirements for impact tests and will be tested in accordance with paragraph NG-2320. A procurement/fabrication specification will describe fracture toughness testing of these materials for each heat of material subjected to the equivalent forming/bending process or heat-treated condition. Acceptance values shall be per ASTM A370, Section 26.1, with values meeting the requirements of Table NG-2331(a)(1) at a Lowest Service Temperature (LST) of -40°F.

The concrete cask lift lugs and anchors are fabricated from two-inch thick, ASTM A537 Class 2, carbon steel plate. Utilization of the lift lugs and anchors for handling the concrete cask is considered a noncritical lift and will be restricted for use only when the surrounding air temperature is ≥ 0°F. Therefore, impact testing of the material is not required.

The structural components of the MTC1 transfer cask are fabricated from low alloy carbon steels selected based on their low-temperature facture toughness. The nil ductility transition temperature for these steels is established as –40°F. Based on Regulatory Guide 7.11 [1], the minimum temperature for use is 40°F above the transition temperature, with no credit taken for heat produced by the contents of the transfer cask. Consequently, a minimum ambient temperature of 0°F for use of the MTC1 transfer cask is established. This condition is administratively controlled by procedure and is consistent with the analysis. Since the use of the MTC1 transfer cask is restricted to conditions when the surrounding air temperature is greater than, or equal to, 0°F, impact testing of the MTC1 transfer cask materials is not required. The

structural components of the MTC2 transfer cask are fabricated from austenitic stainless steel. In accordance with ASME Code, Section III, Subsection NB, Article NB-2311, these materials do not require testing for fracture toughness.

8.2 Applicable Codes and Standards

The principal codes and standards applied to MAGNASTOR components are the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, the American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI). Materials meeting the requirements of these codes and/or standards conform to acceptable minimum thickness, chemical content and formulation specifications and are fabricated using controlled processes and procedures.

The TSC steel components, except the shield plate and shield plate attachment bolts used for the composite closure lid assembly, and associated weld filler materials are procured in accordance with the ASME Code, Section III, Subsection NB [3] requirements, except as listed in the Code Alternatives in Table 2.1-2. The materials for the shield plate and shield plate attachment bolts used for the composite closure lid assembly materials are procured in accordance with the requirements of the applicable ASTM and ASME standards, respectively. The fuel basket steel components and associated weld filler materials are procured in accordance with ASME Code, Section III, Subsection NG [4] requirements, except as stated in the Code Alternatives in Table 2.1-2.

The transfer cask steel components, associated weld filler materials and lead gamma shield materials are procured in accordance with the requirements of the applicable ASTM standards. The NS-4-FR material in the transfer cask is a commercially available product specifically designed for neutron attenuation and absorption.

The concrete cask steel components and associated weld filler materials are procured in accordance with the requirements of the applicable ASTM standards. The concrete portion of the cask is procured in accordance with the requirements of ACI 318 [2], as supplemented by applicable ASTM standards.

8.3 Material Properties

The mechanical properties of steels used in the fabrication of the MAGNASTOR components are presented in Table 8.3-1 through Table 8.3-21. The thermal properties of materials used in the fabrication and evaluation of the storage system are shown in Table 8.3-22 through Table 8.3-33. Derivation of effective thermal conductivities is described in Chapter 4. Table 8.3-22 through Table 8.3-33 include only the materials that form the heat transfer pathways employed in the thermal analysis models. Materials for small components, which are not explicitly modeled, are not included in the property tabulation.

Mechanical material properties for irradiated zircaloy cladding are taken from a PNNL publication by Geelhood and Beyer [36]. Modulus of elasticity and material yield strength are conservatively defined at their minimum value through the maximum normal operating temperature of 752°F , i.e., $E = 10.47 \times 10^6$ psi and $S_y = 69{,}600$ psi.

Table 8.3-1 Mechanical Properties of SA240, Type 304, Stainless Steel

Property (units)	Value at Temperature (°F)									
	-40	-20	70	200	300	400	500	650	800	900
Ultimate strength, S_u (ksi) [a]	75.0	75.0	75.0	71.0	66.2	64.0	63.4	63.4	62.8	60.8
Yield Stress, S_y (ksi) [a]	30.0	30.0	30.0	25.0	22.4	20.7	19.4	18.0	16.9	16.2
Design Stress Intensity, S_m (ksi) [a]	20.0	20.0	20.0	20.0	20.0	18.7	17.5	16.2	15.2	14.6 [b]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	28.8	28.7	28.3	27.6	27.0	26.5	25.8	25.1	24.1	23.5
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	8.13[b]	8.2[b]	8.5	8.9	9.2	9.5	9.7	9.9	10.1	10.2
Poisson's Ratio [a]	0.31									
Density (lb/in^3) [c]	0.29									

Table 8.3-2 Mechanical Properties of SA182, Type F304 Stainless Steel (Size > 5 in)

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	750
Ultimate strength, S_u (ksi) [a]	70.0	70.0	66.3	61.8	59.7	59.2	59.0
Yield Stress, S_y (ksi) [a]	30.0	30.0	25.0	22.4	20.7	19.4	17.2
Design Stress Intensity, S_m (ksi) [a]	20.0	20.0	20.0	20.0	18.6	17.5	15.5
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	28.8	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	8.1 [b]	8.5	8.9	9.2	9.5	9.7	10.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [c]	0.29						

Note: For thickness less than, or equal to, five inches, SA182, Type F304 stainless steel has equivalent mechanical properties to SA240, Type 304 stainless steel.

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated value

[c] Metals Handbook Desk Edition [23]

Table 8.3-3 Mechanical Properties of A693/A564, Type 630, 17-4 PH Stainless Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	600	700
Ultimate strength, S_u (ksi) [a]	135.0	135.0	135.0	135.0	131.2	128.6	126.7	123.8
Yield Stress, S_y (ksi) [a]	111.7	105.0	97.1	93.0	89.7	87.0	84.7	82.5
Design Stress Intensity, S_m (ksi) [a]	45.0	45.0	45.0	45.0	43.7	42.9	42.2	41.3 [b]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.4	28.5	27.8	27.2	26.6	26.1	25.5	24.9
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	5.9							
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [c]	0.29							

Table 8.3-4 Mechanical Properties of A350, Grade LF 2, Class 1, Low Alloy Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield strength, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	25.8
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	22.0	21.2	20.5	19.6	17.2
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.7	29.2	28.5	28.0	27.4	27.0	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [c]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated value

[c] Metals Handbook Desk Edition [23]

Table 8.3-5 Mechanical Properties of SA516/A-516, Grade 70, Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield Stress, S_y (ksi) [a]	40.7	38.0	34.8	33.6	32.5	31.0	27.2
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.2	22.4	21.6	20.6	18.1
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [b]	0.284						

Table 8.3-6 Mechanical Properties of SA537, Class 1, Carbon Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	700	800
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	69.1	68.4	68.4	68.4	65.4
Yield Stress, S_y (ksi) [a]	54.9	50.0	44.2	40.5	37.6	35.4	32.3	30.5
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	22.9	22.9	22.9	21.4	20.3[c]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5	24.2
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.1	6.4	6.7	6.9	7.1	7.3	7.6	7.8
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [b]	0.284							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Code Case N-707 [34]. Code Case N-707 requires that the material creep strain is to be negligible. The only primary load for the normal condition of the basket is dead weight. Since only the top 3 feet of the basket are above 700°F, the maximum stress due to dead weight is 36×0.284 or 10 psi. The stress level is considered to be negligible and the dead weight loading at the top of the basket results in a negligible level of creep. Therefore, the requirements of Code Case N-707 are satisfied.

Table 8.3-7 Mechanical Properties of A537, Class 2, Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	80.0	80.0	80.0	78.9	78.2	78.1	78.1
Yield Stress, S_y (ksi) [a]	60.0	60.0	53.0	48.6	45.1	42.4	38.7
Design Stress Intensity, S_m (ksi) [a]	26.7	26.7	26.7	26.7	26.7	26.7	24.3
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.1	6.4	5.9	6.3	6.6	6.9	7.4
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [b]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

Table 8.3-8 Mechanical Properties of SA695, Type B, Grade 40, and SA696, Type C, Carbon Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	700	800
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	64.3
Yield Stress, S_y (ksi) [a]	40.0	40.0	36.6	35.4	34.2	32.6	28.6	26.8
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	23.3	22.8	21.7	19.2	--
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3	24.0
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6	7.8
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [b]	0.284							

Table 8.3-9 Mechanical Properties of A588, Type A and B, Carbon Steel, Small Plates

Property (units)	Value at Temperature (°F)								
	-40	100	200	300	400	500	600	650	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield Stress, S_y (ksi) [a]	53.5	50.0	47.5	45.6	43.0	41.8	39.9	38.9	37.9
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.7	29.0	28.5	28.0	27.4	27.0	26.4	25.9	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
Poisson's Ratio [a]	0.31								
Density (lb/in^3) [b]	0.284								

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

Table 8.3-10 Mechanical Properties of SA479, Type 304 Stainless Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	750
Ultimate strength, S_u (ksi) [a]	75.0	75.0	71.0	66.2	64.0	63.4	63.3
Yield strength, S_y (ksi) [a]	30.0	30.0	25.0	22.4	20.7	19.4	17.2
Design Stress Intensity, S_m (ksi) [a]	20.0	20.0	20.0	20.0	18.6	17.5	15.5
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	28.8	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	8.1 [b]	8.5	8.9	9.2	9.5	9.7	10.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [c]	0.29						

Table 8.3-11 deleted by 10 CFR 72.48 Determination

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated value

[c] Metals Handbook Desk Edition [23]

Table 8.3-12 Mechanical Properties of SA36/A36 Carbon Steel

Property (units)	Value at Temperature (°F)								
	-40	100	200	300	400	500	600	650	700
Ultimate strength, S_u (ksi) [a]	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0
Yield Stress, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	27.6	26.7	25.8
Design Stress Intensity, S_m (ksi) [a]	19.3	19.3	19.3	19.3	19.3	19.3	18.4	17.8	17.3
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.95	29.3	28.8	28.3	27.7	27.3	26.7	26.1	25.5
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
Poisson's Ratio [a]	0.31								
Density (lb/in^3) [b]	0.284								

[redacted]

Table 8.3-13 Mechanical Properties of SA193, Grade B6, High Alloy Bolting Steel

Property (units)	Value at Temperature (°F)							
	-40	-20	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [c]	110.0	110.0	110.0	104.9	101.4	98.3	95.6	90.6
Yield Stress, S_y (ksi) [c]	85.0	85.0	85.0	81.1	78.4	76.0	73.9	70.0
Design Stress Intensity, S_m (ksi) [a]	28.3	28.3	28.3	27.0	26.1	25.3	24.6	23.3
Bolt Stress Intensity, S_{mbm} (ksi) [a]	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.8	29.7	29.2	28.5	27.9	27.3	26.7	25.6
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	5.65 [d]	5.69 [d]	5.90	6.20	6.30	6.40	6.50	6.60
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [b]	0.28							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Calculated based on design stress intensity $\frac{S_{mtemp}}{S_{m70\ F}}(S_{u70\ F}) = S_{utemp}$

[d] Extrapolated value

Table 8.3-14 Mechanical Properties of SA193, Grade B8, Bolting Steel

Property (units)	Value at Temperature (°F)							
	-40	-20	70	200	300	400	500	700
Ultimate Strength, S_u (ksi) [a]	75.0	75.0	71.0	66.2	64.0	63.4	63.4	62.8
Yield Stress, S_y (ksi) [a]	30.0	30.0	25.0	22.4	20.7	19.4	17.6	16.9
Design Stress Intensity for Bolts, S_m (ksi) [a]	10.0	10.0	8.3	7.5	6.9	6.5	5.9	5.6
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	28.8	28.3	27.6	27.0	26.5	25.8	25.1	24.1
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	8.13 [b]	8.5	8.9	9.2	9.5	9.7	9.9	10.1
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [c]	0.29							

Table 8.3-15 Mechanical Properties of SA240, Type 347 Stainless Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	600	750
Ultimate strength, Su (ksi) [a]	75.0	75.0	71.7	65.9	62.1	60.0	59.1	58.8
Yield Stress, Sy (ksi) [a]	30.0	30.0	27.6	25.7	24.0	22.6	21.5	20.5
Design Stress Intensity, Sm (ksi) [a]	20.0	20.0	20.0	20.0	20.0	20.0	19.3	18.5
Modulus of Elasticity, E (× 106 psi) [a]	28.8	28.3	27.6	27.0	26.5	25.8	25.3	24.5
Coefficient of Thermal Expansion, α (×10-6 in/in/°F) [a]	8.1 [b]	8.5	8.9	9.2	9.5	9.7	9.8	10.0
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [c]	0.29							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated value

[c] Metals Handbook Desk Edition [23]

Table 8.3-16 Mechanical Properties of SB637, Grade N07718, Nickel Alloy Bolting Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	185.0	185.0	177.6	173.5	170.6	168.7	165.8
Yield Stress, S_y (ksi) [a]	150.0	150.0	144.0	140.7	138.3	136.8	134.4
Design Stress Intensity, S_m (ksi) [b]	50.0	50.0	48.0	46.9	46.1	45.6	44.8
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.6 [c]	29.0	28.3	27.8	27.6	27.1	26.4
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [c]	7.0	7.1	7.2	7.3	7.5	7.6	7.8
Poisson's Ratio [b]	0.31						
Density (lb/in^3) [a]	0.297						

Table 8.3-17 Mechanical Properties of A615, Grade 60

Property (units)	A615, Grade 60
Ultimate Strength (ksi) [d]	90.0
Yield Strength (ksi) [f]	60.0
Modulus of Elasticity, E ($\times 10^6$ psi) [d]	29.88
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [d]	6.1
Density (lbm/in^3) [e]	0.284

[a] Calculated based on design stress intensity $\frac{S_{m_{temp}}}{S_{m70\ F}}(S_{u70\ F}) = S_{u_{temp}}$

[b] ASME Boiler and Pressure Vessel Code [5]

[c] Extrapolated value

[d] Metallic Materials Specification Handbook [6]

[e] Standard Handbook for Mechanical Engineers [13]

[f] Annual Book of ASTM Standards [25]

Table 8.3-18 Mechanical Properties of Chemical Copper Grade Lead

Property (units)	Value at Temperature (°F)					
	-40	-20	70	200	300	600
Tensile Yield Stress, S_y (psi) [a]	700 [b]	680	640	490	380	200
Modulus of Elasticity, E (× 10^6 psi) [c]	2.45 [b]	2.42	2.28	2.06	1.94	1.5
Coefficient of Thermal Expansion, α (×10^{-6} in/in/°F) [c]	15.6 [b]	15.7	16.1	16.6	17.2	20.2
Poisson's Ratio [d]	0.4					
Density (lb/in^3) [d]	0.41					

[a] Determination of the Mechanical Properties of High Purity Lead and a 0.05% Copper-Lead Alloy [26]

[b] Extrapolated value

[c] NUREG/CR-0481 [27]

[d] Standard Handbook for Mechanical Engineers [13]

Table 8.3-19 Mechanical Properties of Concrete

Property (units)	Values at Temperature (°F)						
	-40	70	100	200	300	400	500
Compressive strength (psi) [a]	4000[b]	4000	4000	4000	3800	3600	3400
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	4.0[b]	3.72[b]	3.64	3.38	3.09	2.73	2.43
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	5.5[b]	5.5	5.5	5.5	5.5	5.5	5.5
Density (lb/ft^3) [c]	145						

Table 8.3-20 Mechanical Properties of NS-4-FR

Property (units)	Value at Temperature (°F)			
	86	158	212	302
Coefficient of Thermal Expansion ($\times 10^{-6}$ in/in/°F) [d]	22.2	47.2	58.8	57.4
Compressive Modulus of Elasticity (ksi) [d]	561			
Density (lbm/in^3) [d]	0.0607			

Table 8.3-21 Mechanical Properties of Neutron Absorber

Property (units)	Values at Temperature (°F)									
	-320	-112	-18	75	212	300	400	500	600	700
Ultimate Tensile Strength, S_u (ksi) [e]	25.0	15.0	14.0	13.0	10.0	8.0	6.0	4.0	2.9	2.1
Yield Strength, S_y (ksi) [e]	6.0	5.5	5.0	5.0	4.6	4.2	3.5	2.6	2.0	1.6
Elongation in 2 inches, % [f]	50	43	40	40	45	55	65	75	80	85
Mod. of Elasticity, E (10^6 psi) [f]	11.2	10.5	10.3	10.0	9.6	9.2	8.7	8.1	No value given	
Coefficient of Thermal Expansion, α, (10^{-6} in/in/ F) [f]	8.2	10.3	11.2	12.2	13.0	13.3	13.6	13.9	14.2	N/A
Poisson's Ratio [f]	0.33									
Density, (lb/in^3) [f]	0.098									
Boral Core Modulus of Elasticity, E (psi)	1000 (assumed)									
Boral Core Yield Strength, S_y (psi)	10 (assumed)									

[a] Handbook of Concrete Engineering [8]
[b] Extrapolated value
[c] Specified value
[d] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]
[e] Aluminum alloy 1100-O properties
[f] ASME Boiler and Pressure Vessel Code, Section II, Part D [5]

Table 8.3-22 Thermal Properties of Dry Air

Property (units)	Value at Temperature (°F) [a]					
	-40	70	100	300	500	700
Conductivity (Btu/hr-in-°F)	0.00101	0.00121	0.00128	0.00161	0.00193	0.00223
Specific Heat (Btu/lbm-°F)	0.241	0.2417	0.240	0.244	0.247	0.253
Density ($\times 10^{-5}$ lb/in^3)	5.1	4.19	4.11	3.01	2.38	1.97

Table 8.3-23 Thermal Properties of Helium

Property (units)	Value at Temperature (°F) [b]			
	80	260	440	800
Conductivity (Btu/hr-in-°F)	0.00751	0.00915	0.01068	0.01355

Property (units)	Value at Temperature (°F) [c]			
	260	400	600	800
Density ($\times 10^{-6}$ lb/in^3)	4.83	3.70	3.01	2.52
Specific Heat (Btu/lbm-°F)	1.24			

Property (units)	Value at Temperature (°F) [d]											
	240	300	350	400	450	500	600	650	700	750	800	900
Viscosity ($\times 10^{-7}$ N-s/m^2)	170	199	221	243	263	283	320	332	350	364	382	414

Table 8.3-24 Thermal Properties of Water

Property (units)	Value at Temperature (°F) [e]					
	70	200	300	400	500	600
Conductivity (Btu/hr-in-°F)	0.029	0.033	0.033	0.032	0.029	0.024
Specific Heat (Btu/lbm-°F)	0.998	1.00	1.03	1.08	1.19	1.51
Density (lbm/in^3)	0.036	0.035	0.033	0.031	0.028	0.025

Property (units)	Value at Temperature (°F) [f]											
	273	275	285	295	305	315	325	335	345	355	365	375
Viscosity ($\times 10^{6}$ N-s/m^2)	1750	1652	1225	959	769	631	528	453	389	343	306	274

[a] Principles of Heat Transfer, Kreith & Bohn, Fifth Edition, Table 2 [15]

[b] Handbook of Thermal Conductivity of Liquids and Gases [18]

[c] Principles of Heat Transfer, Kreith, Fifth Edition [17]

[d] Introduction to Heat Transfer [22], Table A.4

[e] Principles of Heat Transfer, Second Edition [21], Table 3

[f] Introduction to Heat Transfer [22], Table A.6

Table 8.3-25 Thermal Properties of NS-4-FR

Property (units)	Value [a]
Conductivity (Btu/hr-in-°F)	0.0311
Density (borated) (lbm/in^3)	0.0589
Density (nonborated) (lbm/in^3)	0.0607
Specific Heat (Btu/lbm-°F)	0.319

Table 8.3-26 Thermal Properties of Concrete

Property (units)	Value at Temperature (°F)		
	100	200	300
Conductivity (Btu/hr-in-°F) [b]	0.091	0.089	0.086
Specific Heat (Btu/lbm-°F) [c]	0.20		
Emissivity [c]	0.90		
Absorptivity [d]	0.60		

[a] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]

[b] Handbook of Concrete Engineering [8], Figure 6-31, Curve 1

[c] Principles of Heat Transfer, Kreith and Bohn, Fifth Edition [15]

[d] Introduction to Heat Transfer [22]

Table 8.3-27 Neutron Absorber Material Minimum Effective Thermal Conductivity - BTU/(hr-in-°F)

Fuel Basket Type	Radial		Axial	
	100°F	500°F	100°F	500°F
[redacted]				
BWR	1.503	1.972	3.295	3.669

Table 8.3-28 Thermal Properties of Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	100	200	400	500	700	800
Conductivity (Btu/hr-in-°F) [a]	2.28	2.30	2.30	2.22	2.16	2.0	1.92
Specific Heat (Btu/lbm-°F) [b]	0.113						
Emissivity [c]	0.80						
Density (lb/in^3) [d]	0.284						

Table 8.3-29 Thermal Properties of Chemical Copper Grade Lead

Property (units)	Value at Temperature (°F)					
	-40	70	200	400	600	800
Conductivity (Btu/hr-in-°F) [e]	1.767	1.707	1.636	1.526	1.131	0.309
Specific Heat (Btu/lbm-°F) [e]	0.03 (68°F)					
Emissivity [c]	0.28 (75°F)					
Density (lb/in^3) [e]	0.411 (68°F)					

Table 8.3-30 Thermal Properties of SA240, Type 304/304L, Stainless Steel

Property (units)	Value at Temperature (°F)							
	-40	100	200	400	550	750	800	900
Conductivity (Btu/hr-in-°F) [a]	0.686	0.725	0.775	0.867	0.925	1.0	1.017	1.058
Specific Heat (Btu/lbm-°F) [f]	0.10[g]	0.116	0.12	0.127	0.131	0.136	0.136	0.138
Emissivity [g, h]	0.36 (300°F)							
Density (lb/in^3) [h]	0.29	0.29	0.289	0.287	0.286	0.284	0.283	0.283

Note: The SA240 stainless steel is dual certified as Type 304 and 304L.

[a] ASME Boiler and Pressure Vessel Code, Table TCD [5]
[b] Principles of Heat Transfer, Kreith, Fifth Edition [15]
[c] Standard Handbook for Mechanical Engineers [13]
[d] Metallic Materials Specification Handbook [6]
[e] TRUMP, A Computer Program for Transient and Steady State Temperature Distributions in Multidimensional Systems [16]
[f] Nuclear Systems Materials Handbook [14]
[g] Metallic Materials and Elements for Aerospace Vehicle Structures [7]
[h] Metals Handbook Desk Edition [23]

Table 8.3-31 Thermal Properties of Zirconium-based Alloy Cladding

Property (units)	Value at Temperature (°F)				
	-40[a]	392	572	752	932
Conductivity (Btu/hr-in-°F)[b]	0.594	0.690	0.730	0.800	0.870
Specific Heat (Btu/lbm-°F)[b]	0.067	0.072	0.074	0.076	0.079
Emissivity[b]	0.75 (302°F)				
Density (lb/in^3)[c]	0.237				

Table 8.3-32 Thermal Properties of Fuel (UO_2)

Property (units)	Value at Temperature (°F)					
	-40[a]	100	257	482	707	932
Conductivity (Btu/hr-in-°F)[b, e]	0.409	0.380	0.347	0.277	0.236	0.212
Specific Heat (Btu/lbm-°F)[b]	0.053	0.057	0.062	0.067	0.071	0.073
Emissivity[b]	0.85 (1,340°F)					
Density (lbm/in^3)[c]	0.396					

Table 8.3-33 Thermal Properties of Nickel-Plated Steel

Property	Value
Emissivity[d]	0.2 – 0.32

[a] Extrapolated value

[b] Matpro-Version 11 A Handbook of Material Properties for Use in the Analysis of Light Water Reactor Rod Behavior [19]

[c] Nuclear Power Plant Engineering [20]

[d] Material Emissivity Properties: Electroless Nickel and Mild Steel [24]

[e] 60% of the conductivities are conservatively used in the evaluations for the PWR configuration

8.4 Weld Design and Specification

The welding operations of the MAGNASTOR components are performed in accordance with the requirements of a number of codes and standards depending on the design and functional requirements of the specific component. The specific requirements met by each component are provided herein.

The TSC and fuel basket assemblies are welded using welding procedures, processes, and welders prepared and qualified in accordance with the ASME Code, Section IX [29] requirements. The specific weld designs and examination requirements for the TSC and fuel basket comply with the applicable subsection of the ASME Code, Section III, which are Subsection NB for the TSC and Subsection NG for the fuel baskets. Alternatives to the Code requirements applicable to these system components are listed in Table 2.1-2. Weld filler materials and processes used in the fabrication of the TSC are in accordance with ASME Code Section II-C requirements for SFA 5.9 and SFA 5.22. For SFA 5.9 and SFA 5.22, respectively, AWS ER 308L and AWS E308LTX-X will be specifically identified in the approved welding procedures.

The steel components of the concrete casks (i.e., liner, baseplate, etc.) and the transfer cask are welded using procedures, processes, and welders prepared, qualified, and certified in accordance with either ASME Section IX or ANSI/AWS D1.1 [28]. The weld design and specification requirements for the steel components of the concrete cask are in accordance with the weld design criteria of the ASME Code, Section VIII, Division 1, Part UW [31] or ANSI/ANS D1.1. The weld design and specification requirements for the transfer cask are in accordance with the weld design criteria of the ASME Code, Section III, Subsection NF [32].

The inspection and examination requirements for all MAGNASTOR component welds, inspector qualification requirements, and the applicable acceptance criteria are specified in Chapter 10 of this SAR.

8.5 Bolts and Fasteners

This section presents information to demonstrate that bolt and fastener materials have been selected for material compatibility to preclude galling during use, and to have the requisite material strength for the application.

The PWR and BWR fuel baskets are assembled using SA-193 Grade B6 stainless steel bolts. The bolts are used initially to assemble the basket by securing the outer fuel tubes to the arrangement of gussets, bars, support plates, and weldments. The applied preload of the bolts provides rigidity to the basket for its installation into the TSC. During certain accident events, the bolts may be subjected to increased tensile loading. The evaluation of these accident conditions is provided in Chapter 3. As shown in that chapter, the bolts have a large margin of safety for the postulated loading conditions.

The MTC2 transfer cask design incorporates a retaining ring, which is bolted to the top ring of the transfer cask, to prevent the inadvertent raising of the loaded TSC through the top of the transfer cask during handling. The MTC2 transfer cask retaining ring is fabricated from ASTM A240, Type 304 stainless steel and is secured using SA-193 Grade B8 stainless steel bolts. During the inadvertent lift accident event, the bolts will be subjected to tensile loading. The evaluation of this accident condition is provided in Chapter 3. As shown in that chapter, the bolts and retaining ring have an adequate margin of safety for the postulated loading conditions.

Stress corrosion cracking does not occur in the bolting materials, as bolts used in assembling the basket are in an inert environment with no significant potential for corrosion to occur. Lifting bolts are not permanently installed. Consequently, cracking that could be induced from the combined influence of tensile stress and a corrosive environment does not occur.

Weld posts are used to attach the neutron absorber plate and retainer to the inside of the fuel tube and are fabricated from SA-479, Type 304 stainless steel. Following installation of the weld post, the backside of the weld post is heated and melted to form a flared head. The Type 304 stainless steel retainer protects the neutron absorber during fuel loading. The weld posts provide structural support to the neutron absorber and retainer to prevent significant movement of the neutron absorber. As shown in this SAR, the weld posts have adequate strength to hold the neutron absorber in place during evaluated normal operating conditions, off-normal events and postulated accident events.

The assembled TSC design does not include bolted or fastened connectors, except for the composite closure lid assembly. For vertical lifting and handling of the loaded TSC, hoist rings or other suitable lift fixtures are bolted into the six threaded lift points in the TSC closure lid. The lift attachment points are evaluated in Chapter 3. The composite closure lid assembly uses

A193, Grade B6 bolts to attach the shield plate to the closure lid. The shield lid attachment bolts are evaluated in Chapter 3 for preload combined with normal operating conditions, off-normal events and postulated accident events. As shown in that chapter, the shield plate attachment bolts satisfy the applicable allowable stress analysis criteria.

The concrete cask, holding a loaded TSC, can be lifted vertically using bolted lugs to move the cask on the ISFSI or to or from a handling site for either installing or removing a loaded TSC. The concrete cask incorporates two lifting load paths, one each on opposite sides of the cask. The load paths are formed by lift anchors embedded in the standard cask or bolted in cavities of the segmented cask. For lifting the segmented cask, eight SB-637 Grade N07718 high-strength lift lug bolts are used for attachment of each lift lug. In the lift configuration, the high-strength bolts connect top and bottom concrete cask sections. The analysis of the attachments, load path and bolts is provided in Chapter 3. As shown in that chapter, based on the material specified, the bolts have adequate margin for the application.

When lifting operations are complete, the lift lugs and bolts are removed and commercial-grade stainless steel bolts are installed to connect the two cask sections. These commercial-grade bolts are used to replace the lift lug bolts, since there are no normal operations or off-normal events, and no credible accident events that apply significant forces to the cask top section.

The cask lid is retained by six commercial-grade stainless steel bolts. Commercial grade bolts are sufficient since only negligible forces are applied to the lid connections during normal operations or off-normal and credible accident events.

The concrete cask includes inlet and outlet screens, a lid, and may have temperature monitors at the outlets. There are no evaluated events that are expected to dislodge these components.

The MTC1 transfer cask design incorporates a set of three retaining blocks and pins to prevent the inadvertent raising of the loaded TSC through the top of the transfer cask during handling. The retaining blocks and pins are designed to support the weight of the transfer cask if the TSC engages them during lifting. As designed, if engaged, the retaining blocks would be loaded in shear and the pins in tension, due to the prying action of the blocks. The retaining blocks and pins are fabricated from ASTM A693/A564 17-4 PH stainless steel and ASTM A516, Grade 70 low alloy steel, respectively. The structural evaluation in Chapter 3 demonstrates that the retaining blocks and pins have a significant margin of safety under the evaluated loading conditions.

Lifting of the transfer cask and concrete cask is controlled by procedure and Technical Specifications that restrict lifting operations to times where the ambient temperature is above 0°F. This restriction precludes the potential for brittle fracture of carbon steel bolting or structural components.

8.6 Coatings

The exposed surfaces of carbon steel and concrete components of MAGNASTOR are coated with specially designed and applied coating systems. The coatings are provided to reduce corrosion of exposed carbon steel surfaces, to minimize adverse reactions between dissimilar materials, and to minimize adverse interactions of components with their operating environment during in-pool loading, dry transfer and storage. The details on the various types of coating systems utilized on MAGNASTOR components are discussed in the following sections.

8.6.1 Electroless Nickel

The PWR and BWR fuel baskets are fabricated primarily of carbon steel. Additionally, the shield plate of the TSC composite closure lid assembly is fabricated from carbon steel. The potential for corrosion exists from fabrication through spent fuel loading up to final closure operations. After final closure welding, drying and inert gas backfill of the TSC cavity, the potential for corrosion of the carbon steel baskets is effectively eliminated.

The most critical period, both from a material corrosion aspect and an operational aspect, is the time period when the TSC is submerged in the fuel pool during the fuel loading cycle. Specifically, at PWR sites, the fuel pool water may contain boric acid in solution in the range of 2,500 ppm. To minimize the level of corrosion during fuel loading, the carbon steel components of the fuel baskets and the shield plate of the TSC composite closure lid assembly will be electroless nickel-coated. The electroless nickel coating provides the appropriate protection to restrict material reduction due to corrosion and minimize the loss of water clarity that can affect the fuel loading process. The electroless nickel coating is also effective in eliminating the potential for production of explosive levels of hydrogen due to cathodic reaction of basket components with spent fuel pool water. The cavity gas volume will be sampled for explosive levels of hydrogen before and during closure lid root pass welding and closure lid weld removal operations.

During the TSC and fuel basket assembly process, coating damage can occur. Localized scratches, etc., can result in coating damage, but are considered insufficient to cause concerns relative to the functional and structural performance of the basket. Additionally, due to the configuration of the fuel basket, some areas of the fuel basket may not be completely coated. These areas are also considered minor and insufficient to affect either the functional or operational aspects of the fuel basket.

The electroless nickel coating process applied to the basket components and shield plate of the TSC composite closure lid assembly will use ASTM B733 [30] for guidance. The coating thickness shall be in the service condition SC3, and Alloy Type IV or V will be specified with no post-heat treatment invoked. Lot testing will be performed on batch specimens and acceptance will be based on appearance and adhesion. Specimens will be representative of the material and condition of the pieces to be coated.

8.6.2 Other Coating Systems

The exposed carbon steel surfaces of the MTC1 transfer cask, other than wear surfaces, i.e., shield door and rail mating surfaces, are coated with an epoxy enamel coating system tested and certified for use in Nuclear Service Level 1 conditions such as Carboline Carboguard 890N and Keeler & Long/PPG KLE Series. Uncoated exposed wear surfaces are protected from corrosion and adverse interactions with spent fuel pool water by the application of approved nuclear grade lubricants during use and storage of the MTC1 transfer cask. Proper lubrication is confirmed or augmented prior to each TSC loading sequence. The enamel coating system and lubricated wear surfaces ensure that interactions with the spent fuel pool water will not generate excessive hydrogen gas, corrosion of the carbon steel, or loss of the coating materials in the spent fuel pool. Nitronic 30 wear strips are incorporated on the MTC1 transfer cask inner surface and the top of the shield doors to provide protection of the coating system from excessive wear caused by TSC handling operations.

The exposed carbon steel surfaces of the transfer adapter, other than the shield door rail surfaces, are coated with an approved two-coat painting system designed to minimize corrosion under long-term exposure in air. The transfer adapter is only used for the dry loading and transfer of a TSC into a concrete cask, or retrieval. Therefore, a special nuclear-grade coating system is not required. Wear surfaces are lubricated with a nuclear-grade lubricant. There are no potential adverse interactions of the transfer adapter surfaces with the operating environment.

The carbon steel components of the concrete cask that are not covered by installed concrete are coated with a heat-resistant coating system. The coating system is designed to provide protection against corrosion when exposed to an external environment, while being capable of withstanding long-term exposure to the elevated temperatures of the concrete cask components during the storage operations.

The exposed concrete surfaces of the concrete cask are coated with a commercial-grade sealant to provide protection to the cask surfaces during curing and long-term storage operations.

As with the nickel plating, no positive characteristics of the coating systems are considered in the applicable analyses and, therefore, minor scratches and wear of the coatings is not a concern. The coating systems of the accessible exposed carbon steel surfaces of MAGNASTOR components are inspected annually. Required repairs to coating systems are completed as part of the maintenance program in accordance with the manufacturer's recommendations.

8.7 Gamma and Neutron Shielding Materials

MAGNASTOR uses lead, concrete, steel, and NS-4-FR as the principal shielding materials.

8.7.1 Gamma Shielding Material

Lead and steel are the primary gamma radiation shielding materials in the transfer cask. The lead gamma shield is constructed of solid Chemical Copper grade lead bricks. The lead conforms to ASTM Specification B29 (Section 8.13.6) [33]. The specification provides essentially elemental lead, with some trace elements such as copper, which improve the machining characteristics of the material. The bricks are designed to "nest" such that both horizontal gaps (between adjacent bricks) and vertical gaps (between stacked bricks) are precluded. The lead bricks are installed around the inner steel shield, and enclosed by the upper and lower forgings and the outer steel shell. The gap between the lead bricks and the outer shell is filled with neutron shield material. During fabrication assembly, visual inspection is used to verify uniform brick installation for the lead shielding. The transfer cask gamma shielding details are shown in the licensing drawings.

The carbon steel liner provides the primary gamma radiation shielding for the concrete cask. The installed concrete and rebar of the cask also provide measurable gamma radiation shielding capabilities. The steel shell of the TSC is also accounted for in the shielding analysis of the transfer cask and concrete cask.

8.7.2 Neutron Shielding Material

Concrete provides neutron radiation shielding for the concrete cask based on the silicon and water content of the concrete. Silicon, hydrogen and oxygen are low atomic number materials that are effective in thermalizing and capturing energetic neutrons. Since the density of these materials is a relatively fixed function of the concrete mix, the thickness of the concrete shell is designed to establish the required neutron shielding. The concrete is poured and cured in place around reinforcing bar that provides structural rigidity.

The transfer cask incorporates NS-4-FR neutron shielding material containing ≥ 0.6 weight percent boron. NS-4-FR is a proprietary commercial product of NAC International that consists primarily of aluminum, carbon, oxygen, and hydrogen.

The low-density NS-4-FR components interact and thermalize the neutrons emitted from the TSC. The boron is effective in absorbing the resultant thermal neutrons. The material is installed in the transfer cask by pouring it into the annulus formed by the outer shell and the lead gamma shield of the transfer cask. The arrangement of the NS-4-FR is shown in the license

drawings. Installation of the material is by a proprietary pouring process that ensures the absence of gaps and voids in the installed material. Consequently, no shop testing of the transfer cask for neutron shielding is required or performed.

The acceptable performance of NS-4-FR has been demonstrated by more than 15 years of use in licensed storage casks in the United States, Japan, Spain, and the United Kingdom. There are no reports that the shielding effectiveness of the materials has degraded in these applications, thereby demonstrating the long-term reliability for the purpose of shielding neutrons from personnel and the environment. There are no potential reactions associated with the polymer structure of the NS-4-FR materials and the stainless steel, carbon steel or lead that are contacted during use.

The thermal performance of NS-4-FR has been demonstrated by long-term functional stability tests of the material at temperatures from -40°F to 338°F. These tests included specimens open to the atmosphere and enclosed in a cavity at both constant and cyclic thermal loads. The tests evaluated material loss though off-gassing and material degradation. The results of the tests demonstrate that, in the temperature range of interest, the NS-4-FR does not exhibit loss of material by off-gassing, does not generate any significant gases, and does not suffer degradation or embrittlement. Consequently, the formation of flammable gases is not a concern. Further, the tests demonstrated that encased material, as it is used in MAGNASTOR, performed significantly better than exposed material.

Radiation exposure testing of NS-4-FR in reactor pool water has demonstrated no physical deterioration of the material and no significant loss of hydrogen (less than 1%). The tests also demonstrated that the NS-4-FR retains its neutron shield capability over the cask's 50-year design life with substantial margin. The radiation testing has shown that detrimental embrittlement and loss of hydrogen from the material do not occur at dose rates (9×10^{14} n/cm^2) that exceed those that would occur assuming the continuous storage of design basis fuel for a 50-year life (estimated to be 1.7×10^{12} cm^2/yr). Consequently, detrimental deterioration or embrittlement due to radiation flux does not occur.

Since the NS-4-FR in the transfer cask is sandwiched between the outer shell and the lead, and enclosed within a welded steel shell where the shell seams are welded to top and bottom plates with full-penetration or fillet welds, it will maintain its form over the expected lifetime of the transfer cask. Additionally, the material's placement between the lead shield and the outer shell does not allow the material to redistribute within the annulus.

8.8 Neutron Absorber Material

Neutron absorber materials containing the element boron, specifically the isotope ^{10}B, are widely used in the nuclear industry because of their high cross-section for absorbing thermal neutrons, commonly to ensure subcriticality inside spent nuclear fuel storage and/or transport casks during normal handling and off-normal/accident service conditions. Criticality safety is dependent upon the neutron absorber material remaining fixed in position on the fuel tubes and containing the required amount of boron uniformly distributed throughout the sheet. A neutron absorber (criticality control) material can be a composite of fine particles in a metal matrix or an alloy of boron compounds with aluminum. Fine particles of boron-carbide that are uniformly distributed are required to obtain the best neutron absorption. The specified areal density of ^{10}B in a neutron absorber is determined based on fuel assembly type and reactivity. Three types of neutron absorber materials are commonly used in spent fuel storage and transport cask fuel baskets – borated aluminum alloy, borated metal matrix composites (MMC), and Boral (registered trademark of Ceradyne).

Applicable terminology definitions for the neutron absorber materials:

acceptance –	tests conducted to determine whether a specific production lot meets selected specified material properties and characteristics, or both, so that the lot can be accepted for commercial use.
areal density –	for sheets with flat parallel surfaces, the density of the neutron absorber times the thickness of the material.
designer –	the organization responsible for the design or the license holder for the dry cask storage system or transport packaging. The designer is usually the purchaser of the neutron absorber material, either directly or indirectly (through a fabrication subcontractor).
lot –	a quantity of a product or material accumulated under conditions that are considered uniform for sampling purposes.
neutron absorber –	a nuclide that has a large thermal or epithermal neutron absorption cross section, or both.
neutron absorber material –	a compound, alloy, composite or other material that contains a neutron absorber.

neutron transmission test –	a process in which a material is placed in a thermal neutron beam, and the number of neutrons transmitted through the material in a specified period of time is counted. The observed neutron counting rate may be converted to areal density by performing the same test on a series of calibration standards. The transmission test uses a collimated thermal neutron beam of up to 2.54 cm in diameter, with a tolerance of 10 percent.
neutron cross section –	a measure of the probability that a neutron will interact with a nucleus; a function of the neutron energy and the structure of the interacting nucleus.
packaging –	in transport of radioactive material, the assembly of components necessary to enclose the radioactive contents completely.
qualification –	the process of evaluating, testing, or both, a material produced by a specific manufacturing process to demonstrate uniformity and durability for a specific application.

The MAGNASTOR storage system utilizes sheets of neutron absorber material that are attached to the sides of the spent fuel storage locations in the fuel baskets. The materials and dimensions of the neutron absorber sheets are defined on NAC drawing numbers 71160-571 and 71160-572. The material in the Bill of Materials is identified as a metallic composite (includes borated aluminum alloy, borated metal matrix composites (MMC), and Boral), which is available under various commercial trade names. Incorporating alternative neutron absorber materials in the design provides fabrication flexibility for the use of the most economical and available neutron absorber material that meets the characteristics necessary to assure criticality safety. The critical design characteristics of the neutron absorber material are:

- A minimum "effective" areal density of 0.027 g/cm^2 ^{10}B for the PWR basket and 0.020 g/cm^2 ^{10}B for the BWR basket; and
- A uniform distribution of boron carbide; and
- A strength at least equivalent to that of 1100 series aluminum at 700°F, which is sufficient to maintain its form; and
- An effective thermal conductivity greater than, or equal to, that used in the thermal analyses (Chapter 4).

The required minimum as-fabricated ^{10}B loading in a neutron absorber sheet is determined based on the effectiveness of the material, i.e., 75% for Boral and 90% for borated aluminum alloys and for borated metal matrix composites. Neutron transmission testing, as described in Section 10.1.6, will be used to verify the ^{10}B areal density for the neutron absorber materials. Table 8.8-1 presents a tabulation of the types of neutron absorber materials, the required minimum effective areal density of ^{10}B, and the required minimum as-fabricated areal density of ^{10}B. Since an oxide layer forms on the surfaces of the metallic composite neutron absorber material shortly after fabrication, interaction with the stainless steel as well as the electroless nickel coating is inhibited and the material is protected against degradation. Consequently, no potential reactions associated with the aluminum-based criticality control materials are expected. The positions and attachments of the neutron absorber sheets and the retainers to the fuel tubes are shown on drawings NAC drawing numbers 71160-551 and 71160-591.

Standard industrial inspections will be performed on the neutron absorber products to verify the acceptability of physical characteristics such as dimensions, flatness, straightness, thermal conductivity, tensile properties (if structural considerations are applicable), other mechanical properties as appropriate, surface quality and finish in accordance with the design drawings and fabrication specifications. Specific acceptance criteria and the associated industry standard/code are described in Section 10.1.6.

Qualification of the neutron absorber material will be specified to demonstrate that the material will perform its design functions under the defined environmental conditions during the licensed period. Material qualification and validation specifications are defined in Section 10.1.6 for a range of environmental conditions, including short-term transfer operations, normal conditions, and off-normal and accident events.

Acceptance testing of the neutron absorber material, as described in Section 10.1.6, will be performed to validate that the production materials comply with the specified requirements, including absorber content and uniformity of distribution, mechanical properties, thermal conductivity, surface finish and dimensions.

All qualification and acceptance validation will be conducted in accordance with the NAC International quality assurance program.

Table 8.8-1 Neutron Absorber Material Minimum ^{10}B Loading

Neutron Absorber Type	Required Minimum Effective Areal Density (^{10}B g/cm^2)		% Credit Used in Criticality Analyses	Required Minimum Actual Areal Density (^{10}B g/cm^2)	
	PWR Fuel	BWR Fuel		PWR Fuel	BWR Fuel
Borated Aluminum Alloy	0.036	0.027	90	0.04	0.03
	0.030	0.0225		0.334	0.025
	0.027	0.020		0.03	0.0223
Borated MMC	0.036	0.027	90	0.04	0.03
	0.030	0.0225		0.334	0.025
	0.027	0.020		0.03	0.0223
Boral	0.036	0.027	75	0.048	0.036
	0.030	0.0225		0.04	0.030
	0.027	0.020		0.036	0.0267

8.9 Concrete and Reinforcing Steel

The concrete cask is fabricated of 28-day, 4000 psi, Type II Portland cement that is reinforced with vertical and circumferential carbon steel reinforcing bar. The cask is fabricated in accordance with American Concrete Institute, "Building Code Requirements for Structural Concrete," (ACI 318) [2].

Quality control of the proportioning, mixing, and placing of the concrete, in accordance with the NAC fabrication/construction specification, will make the concrete highly resistant to water. The concrete shell is not expected to experience corrosion or significant degradation from the storage environment through the life of the cask. The design and analysis considers the maximum temperatures that the concrete could reach to avoid any significant loss of concrete hydration.

The reinforcing bar used is ASTM A615/A615M, Grade 60 material of various diameters and lengths, depending on its position in the cask. The reinforcing bar is completely within the concrete matrix so that degradation of the bar during the storage life is unlikely. The reinforcing bar is installed in accordance with the requirements of ACI 318.

8.10 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of MAGNASTOR are 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 — are considered for the environments that may be encountered under normal conditions and off-normal or accident events. Based on the evaluation, no potential reactions that could adversely affect the overall integrity of the concrete cask, the fuel basket, the TSC, or the structural integrity and retrievability of the fuel from the TSC have been identified. The evaluation conforms to the guidelines of ISG-15 [10].

No potential chemical, galvanic, or other reactions have been identified for MAGNASTOR. Therefore, the overall integrity of the TSC and the structural integrity and retrievability of the spent fuel are not adversely affected for any operations throughout the design basis life of the TSC. Based on the evaluation, no change in the TSC or fuel cladding thermal properties is expected, and no corrosion of mechanical surfaces is anticipated. No change in basket clearances or degradation of any safety components, either directly or indirectly, is likely to occur since no potential reactions have been identified.

8.10.1 Component Operating Environment

Most of the component materials of MAGNASTOR are exposed to two typical operating environments: 1) an open TSC containing fuel pool water or borated water with a pH of 4.5 and spent fuel or other radioactive material; or 2) a sealed TSC containing helium, but with external environments that include air, rain water/snow/ice and marine (salty) water/air. Each category of TSC 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 conditions or off-normal and accident events.

The long-term environment to which the TSC's internal components are exposed is dry helium. Both moisture and oxygen are removed prior to sealing the TSC. The helium displaces the oxygen in the TSC, effectively precluding chemical corrosion. The dry environment inside the sealed TSC also inhibits galvanic corrosion between dissimilar metals in electrical contact.

In addition to the spent fuel, the fuel assemblies in the basket may hold control element assemblies, thimble plugs or other nonfuel components that are nonreactive with the fuel assembly. By design, the control components and nonfuel components are inserted in the guide tubes of a fuel assembly. During reactor operation, the control and nonfuel components are

immersed in acidic water having a high flow rate and are exposed to significantly higher neutron flux, radiation and pressure than will exist in dry storage. The control and nonfuel components are physically placed in storage in a dry, inert atmosphere in the same configuration as when used in the reactor. Therefore, there are no adverse reactions, such as gas generation, galvanic or chemical reactions or corrosion, since these components are nonreactive with the zirconium-alloy guide tubes and fuel rods. There are no aluminum or carbon steel fuel assembly parts, and no gas generation or corrosion occurs during prolonged water immersion (20 – 40 years). Thus, no adverse reactions occur with the control and nonfuel components over prolonged periods of dry storage.

8.10.2 Component Material Categories

The component materials are categorized in this section for their chemical and galvanic corrosion potential on the basis of similarity of physical and chemical properties and component functions. The categories are stainless steels, nonferrous metals, carbon steel, coatings, concrete, and criticality control materials. The evaluation is based on the environment to which these categories could be exposed during operation or use.

The TSC component materials are not reactive among themselves with the TSC's contents, or with the TSC's operating environments during any phase of normal conditions, off-normal or accident events, loading, unloading, handling or storage operations. Since no reactions will occur, no gases or other corrosion by-products will be generated.

The control component and nonfuel component materials are those that are typically used in the fabrication of fuel assemblies, i.e., stainless steels, Inconel 625, and zirconium-based alloy, so no adverse reactions occur in the inert atmosphere that exists in storage. The control element assembly, thimble plugs and nonfuel components—including start-up sources or instrument segments to be inserted into a fuel assembly—are nonreactive among themselves with the fuel assembly or with the TSC's operating environment for any storage condition.

8.10.2.1 Stainless Steels

No reaction of the TSC and MTC2 component stainless steels is expected in any environment, except for the marine environment where chloride-containing salt spray could potentially initiate pitting of the TSC stainless steel if the chlorides are allowed to concentrate and stay wet for extended periods of time (weeks). Only the external TSC surface could be so exposed. The corrosion rate will, however, be so low that no detectable corrosion products or gases will be generated. MAGNASTOR has smooth external surfaces to minimize the collection of such materials as salts.

The TSC confinement boundary uses Type 304/304L dual-certified stainless steel for all components except the closure lid. The MTC2 transfer cask structural components are fabricated primarily from ASTM A240/A182 Type 304 stainless steel. No coatings are applied to the stainless steels. Type 304/304L stainless steel resists chromium-carbide precipitation at the grain boundaries during welding and assures that degradation from intergranular stress corrosion will not be a concern over the life of the TSC. Fabrication specifications control the maximum interpass temperature for austenitic steel welds to less than 350°F. The material will not be heated to a temperature above 800°F, other than by welding or thermal cutting. Minor sensitization of Type 304/304L stainless steel that may occur during welding will not affect the material performance over the design life.

8.10.2.2 Carbon Steel

Carbon steel is used to fabricate all of the structural components of the PWR and BWR baskets, and the shield plate of the TSC composite closure lid assembly. There is a small electrochemical potential difference between carbon steel and the stainless steel of the TSC shell and the stainless steel sheet used to protect the neutron absorber in the fuel tubes. However, the carbon steel basket components and the shield plate of the TSC composite closure lid assembly are coated with electroless nickel using an immersion process. The immersion process ensures that the carbon steel is appropriately coated, reducing the possibility of corrosion due to exposure to air or pool water. When in contact with stainless steel in water, the carbon steel exhibits a limited electrochemically driven corrosion. Typically, BWR pool water is demineralized, and is not sufficiently conductive to promote detectable corrosion for these metal couples. Once the TSC is loaded, the water is drained from the cavity, the air is removed, and the TSC is backfilled with helium and sealed. Removal of the water and the moisture eliminates the catalyst for galvanic corrosion between the carbon and stainless steels. In addition, the displacement of oxygen by helium effectively inhibits oxidation.

The MTC1 transfer cask structural components are fabricated primarily from ASTM A588 and A36 carbon steel. The exposed carbon steel components are coated with an epoxy enamel coating system tested and certified for use in Nuclear Service Level 1 conditions to protect the components during in-pool use and to provide a smooth surface to facilitate decontamination.

The concrete shell of the concrete cask contains an ASTM A36 carbon steel liner, as well as other carbon steel components. The exposed surfaces of the carbon steel liner and air inlets and outlets are coated to provide protection from weather-related moisture. The coating is formulated for use in continuous high- temperature environments.

No potential reactions associated with the shield plate of the TSC composite closure lid assembly, basket supports and fuel tubes, the transfer cask components or concrete cask components are expected to occur.

8.10.2.3 Nonferrous Metals

Aluminum is used in the neutron absorber material. The aluminum material in electrical contact with the stainless steel cover and carbon steel fuel tube could experience corrosion driven by an electrochemically induced electromotive force when immersed in water, where the conductivity of the water is the dominant factor. Typically, BWR fuel pool water is demineralized and is not sufficiently conductive to promote detectable corrosion for these metal couples. PWR pool water, however, does provide a conductive medium.

Shortly after fabrication, aluminum produces a thin surface film of oxidation that effectively inhibits further oxidation of the surface. This oxide layer adheres tightly to the base metal and does not react readily with the materials or environments to which the fuel basket will be exposed. The volume of the aluminum oxide does not increase significantly over time. Thus, binding due to corrosion product build-up during future removal of spent fuel assemblies is not a concern. The borated water in a PWR fuel pool is an oxidizing-type acid with a pH on the order of 4.5. However, aluminum is generally passive in pH ranges down to about 4 [11]. Data provided by the Aluminum Association [12] shows that aluminum alloys are resistant to aqueous solutions (1-15%) of boric acid (at 140°F). Based on these considerations and the very short exposure of the aluminum in the fuel basket to the borated water, oxidation of the aluminum is not likely to occur beyond the formation of a thin surface film. No observable degradation of aluminum is expected as a result of exposure to BWR or PWR pool water at temperatures up to 200°F, which is higher than the normal condition permissible fuel pool water temperature.

Aluminum is high on the electromotive potential table, and it becomes anodic when in electrical contact with stainless or carbon steel in the presence of water. BWR pool water is demineralized and is not sufficiently conductive to promote detectable corrosion for these metal couples. PWR pool water is sufficiently conductive to allow galvanic activity to begin. However, exposure time of the aluminum to the PWR pool environment is short. The long-term storage environment is sufficiently dry to inhibit galvanic corrosion.

From the foregoing discussion, it is concluded that the initial surface oxidation of the aluminum component surfaces and the conditions of long-term storage effectively inhibit any potential galvanic reactions.

Vendor and Nuclear Regulatory Commission evaluations have concluded that combustible gases, primarily hydrogen, may be produced by a chemical reaction and/or radiolysis when aluminum

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 TSC that approaches or exceeds the Lower Flammability Limit (LFL) for hydrogen of four percent.

Thus, it is reasonable to conclude that small amounts of combustible gases, primarily hydrogen, may be produced during TSC loading or unloading operations as a result of a chemical reaction between the aluminum neutron absorber in the fuel basket and the spent fuel pool water. The generation of combustible gases stops when the water is removed from the TSC and the aluminum surfaces are dry.

8.10.3 Evaluation of the Operating Procedures

This section evaluates the operating procedures to identify the potential for galvanic reactions, corrosion or flammable gas formation to occur during planned operations. As described in this section, no potential chemical, galvanic, or other reactions have been identified for MAGNASTOR. The use of a dry inert helium atmosphere in storage inhibits galvanic and corrosion events and flammable gas formation. Monitoring for levels of hydrogen approaching the Lower Flammability Limit (LFL) is performed during TSC closure lid root pass welding, and during closure lid weld removal operations in preparation for TSC unloading. If hydrogen levels exceed 60% of LFL (i.e., 2.4%H_2), these operations are stopped and corrective actions are taken until the H_2 levels are reduced to acceptable levels. Therefore, no adverse conditions, such as the ignition of flammable or explosive quantities of combustible gases, can result during any phase of TSC operations.

8.10.3.1 Evaluation of Loading Operations

After the TSC is removed from the pool and during TSC closure operations, the cavity water level is lowered (approximately 70 gallons are removed) to ensure that the closure lid-to-TSC shell weld area is dry during welding. The lowering of the cavity water level will not expose fuel rod cladding to an air environment. As there is limited clearance between the inside diameter of the TSC shell and the outside diameter of the closure lid, it is possible that gases released from a chemical reaction inside the TSC could accumulate beneath the lid.

The aluminum surfaces of the neutron absorber panels oxidize when exposed to air, react chemically in an aqueous solution, and may react galvanically when in contact with stainless steel or carbon steel. The reaction of aluminum in water, which results in hydrogen generation, proceeds as follows.

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

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. BWR spent fuel pool water does not contain boron and typically has a neutral pH (approximately 7.0). 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, but the reaction rate would be less in the neutral pH BWR pool.

The MAGNASTOR basket configurations incorporate carbon steel fuel tubes and support components that are coated with electroless nickel. Additionally, the optional TSC composite closure lid configuration uses a carbon steel shield plate coated with electroless nickel. The coating protects the carbon steel during the comparatively short time that the TSC is immersed in, or contains, water. The coating is nonreactive with the pool water and does not off-gas or generate gases as a result of contact with the pool water. Consequently, there are no flammable gases generated by the coating and no flammable gases generated by the materials of the coated components.

To ensure safe loading of the TSC, the loading procedure described in Chapter 9 provides for the monitoring of hydrogen gas before and during the root pass welding operations that join the closure lid to the TSC shell. The monitoring system is capable of detecting hydrogen at 60% of the Lower Flammability Limit (LFL) for hydrogen (i.e., 2.4% H_2). The hydrogen detector is connected to the cavity volume so as to detect hydrogen prior to initiation of welding. The hydrogen concentration is monitored during the root pass welding operation. The welding operation is stopped upon the detection of hydrogen in a concentration exceeding 2.4%. Hydrogen gas concentrations exceeding 2.4% are removed by flushing air, nitrogen, argon or helium into the region below the closure lid or by evacuating the hydrogen using a vacuum pump.

The vacuum pump exhausts to a system or area where hydrogen flammability is not an issue. 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 potential source of combustible gases, and hydrogen gas monitoring is stopped.

Hydrogen is not expected to be detected prior to, or during, the welding operations. During the completion of the closure lid to TSC shell root pass, the hydrogen gas detector accesses the vent port and is used to monitor the hydrogen gas levels. Following closure lid welding and TSC hydrostatic testing, the TSC is drained. Once the TSC is dry, no combustible gases form within the TSC.

8.10.3.2 Evaluation of Unloading Operations

The TSC is dried and backfilled with helium immediately prior to final closure welding operations, thereby eliminating all oxidizing gases and water. Therefore, it is not expected that the TSC will contain any combustible gases during the time period of storage. To ensure the safe, wet unloading of the TSC, the unloading procedure described in Chapter 9 provides for monitoring for hydrogen gas during closure lid weld cutting/removal operations.

The principal steps in opening the TSC are the removal of the vent and drain port cover welds, and the removal of the closure lid weld. The welds are expected to be removed by cutting or grinding. Following removal of the vent and drain port covers, the TSC is sampled for radioactive gases, vented, flushed with nitrogen gas, and cooled down with water using the vent and drain ports. Prior to cutting the closure lid weld, the cavity water level is lowered to permit removal of the closure lid weld in a dry environment, and the cavity gas volume is sampled for hydrogen gas levels $\geq$2.4% using a hydrogen gas detector connected to the vent port. If unacceptable hydrogen levels are detected during closure lid weld removal operations, weld removal operations are terminated and the cavity is flushed with air, nitrogen, argon or helium, or the cavity is evacuated with a vacuum pump.

8.10.3.3 Conclusions

The steps taken to monitor for the presence of hydrogen will ensure that combustion of any hydrogen gas does not occur due to either closure lid welding or lid removal operations. Based on this evaluation, which results in no identified reactions, it is concluded that MAGNASTOR operating controls and procedures for loading and unloading the TSC presented in Chapter 9 are adequate to minimize the occurrence of hazardous conditions.

8.11 Cladding Integrity

The MAGNASTOR system and processes minimize spent fuel cladding deterioration during transfer and storage conditions by controlling the spent fuel rod environment, in particular clad temperature and the atmosphere contacting the clad.

Fuel cladding is maintained in storage by providing a high purity helium atmosphere at a positive pressure, limiting the amount of oxidants in the canister and controlling clad temperature. Oxidants are limited to less than one mole. Maximum fuel clad temperature is limited to less than 400°C for normal and transfer conditions and to less than 570°C for off-normal and accident events. Thermal cycles during system drying operations that exceed 65°C are restricted to no more than 10 cycles for fuel having burnup greater than 45 GWd/MTU [35] [38].

Oxidants are removed from the canister by the vacuum drying process. During vacuum drying, the residual moisture and free water in the cavity are vaporized as the internal pressure is reduced. The resultant vapor and residual gasses are removed from the canister through the vent and drain ports by the vacuum pump. The internal decay heat of the fuel contents assists in the vaporization process as the canister internals and fuel temperatures increase during the drying process. The vacuum pumping operation is continued until the cavity pressure is reduced to below 10 torr, which corresponds to one-half the vapor pressure of water at 72°F. Under normal loading conditions, the actual temperatures of the canister internals will exceed this temperature. The canister is then isolated from the vacuum pump and the pump is turned off. If free water exists in the canister, the water will vaporize and increase the canister pressure to above the 10 torr acceptance criterion during the dryness verification minimum hold period of 10 minutes. Upon successful completion of the dryness verification, the vacuum pump is restarted and the canister continues to be evacuated until the NUREG-1536 [39] recommended pressure of less than 3 torr is reached. The continued reduction in cavity pressure from 10 torr to less than 3 torr removes any residual noncondensing and oxidizing gases to a level of less than 1 mole. The canister is then backfilled with high purity helium (≥ 99.995%) to a positive pressure. Implementation of the defined vacuum drying procedures provides assurance that the final canister internal atmosphere is a positive pressure of high purity helium that contains less than 1 mole of oxidizing gases, and that the residual oxidizing gas concentration is less than 0.25 vol%, as recommended in PNL-6365 [40].

To prevent oxidation of the uranium oxide (UO_2) fuel pellets in breached rods, classified as undamaged, provided the breach is no greater than a hairline crack or pinhole, operational steps in Section 9.1.1 specify that fuel rods shall not be exposed to air during canister draining operations in accordance with the guidance in Interim Staff Guidance (ISG)-22 [37].

The MAGNASTOR system operating procedures and specific operational completion times have been determined and defined to preclude thermally induced fuel rod cladding deterioration by limiting fuel rod cladding hoop stress and reducing the potential for the reorientation of hydrides. The thermal analyses presented in Chapter 4 provide the system temperatures for loading operations, normal conditions, and off-normal and accident events. The temperature control criteria applicable to the MAGNASTOR system are as follows:

1. Maximum calculated fuel cladding temperatures are limited to 400°C (752°F) for normal conditions of storage and short-term loading operations.
2. During loading operations, repeated thermal cycling (repeated heat-up/cool-down cycles) is limited to a total of 10 cycles for fuel with burnup greater than 45 GWd/MTU. A thermal cycle is defined as a clad temperature change greater than 65°C [35].
3. For off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C.

Normal and accident condition thermal transients experienced by the MAGNASTOR canister, basket and contained fuel are controlled and introduce insignificant thermal loading and material stress to fuel rod cladding. Normal condition cooldown transients during cask operations may be introduced during vacuum drying when the canister dryness criteria are not met within the prescribed heat load-dependent time limit. If the dryness criteria are not met, the canister is backfilled to 7 bar gauge with helium, and the canister is cooled by the annulus cooling water system or by returning the canister to the pool as stated in Section 1.3.1.4. This backfill with helium may be performed when the temperatures in the mid to upper regions of the fuel basket are in the range of 700°F and the fuel local to the bottom plate is in the range of 250°F. Noting the significant difference in mass between helium and fuel, i.e., approximately five orders of magnitude, helium is heated with little temperature change to the fuel – the basket, canister bottom plate and shell mass add heat to the helium in combination with the fuel – reducing the thermal influence of the initial helium fill on the fuel cladding. Following the helium backfill, the canister is cooled by the annulus cooling water system or returned to the pool. Water in contact with the canister wall provides more effective heat transfer than the air boundary when the transfer cask is sitting in a cask processing area outside the pool. Although this water boundary provides a more effective heat transfer path, the influence of the canister cooling does not produce a thermal shock or significant through-wall gradient to the fuel rod cladding.

Investigation of the canister unloading sequence presented in Section 9.3 leads to similar conclusions as those for the introduction of helium gas discussed above. When the canister is first prepared for unloading and the port covers are removed, nitrogen gas is initially cycled through the canister for a minimum of 10 minutes to flush the radioactive gases from the canister. This gas cycling is similar to the helium backfill. Although nitrogen has a higher thermal capacitance than helium (about a factor of 10), when compared to the mass of the metal canister, basket and fuel, the influence of the nitrogen gas on the thermal gradient response in the fuel cladding remains insignificant. Following the nitrogen flush, water is introduced into the canister at a maximum rate of 8 gpm. The maximum flow rate is based on reflood thermal hydraulic analyses of a bounding canister configuration. The bounding maximum flow rate, water temperature and pressure are defined in step 14 of Section 9.3, "Wet Unloading a TSC." The water initially introduced into the canister flashes to steam in the drain tube and on contact with the bottom plate. Steam in the cavity permits additional heat to be removed from the basket and fuel in a smooth transition without introducing thermal shock through wall stresses. Once water is permitted to form on the canister bottom plate, the canister starts to fill at a maximum rate of 8 gpm. Addition of water at 8 gpm permits the water to rise in the canister at a maximum rate of 0.8 inch per minute. The RELAP thermal hydraulic analyses used to evaluate the TSC reflood operation show thermal cladding temperature radial gradients are less than 1°F during the reflooding of the canister. Such a small increase is consistent with the gradual cooling process created by the initial steam condition followed by water. The axial temperature gradient along the fuel assembly is actually larger than the radial gradient. However, in the fuel axial direction, thermal stresses are not developed since the fuel cladding is free to expand in the axial direction. The combination of initial nitrogen purge, followed by the cooling transition of the steam created in the canister cavity, provides a relatively smooth transition to water cooling and insignificant thermal stress in the fuel rod cladding.

There are no evaluated normal conditions, transfer conditions, off-normal events or accident conditions that result in deterioration of, or damage to, the fuel cladding or the TSC that preclude retrieval of the fuel from the TSC or retrieval of the TSC from the concrete cask for transport and ultimate disposal.

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8.13 Vendor Supplied Documentation

This section provides copies of technical data sheets for the coatings described in Section 8.6.

8.13.1 Electroless Nickel Coating

Nonelectrolytic Nickel Plating

*By the ASM Committee on Nickel Plating**

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

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

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

Immersion Plating

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

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

When using this bath, it is desirable, but not mandatory, to move the work at a rate of about 15 ft per min.

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

High-Temperature Chemical-Reduction Coating

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

Electroless Nickel Plating

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

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

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

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

Sulfuric acid (66° Bé)	25% by volume
Hydrochloric acid (18° Bé)	5% by volume
Ferric chloride hexahydrate	0.53 oz per gal

Pretreatments that are unique to electroless nickel plating include:

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

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

$$NiSO_4 + NaH_2PO_2 + H_2O \xrightarrow[\text{catalyst}]{\text{heat}} Ni + NaH_2PO_4 + H_2SO_4$$

The essential requirements for any electroless nickel solution are:

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

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

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

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

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

* See page 432 for committee list.

Table 1. Typical Applications of Electroless Nickel Plating

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

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

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

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

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

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

Table 2. Alkaline Electroless Nickel Baths

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

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

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

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

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

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

pH — Standard electrometric method

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

Phosphite — A 10-ml sample of the plating solution is combined with 20 ml of a 5% solution of sodium bicarbonate and cooled in an ice bath. Next, 50 ml of 0.1*N* iodine solution is added and the flask containing this mixture is stoppered and permitted to stand for 2 hr at room temperature. Then the flask is cooled for 15 min in ice water, after which it is unstoppered, the mixture is acidified with acetic acid, and the excess iodine is titrated with 0.1*N* sodium thiosulfate, with starch as an indicator. Determination is then made as follows:

$$NaH_2PO_2 \text{ per liter} = \frac{\text{net ml of } 0.1N \text{ iodine} \times 6.3}{\text{ml of plating solution}}$$

Hypophosphite (U. S. Patent 2,697,651) — A 25-ml sample of the plating solution is diluted to 1 liter. A 5-ml aliquot of the

Table 3. Acid Electroless Nickel Plating Baths(a)

Constituent or condition	Bath 4	Bath 5	Bath 6	Bath 7	Bath 8	Bath 9
Composition, Grams per Liter						
Nickel chloride	30	..	..	30	..	30
Nickel sulfate	..	21	20	..	15	..
Sodium hypophosphite	10	24	27	10	14	12
Sodium acetate	..	..	..	..	13	..
Sodium hydroxyacetate	50	..	..	10	..	..
Sodium succinate	..	..	16	..	..	..
Lactic acid (80%)	..	34 ml	..	..	..	..
Propionic acid (100%)	..	2.2 ml	..	..	..	10
Operating Conditions						
pH	4 to 6	4.3 to 4.8	4.5 to 5.5	4 to 6	5 to 6	4.5 to 5.5
Temperature, F	190 to 210	203	200 to 210	190 to 210	190 to 210	190 to 210
Plating rate (approx), mil per hr	0.5	1.0	1.0	0.4	0.7	0.5

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

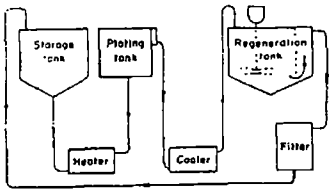


Fig. 1. Schematic of continuous-type system for electroless nickel plating. See text.

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

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

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

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

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

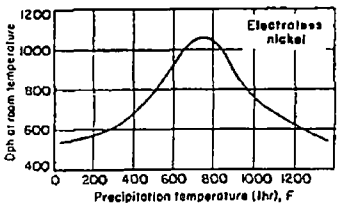
Accessory equipment required or recommended for the tank includes:

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

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

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

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



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

Fig. 2. Heat treatment of coating

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

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

Table 4. Physical Properties of Electroless Nickel Deposits

Property	Value
Specific gravity	7.8 to 8.5
Melting point	1635 to 1850 F
Electrical resistivity	60 microhm-cm
Thermal expansion	13 × 10^{-6} per °C
Thermal conductivity	0.0106 to 0.0135 cal/cm sec/°C

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

Cost factor	Cost per year (b)
Original investment	$18,000
Fixed costs:	
Depreciation (10 years)	$ 1,800
Insurance	450
Floor space (200 sq ft)	182
Repairs and maintenance	450
Variable costs:	
Raw material	6,100
Utilities	740
Labor costs:	
Direct	10,400
Indirect	2,630
Total	$22,782
Total cost per hr	$9.48
Total cost per sq ft coated to 1 mil	$1.00

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

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

Advantages and Limitations. Some advantages of electroless nickel are:

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

Limitations of electroless nickel are:

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

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

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

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

Selected References

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G. Gutzeit, Industrial Nickel Coating by Chemical Catalytic Reduction, *Trans Inst Metal Finishing*, 31, 383-423 (1953-1954), and *Corrosion Technol*, 3, 108 (1956)

G. Gutzeit, An Outline of the Chemistry Involved in the Process of Catalytic Nickel Deposition from Aqueous Solution, *Plating*, Oct 1959, p 1158-1164; Nov 1959, p 1273-1278; Dec 1959, p 1377-1378; Jan 1960, p 63-70

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

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

8.13.2 Keeler & Long Kolor-Poxy Primer (typical)

E.140

KEELER & LONG INC.

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

KOLOR-POXY PRIMER
No. 3200

GENERIC TYPE: POLYAMIDE EPOXY

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

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

NOT RECOMMENDED FOR: Immersion in strong acids.

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

PRODUCT CHARACTERISTICS:

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

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

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

June, 1994

TECHNICAL BULLETIN

No. 3200 F-140

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	13.6 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F
	Shelf Life:	2 Years
	Pot Life @ 72°F:	8 Hours
	Temperature Resistance:	350°F
	Viscosity @ 77°F:	87 ± 5 (Krebs Units)
	Gloss (60° meter):	6 ± 5
	Storage Temperature:	50 - 95°F
	Mixing Ratio (Approx. by Volume):	4:1
APPLICATION DATA:	Application Procedure Guide:	APG-3
	Wet Film Thickness Range:	3.8 - 9.1 mils
	Dry Film Thickness Range:	2.5 - 6.0 mils
	Temperature Range:	50 - 120°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	SSPC-SP6, SP10, SP5
	Induction Time @ 72°F:	45 Minutes
	Recommended Solvent	
	@ 50 - 85°F:	No. 3700
	@ 86 - 120°F:	No. 2200
	Application Methods	
	Air Spray	
	Tip Size:	.055" - .073"
	Pressure:	30 - 60 PSIG
	Thin:	1.0 - 2.0 Pts/Gal
	Airless Spray	
	Tip Size:	.015" - .019"
	Pressure:	2500 PSIG
	Thin:	0.5 - 1.5 Pts/Gal
	Brush or Roller	
	Thin:	0.5 - 1.5 Pts/Gal

KEELER & LONG INC.

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

KOLORS

SSPC SUSTAINING MEMBER

This information is presented as accurate and correct, in good faith, to assist the user in specification and application. No warranty is expressed or implied. No liability is assumed. Product specifications are subject to change without notice. Data listed above is for white or base color of the product. Data for other colors may differ.

8.13.3 PPG METALHIDE (typical)

PPG METALHIDE® 97-694 Series

HPC/Industrial Maintenance

METALHIDE® 2000 Inorganic Zinc Rich Coating

GENERAL DESCRIPTION

Heavy duty corrosion resistant primer for ferrous metal surfaces in industrial environments. Provides galvanic protection similar to galvanizing. Particularly suited as a lining for the interior, and as a primer to be topcoated for the exterior of tanks containing organic solvents, gasoline, and other fuels. It is also excellent for application in coastal, marine, and other offshore environments.

RECOMMENDED USES

Ferrous Metal

FEATURES AND BENEFITS

Provides galvanic corrosion protection
Excellent resistance to organic solvents
Can be handled with slings in 5-6 hours (77°F at 50% relative humidity)
Class B Slip Coefficent under ASTM A-325

PACKAGING

1-Gallon (3.78L)
3-Gallon (11.3L)
5-Gallon (18.9L)

Not all products are available in all sizes. Not all containers are full-filled.

TINTING AND BASE INFORMATION

97-694	Liquid Component A - Red
97-695	Liquid Component A - Green
97-697P	Powder Component

DO NOT TINT.

PRODUCT DATA

PRODUCT TYPE: Inorganic self-curing ethyl silicate-metallic zinc
GLOSS: Matte
VOC*: 3.88 lbs./gal. (466 g/L)
COVERAGE: 330 to 500 sq. ft./gal. (31 to 46 sq.m/3.78L)

WEIGHT/GALLON*: 20.3 lbs. (9.2 kg) +/- 0.3 lbs. (136 g)
WEIGHT SOLIDS*: 80.3% +/- 2%
Results will vary by color, thinning and other additives.
*Product data calculated on mixed 97-695/97-697P.
Dry Film Thickness*: 2 to 5 mils not to exceed 8 mils on spot readings

POT LIFE: 16 hours
MIX RATIO: Mix as packaged. See mixing instructions.
IN SERVICE TEMPERATURE: 750°F (399°C) Dry heat
140°F (60°C) Wet heat

DRYING TIME@ 77°F (25°C), 50% relative humidity.
To Touch: 15 minutes
To Handle: 4 hours
To Recoat: 24 hours
Drying times listed may vary depending on temperature, humidity, color and air movement.

CLEANUP: 97-727 PPG Thinner
FLASH POINT: 97-695 60°F (15.6°C)

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METALHIDE® 97-694 Series

METALHIDE® 2000 Inorganic Zinc Rich Coating — HPC/Industrial Maintenance

GENERAL SURFACE PREPARATION

Remove all paint, mill scale, and rust. The surface to be coated must be dimensionally stable, dry, clean, and free of oil, grease, and other foreign materials.

WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

STEEL: Non-Immersion Service -- The minimum surface preparation for ferrous metal substrates is SSPC-SP6 Commercial Blast cleaning. Service life of coating is in direct proportion to surface preparation. Immersion Service -- Near White Metal Blast SSPC-SP10 is mandatory for ferrous metals. The surface to be coated must be clean, dry, and well prepared to receive the coating. For specific recommendations, see your PITTSBURGH® Paints dealer or call 1-800-441-9695.

RECOMMENDED PRIMERS

Self priming on properly prepared surfaces.

MIXING AND APPLICATIONS INFORMATION

MIXING INSTRUCTIONS: Mix the 97-694 or 695 opaque liquid base using a mechanical mixer until no pigment remains at the bottom of the container. Transfer to a large container to facilitate mixing, and slowly sift in the zinc dust, 97-697P under continuous agitation. Mix until blend is uniform and free of lumps. Strain through a 30-60 mesh screen. DO NOT MIX IN REVERSE ORDER. Maintain constant agitation during use to prevent zinc dust from settling. The liquid component and the mixed paint must be protected from moisture. Relatively small amounts of contamination will cause gelation.

Changes in application equipment, pressures and/or tip sizes may be required on ambient temperatures and application conditions.

Airless Spray: Pressure 1500 psi, tip 0.017" - 0.021" Filter: 30 mesh

Conventional Spray: Fluid Nozzle: DeVilbiss MBC-510 gun, with 64 air cap with E tip and needle, or comparable equipment. Atomization Pressure: 55 - 70 Fluid Pressure: Can not specify, dependent on numerous factors.

Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury.

Brush: Not recommended

Roller: Not recommended

Thinning: Thinning not normally required. If thinning is desired do not thin more than 12% with 97-727.

MIXING AND APPLICATIONS INFORMATION (cont.)

Permissible temperatures during application:

Material:	50 to 90°F	10 to 32°C
Ambient:	0 to 100°F	-18 to 38°C
Substrate:	0 to 140°F	-18 to 60°C

LIMITATIONS OF USE

Apply in good weather when air and surface temperatures are between 50°F (10°C) and 100°F (37.8°C) with maximum relative humidity of 85%. Optimum paint temperatures is 70°F (21°C) - 80°F (26.7°C). Surface temperatures must be at least 5°F (3°C) above the dew point. Do not expose container to temperatures greater than 135°F (57°C). Do not use for potable water.

For Professional Use Only; Not Intended for Household Use.

SAFETY

Proper safety procedures should be followed at all times while handling this product. USE WITH ADEQUATE VENTILATION. KEEP OUT OF REACH OF CHILDREN. Explosion-proof equipment must be used when coating with these materials in confined areas. Keep containers closed and away from heat, sparks, and flames when in use. Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury. Read all label and Material Safety Data Sheet for important health/safety information prior to use. MSDS are available through our website www.ppghpc.com or by calling 1-800-441-9695.

PPG Architectural Finishes, Inc. believes the technical data presented is currently accurate; however, no guarantee of accuracy, comprehensiveness, or performance is given or implied. Improvements in coatings technology may cause future technical data to vary from what is in this bulletin. For complete, up-to-date technical information, visit our web site or call 1-800-441-9695.

PPG Industries, Inc.
Architectural Coatings
One PPG Place
Pittsburgh, PA 15272
www.ppghpc.com

Technical Services
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1-888-807-5123 fax

Architect/Specifier
1-800-PPG-IDEA

PPG Canada, Inc.
Architectural Coatings
4 Kenview Blvd
Brampton, ON L6T 5E4

123 11/2011
Supersedes (2/2009)

8.13.4 PPG PITT-THERM (typical)

PITT-THERM® **97-724 Series**

HPC/Industrial Maintenance **PITT-THERM® High Heat & Stress Corrosion Coating**

Generic Type

Air Dry Silicone, One Component

General Description

This coating is intended for use on austenitic stainless and carbon steel to provide protection against chloride attack and stress corrosion cracking on both insulated and uninsulated surfaces. PITT-THERM® has excellent thermal shock and barrier properties, and may be used as a heat resistant coating for carbon steel.

Recommended Uses

Austenitic Stainless Steel
Carbon Steel

Features / Benefits

High heat and thermal stress resistance.
Protects stainless steel against chloride attack and stress corrosion cracking.

Limitations of Use

For Professional Use Only; Not Intended for Household Use. Apply only when air, product and surface temperatures are 40°F (4.4°C) and when surface temperature is at least 5°F (3°C) above the dew point. Avoid exterior painting late in the day when dew or condensation are likely to form, or when rain is threatening. Special attention should be given to insure that this product is not contaminated by moisture during the application process. Drying times listed may vary depending on temperature, humidity, color and air movement.

Tinting and Base Information

97-724	Black
UC59571	Gray

Product Data

Gloss:	Matte
VOC*:	4.62 lbs/gal 554.00 g/L
Coverage:	279 to 372 sq ft/gal (26 to 35 sq. m/3.78L)

Note: Does not include loss due to varying application method, surface porosity, or mixing.

DFT:	1.5 minimum to 2.0 maximum
Weight/Gallon*:	9.6 lbs. (4.5 kg) +/- 0.2 lbs. (91 g)
Volume Solids*:	34.8% +/- 2%
Weight Solids*:	52.1% +/- 2%
Clean-up:	97-727 PPG Xylol Thinner

Results will vary by color, thinning and other additives.
*Product data calculated on full formula.

Drying Time:

To Touch:	20 minutes
To Handle:	2 hours
To Recoat:	16 hours

Dry Time @77°F (25°C); 50% relative humidity

In Service Temperature:

Dry Heat (F): 850° Dry Heat (C): 454°

Flash Point: 62°F, (16.7°C)

17

PITT-THERM® 97-724 Series

HPC/Industrial Maintenance **PITT-THERM® High Heat & Stress Corrosion Coating**

General Surface Preparation

Remove all loose paint, mill scale, and rust. The surface to be coated must be dimensionally stable, dry, clean, and free of oil, grease, and other foreign materials. Service life of coating is in direct proportion to surface preparation. WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

For application to Austenitic Stainless Steel SSPC-SP1 Solvent Wash is the minimum surface preparation. For Carbon Steel applications, SSPC-SP10 Near White Metal Blast is required. Where appropriate bare areas should be primed with a suitable primer.

HPC Systems in Detail Brochure (H10788) COATING SYSTEMS: 225-HD, 226-HD, 227-HD

Recommended Primers

none	Refer to HD Coating Systems.
Steel	Self Priming, 97-673/674 or 675, 97-676 or 677

Directions for Use

Mix thoroughly to suspend all pigmentation before, and during use. Explosion-proof equipment must be used when coating with these materials in confined areas. Keep containers closed and away from heat, sparks, and flames when not in use. USE WITH ADEQUATE VENTILATION. KEEP OUT OF REACH OF CHILDREN. Read all label and Material Safety Data Sheet (MSDS) information prior to use. MSDS are available through our website or by calling 1-800-441-9695.

Permissible temperatures during application:

Material:	40 to 90°F	4 to 32°C
Ambient:	40 to 100°F	4 to 38°C
Substrate:	40 to 130°F	4 to 54°C

Application Information

Recommended Spread Rates:

Wet Mils :	4.3	minimum to	5.7	maximum
Wet Microns:	109.2	minimum to	144.8	maximum
Dry Mils :	1.5	minimum to	2.0	maximum
Dry Microns:	38.1	minimum to	50.8	maximum

Application Equipment: Changes in application equipment, pressures and/or tip sizes may be required depending on ambient temperatures and application conditions. Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury.

Conventional Spray: Fluid Nozzle: DeVilbiss MBC gun, with 704 or 777 air cap with E or FF tip and needle, or comparable equipment. Atomization Pressure: 55 - 70 Fluid Pressure: Can not specify, dependent on numerous factors.

Airless Spray: Pressure 1500 psi, tip 0.011" - 0.015"

Brush: Not Recommended

Roller: Not Recommended

Thinning:
DO NOT THIN. Spray product as received.

Packaging: 1-Gallon (3.78L)

Not all products are available in all sizes. All containers are not full-filled.

PPGAF believes the technical data presented is currently accurate: however, no guarantee of accuracy, comprehensiveness, or performance is given or implied. Improvements in coatings technology may cause future technical data to vary from what is in this bulletin. For complete, up-to-date technical information, visit our web site or call 1-800-441-9695.

PPG Industries, Inc.
Architectural Coatings
One PPG Place
Pittsburgh, PA 15272
www.ppghpc.com

Technical Services
1-800-441-9695
1-888-807-5123 fax

Architect/Specifier
1-888-PPG-IDEA

PPG Architectural Finishes
400 S. 13th Street
Louisville, KY 40203

PPG Canada, Inc.
Architectural Coatings
4 Kenview Blvd
Brampton, ON L6T 5E4

I7 10/2006

8.13.5 Keeler & Long/PPG KLE Series (typical)

E.340

Product Data Sheet

Keeler&Long

PPG High Performance Coatings

Keeler & Long/PPG
856 Echo Lake Road
Watertown, CT 06795
1-800-238-8596

Epoxy Enamel
KLE Series

Product Information

Product Code: KLE1XXXX Part A where XXXX is a color designation.
KLE2XXXX Part A
KLE1B Curing Agent Part B

Product: Polyamide Epoxy

Suggested Use: A two component, polyamide epoxy enamel formulated to provide excellent chemical, abrasion and direct impact resistance for interior exposures.

Use as a topcoat for concrete and steel surfaces, subject to radiation, decontamination, and loss-of-coolant accidents in Coating Service Level I areas of nuclear power plants.

Not Recommended: Areas other than above, as the KLJ Series can be utilized in Coating Service Level II and certain Level III areas, as well as balance of plant, of nuclear power plants.

Product Description

Colors: Available in a wide range of colors.

Gloss 60°: KLE1XXXX 85 minimum
KLE2XXXX 35 - 65

VOC: 3.47 lbs./gal. (416 g/L) * mixed, unthinned

Method: Calculated

Weight/Gallon: 10.2 ± 0.5 lbs./gal. *

In Service Heat Limitations: 250°F (121°C) **

Flash Point: Part A 82°F (27.8°C)
Part B 104°F (40°C)

Package: Part A is available in one gallon containers at 0.80 gallon (3.03 liters) and five gallon containers filled at 4.00 gallons (15.1 liters).

KLE1B Part B is available filled in quart containers at 25.6 fluid ounces (751 mL) and full filled gallon containers.

Percent Solids by Volume: 53.9 ± 3.0% *

Percent Solids by Weight: 66.1 ± 3.0% *

Drying Schedule

Air Dry @ 77°F (25°C) ASTM D5895

Dry to Touch: 4 hours

Dry to Handle: 8 hours

Drying Schedule (continued)

Dry to Recoat: 48 hours

Drying times listed may vary depending on temperature, humidity and air movement.

Application Data

Substrate: Metal or masonry

Substrate Preparation: The service life of the coating is directly related to the surface preparation. The surface to be coated must be properly prepared and primed, dry, clean and free of contamination including oil, dirt, grease and rust.

Basecoats: Epoxy Surfacer, Epoxy White Primer

Application Method: Apply by spray, brush or roller application.

Air Spray: DeVilbiss MBC gun, 704 or 777 air cap, "E" for "F" tip and needle or equivalent equipment. Atomization Pressure: 30-60 psi.

Airless Spray: Equipment capable of maintaining a minimum of 2500 psi without surge at the tip. 0.011" (0.279 mm) to 0.017" (0.432 mm) orifice.

Brush: Use a high quality natural bristle brush.

Roller: Use a high quality roller cover with a solvent resistant core.

Refer to Application Guide APG-2 for additional information.

Thinner Code & Percent: Thin up to 5% by volume with KL4093 as needed for application.

Coverage Sq. Ft./Gal. @ 2 mils: 362 sq. ft./gal.*

Mixing Instructions: Thoroughly mix Part A before blending. Add KLE1B Part B to Part A. Mix until uniform. Allow to digest for 1 hour before use.

Wet Film Per Coat: 3.7 to 4.6 mils *

Dry Film Per Coat: 2.0 to 2.5 mils

Clean Up Solvent: KL4093

The statement and methods presented in this bulletin are based upon the best available data and practices known to PPG/Keeler & Long at the present time. They are not representations or warranties of performance, results or comprehensiveness of such data. Since PPG /Keeler & Long is constantly improving its coatings and paint formulas, future technical data may vary somewhat from what was available when this bulletin was printed. Contact your PPG/Keeler & Long Sales Representative for the most up-to-date information.

E.340 March, 2005

E.340

Product Data Sheet

Keeler&Long

PPG High Performance Coatings

Keeler & Long/PPG
856 Echo Lake Road
Watertown, CT 06795
1-800-238-8596

Epoxy Enamel
KLE Series

Application Information (continued)

Parts Base by Volume: 4 part "A"

Parts Catalyst by Volume: 1 part KLE1B Part "B"

Digestion Time: 1 hour @ 77°F (25°C)

Potlife: 8 hours @ 77°F (25°C)

Additional Information

Apply only when air, product and surface temperatures are at least 55 °F (12.8°C) and surface temperature is at least 5°F (3°C) above the dew point. Curing is retarded below 60°F (15.6°C).

Store materials at temperatures between 45°F (7.2°C) and 95°F (35°)

Permissible substrate temperatures during application is 55°F (12.8°C) and 120°F (48.9°C).

*Values are calculated using KLE16002 White mixed 4:1 by volume with KLE1B. Values will vary with color.

**KLE Series coating system was evaluated and passed the 7-Day 340°F Design Basis Accident Test per ANSI N101.2 and ASTM D3911.

Read all label and Material Safety Data Sheet (MSDS) information prior to use. MSDS are available by calling 1-800-238-8596.

Not intended for residential use.

Spray equipment must be handled with due care and in accordance with manufacturer's recommendation.

High-pressure injection of coatings into the skin by airless equipment may cause serious injury, requiring immediate medical attention at a hospital.

WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

The statement and methods presented in this bulletin are based upon the best available data and practices known to PPG/Keeler & Long at the present time. They are not representations or warranties of performance, results or comprehensiveness of such data. Since PPG /Keeler & Long is constantly improving its coatings and paint formulas, future technical data may vary somewhat from what was available when this bulletin was printed. Contact your PPG/Keeler & Long Sales Representative for the most up-to-date information.

E.340 March, 2005

8.13.6 Carboline Carboguard 890N (typical)

product data carboline® Carboguard® 890N

Selection & Specification Data

Generic Type Cycloaliphatic Amine Epoxy

Description Nuclear grade, DBA tested, self priming epoxy. Tested and certified for use in Nuclear Level 1 areas in a variety of systems.

Features
- Can be applied direct to steel without a primer
- Single coat, high build capabilities
- Can be applied to minimally prepared surfaces
- Compatible to many existing, aged epoxies and inorganic zinc coatings
- Easily decontaminated
- DBA tested and qualified for Nuclear Service Level 1
- Resistant to high levels of radiation
- High solids and low VOC help reduce effects on charcoal filters
- Application-friendly characteristics minimize man-rem exposure
- Suitable for use under insulation on hot surfaces operating up to 250°F (121°C) outside Level 1 areas

Color Refer to Carboline Color Guide. Certain colors may require multiple coats for hiding.

Finish Gloss

Primers Self-priming. Qualified over Carbozinc 11SG and Carboguard 893 for fabrication applications. May be applied over existing inorganic zinc primers and epoxy based systems. A mist coat may be required to minimize bubbling over inorganic zinc primers. Consult Carboline for system recommendations and test data for use in nuclear applications.

Dry Film Thickness 4.0-6.0 mils (100-150 microns) per coat
6.0-8.0 mils (150-200 microns) over light rust and for uniform gloss over inorganic zincs.
Don't exceed 10 mils (250 microns) in a single coat. Excessive film thickness over inorganic zincs may increase damage during shipping or erection.
Note: Acceptable DFT ranges are based on plant specific DBA test data. Carboguard 890 has been tested in multi-coat and wide DFT range scenarios. Consult Carboline for applicable DBA test data.

Solids Content By Volume:75% ± 2%

Theoretical Coverage Rate 1203 mil ft^2 (30.0 m^2/l at 25 microns)
241 ft^2 at 5 mils (6.0 m^2/l at 125 microns)
Allow for loss in mixing and application

VOC Values
As supplied 1.80 lbs/gal (216 g/l)
Thinned w/#2: 7oz/gal: 2.03 lbs/gal (244 g/l)
13oz/gal: 2.26 lbs/gal (271 g/l)
Thinned w/#33: 7oz/gal: 2.05 lbs/gal (246 g/l)
16oz/gal: 2.40 lbs/gal (288 g/l)

Dry Temp. Resistance
Continuous: 250°F (121°C)
Non-Continuous: 300°F (149°C)
Carboguard 890 N has been successfully tested under DBA / LOCA temperatures up to 340°F (171°C). Please contact Carboline for specific variables.
Discoloration and loss of gloss is observed above 200°F (93°C).

Temp. Resistance (Under Insulation) Under Insulation: 250°F (121°C)
(Normally dry)
Not for use under insulation in Level 1 areas.

Limitations Qualification of Carboguard 890N for Level 1 applications is plant specific and must be supported with relevant DBA test data.

Substrates & Surface Preparation

General Surfaces must be clean and dry. Employ adequate methods to remove dirt, dust, oil and all other contaminants that could interfere with adhesion of the coating. Follow approved specification for specific project.

Steel (General) For shop painting :SSPC-SP6
1.5-3.0 mils (38-75 microns)
For plant maintenance: SSPC-SP2 or SP3
Refer to applicable DBA testing specific to plant postulated LOCA conditions.

Concrete (General) Concrete must be cured 28 days at 75°F (24°C) and 50% relative humidity or equivalent. Prepare surfaces in accordance with ASTM D4258 Surface Cleaning of Concrete and ASTM D4259 Abrading Concrete. Voids in concrete may require surfacing. Prime with approved primer.

Previously Painted Surfaces Follow approved specification for specific project. Consult Carboline for available compatibility test data.

Performance Data

Test Method	System*	Results	Report #
ASTM D3911 DBA	890 / 890 Steel, SP3, SP11	Pass	02658, 02732, 02927
ASTM D3911 DBA	2011S / 890 Concrete	Pass	02658, 02732, 02927
ASTM D3911 DBA	893 / 890	Pass	02689
ASTM D3911 DBA	CZ11SG / 890	Pass	02927
ASTM D4082 Radiation Tolerance	890 / 890 893 / 890	No Defects	02658, 02689
ASTM D4256 Decontamination	890	99.96%	02411
ASTM D4541 Elcometer Adhesion	890	980 PSI	02411
ASTM D3912 Chemical Resistance	890	Pass all chemicals except Potassium Permanganate, Nitric Acid and MIBK	02411
ASTM E84 Flame Spread	890/890	Flame Spread 5 Smoke Generation 20	02919
ASTM E1461 Thermal Conductivity	890	4.79 btu-in/hr-ft^2-°F	03683
ASTM D4060 Taber Abrasion	890	85 mg lost	02411

Test reports and additional data available upon written request.
** Carboguard 890 received a name change in June 2004 to Carboguard 890N for nuclear service projects.*

May of 2011 replaces April 2011 0986

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Carboguard® 890N

Application Equipment

Listed below are general equipment guidelines for the application of this product. Job site conditions may require modifications to these guidelines to achieve the desired results. **General Guidelines:**

Spray Application (General) This is a high solids coating and may require adjustments in spray techniques. Wet film thickness is easily and quickly achieved. The following spray equipment has been found suitable and is available from manufacturers such as Binks, DeVilbiss and Graco.

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

Airless Spray

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

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

HVLP 3M Accuspray Spray Gun Model HG09

Brush & Roller (General) Multiple coats may be required to obtain desired appearance, recommended dry film thickness and adequate hiding. Avoid excessive re-brushing or re-rolling. For best results, tie-in within 10 minutes at 75°F (24°C).

Brush Use a medium bristle brush.

Roller Use a short-nap synthetic roller cover with phenolic core.

Mixing & Thinning

Mixing Power mix separately, then combine and power mix. Partial mixing of kits is not recommended without specific approval and written procedures from plant engineering and QA.

Ratio 1:1 Ratio (A to B)

Thinning* Spray: Up to 13 oz/gal (10%) w/ #2
Brush: Up to 16 oz/gal (12%) w/ #33
Roller: Up to 16 oz/gal (12%) w/ #33
Thinner #33 can be used for spray in hot/windy conditions. Use of thinners other than those supplied or recommended by Carboline may adversely affect product performance and void product warranty, whether expressed or implied.
*See VOC values for thinning limits.

Pot Life 3 Hours at 75°F (24°C)
Pot life ends when coating loses body and begins to sag. Pot life times will be less at higher temperatures.

Cleanup & Safety

Cleanup Use Thinner #2 or Acetone. In case of spillage, absorb and dispose of in accordance with local applicable regulations.

Safety Read and follow all caution statements on this product data sheet and on the MSDS for this product. Employ normal workmanlike safety precautions. Hypersensitive persons should wear protective clothing, gloves and use protective cream on face, hands and all exposed areas.

Ventilation When used as a tank lining or in enclosed areas, thorough air circulation must be used during and after application until the coating is cured. The ventilation system should be capable of preventing the solvent vapor concentration from reaching the lower explosion limit for the solvents used. User should test and monitor exposure levels to insure all personnel are below guidelines. If not sure or if not able to monitor levels, use MSHA/NIOSH approved supplied air respirator.

Caution This product contains flammable solvents. Keep away from sparks and open flames. All electrical equipment and installations should be made and grounded in accordance with the National Electric Code. In areas where explosion hazards exist, workmen should be required to use non-ferrous tools and wear conductive and non-sparking shoes.

Application Conditions

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

This product simply requires the substrate temperature to be above the dew point. Condensation due to substrate temperatures below the dew point can cause flash rusting on prepared steel and interfere with proper adhesion to the substrate. Special application techniques may be required above or below normal application conditions.

Curing Schedule

890N (Based on 4–8 mils, 100-200 microns dry film thickness.)

Surface Temp. & 50% Relative Humidity	Dry to Recoat	Dry to Topcoat w/ Other Finishes	Final Cure	
			General	Immersion
50°F (10°C)	12 Hours	24 Hours	3 Days	N/R
60°F (16°C)	8 Hours	16 Hours	2 Days	10 Days
75°F (24°C)	4 Hours	8 Hours	1 Day	5 Days
90°F (32°C)	2 Hours	4 Hours	16 Hours	3 Days

Higher film thickness, insufficient ventilation or cooler temperatures will require longer cure times and could result in solvent entrapment and premature failure. Excessive humidity or condensation on the surface during curing can interfere with the cure, can cause discoloration and may result in a surface haze. Any haze or blush must be removed by water washing before recoating. During high humidity conditions, it is recommended that the application be done while temperatures are increasing. **Maximum recoat/topcoat times are 30 days for epoxies and 90 days for polyurethanes at 75°F (24°C).** If the maximum recoat times have been exceeded, the surface must be abraded by sweep blasting or sanding prior to the application of additional coats.

Packaging, Handling & Storage

Shipping Weight (Approximate)	2 Gallon Kit 29 lbs (13 kg)	10 Gallon Kit 145 lbs (66 kg)
Flash Point (Setaflash)	89°F (32°C) for Part A 73°F (23°C) for Part B	
Storage Temperature & Humidity	40°-110°F (4°-43°C) Store indoors. 0-100% Relative Humidity	
Shelf Life	Part A: 36 months at 75°F (24°C) Part B: 15 months at 75°F (24°C)	

***Shelf Life: (actual stated shelf life) when kept at recommended storage conditions and in original unopened containers.**

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May of 2011 replaces April 2011

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8.13.7 ASTM Specification B29 – Standard Specification for Refined Lead

Designation: B 29 – 03

Standard Specification for Refined Lead[1]

This standard is issued under the fixed designation B 29; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers refined lead in pig, block, or hog form.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[2]

E 37 Test Methods for Chemical Analysis of Pig Lead[3]

E 88 Practice for Sampling Nonferrous Metals and Alloys in Cast Form for Determination of Chemical Composition[3]

3. Ordering Information

3.1 Orders for refined lead under this specification shall include the following information:

3.1.1 ASTM designation and year of issue,

3.1.2 Quantity (weight),

3.1.3 Name of material (for example, pure lead),

3.1.4 Size and shape (see Section 6),

3.1.5 Grade (see Table 1 and accompanying notes), and

3.1.6 Certification or test report if specified (Section 13).

TABLE 1 Chemical Requirements[A,B]

Grade	Composition (Weight Percent)			
	Low Bismuth Low Silver Pure Lead, max[C]	Refined Pure Lead, max[D]	Pure Lead, max.	Chemical-Copper Lead[E]
Sb	0.0005	0.0005	0.001	0.001 max
As	0.0005	0.0005	0.001	0.001 max
Sn	0.0005	0.0005	0.001	0.001 max
Sb As and Sn	...	...	0.002	0.002 max
Cu	0.0010	0.0010	0.0015	0.040–0.080
Ag	0.0010	0.0075	0.010	0.020 max
Bi	0.0015	0.025	0.05	0.025 max
Zn	0.0005	0.001	0.001	0.001 max
Te	0.0001	0.0001	...	...
Ni	0.0002	0.0002	0.0005	0.002 max
Fe	0.0002	0.001	0.001	0.002 max
Lead (min) by difference	99.995	99.97	99.94	99.90
UNS Number	L50006	L50021	L50049	L51121

[A] The following applies to all specified limits in Table 1: For the purpose of determining conformance with this specification, an observed value obtained from the analysis shall be rounded off "to the nearest unit" in the last right hand place of figures used in expressing the limiting value, in accordance with the rounding method of Practice E 29.

[B] By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

[C] This grade is intended for chemical applications where low silver and low bismuth contents are required.

[D] This grade is intended for lead acid battery applications.

[E] This grade is intended for applications requiring corrosion protection and formability.

4. Materials and Manufacture

4.1 Lead shall be supplied in commercial standard forms or shapes requested by the purchaser in the following grades:

4.1.1 Low bismuth low silver pure lead,

4.1.2 Refined pure lead,

4.1.3 Pure lead, and

4.1.4 Chemical copper lead.

4.2 The grades of lead listed in 4.1.1-4.1.4 shall be produced by any smelting and refining process from ore or recycled materials to meet the chemical requirements of this specification.

[1] This specification is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.02 on Refined Lead, Tin, Antimony, and Their Alloys.

Current edition approved June 10, 2003. Published July 2003. Originally approved in 1919. Last previous edition approved in 1997 as B 29 - 92 (1997).

[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

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5. Composition

5.1 The lead shall conform to the requirements prescribed in Table 1 and accompanying notes.

6. Sizes and Shapes

6.1 Pigs shall weigh up to a nominal 110 lb (50 kg).

6.2 Blocks or hogs shall be square or oblong and weigh up to 2530 lb (1150 kg).

7. Appearance

7.1 The lead shall be reasonably free from surface corrosion and adhering foreign material.

8. Lot

8.1 All lead of the same type produced and cast at one time shall constitute a lot for chemical analysis. Each pig or block of the lot shall bear a single identifying number that can be related to the manufacturing lot.

9. Sampling for Chemical Analysis

9.1 The sample for chemical analysis shall be selected by one of the following methods:

9.1.1 Test samples taken from the lot during casting, or

9.1.2 Test samples taken from the final solidified cast product.

9.2 *Sampling for Lot Analysis*—The supplier may obtain samples from the lot of molten metal during casting. All or part of these samples may be cast into shapes suitable for use in spectrographic analytical methods.

9.3 *Sampling of Cast Product*:

9.3.1 If the lead is in the form of standard pigs (Fig. 1), the sample for chemical analysis shall be taken in accordance with 9.3.3.1, 9.3.3.2, or 9.3.3.3.

9.3.1.1 If the pigs differ in shape from those shown in Fig. 1 or the product is cast into blocks or hogs, the supplier and the purchaser shall agree mutually as to the method to be followed in sampling such shapes.

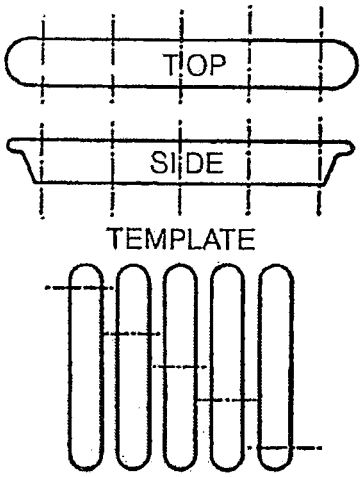
9.3.2 *Sampling Pig Lead*—A portion representative of the total shipment shall be selected at random for the final sample. For lots containing at least 100 000 lb (45 400 kg) of pig lead, one pig shall be taken from every 20.000 lb (9080 kg). For smaller lots, a total of five pigs shall be taken.

9.3.3 *Sample Preparation*—Each pig shall be cleaned thoroughly to rid the surface of dirt or adhering foreign material prior to sampling by one of the following methods: sawing, drilling, or melting.

9.3.3.1 *Sawing*—The pigs selected shall be sawed completely through as illustrated in Fig. 1. The sawings from the pigs shall be mixed thoroughly and quartered, and the samples for analysis taken from the mixed material. The sawings must be free of extraneous material introduced from the saw blade. All sawings shall be treated with a strong magnet in order to remove iron introduced by sawing.

9.3.3.2 *Drilling*—The pigs shall be drilled at least halfway through from two opposite sides as illustrated in Fig. 2. A drill of about ½ in. (12.7 mm) in diameter shall be used. In drilling, the holes shall be spaced along a diagonal line from one corner of the pig to the other. Holes may be made in a single pig or in each of several pigs placed as illustrated in Fig. 2. The drillings shall be clipped into pieces not over ½ in. (12.7 mm) in length, mixed thoroughly, and treated with a strong magnet to remove iron introduced by drilling.

9.3.3.3 *Melting*—Whole pigs, portions of pigs produced by sawing, drillings, or sawings shall be melted in a clean vessel.



Pigs sampled in sets of five according to template as shown above.

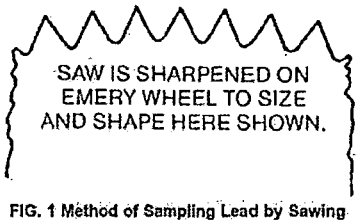
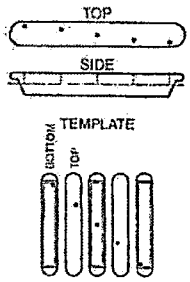


FIG. 1 Method of Sampling Lead by Sawing



NOTE 1—Pigs selected for sampling shall be placed side by side, every other pig bottom side up, and sampled according to template in sets of five pigs each as indicated above. The pigs shall be drilled at least halfway through: when a larger sample is desired, the pigs shall be turned over and sampled on the other diagonal.

FIG. 2 Method of Sampling Lead by Drilling

The melting temperature must not exceed 685°F (363°C) to prevent excessive drossing. The lead must be stirred immediately prior to sampling. The molten lead shall be cast into shapes suitable for use in spectrographic analysis, cast into thin sample bars not to exceed ⅜ in. (9.5 mm) thick for sawing, or granulated by pouring into distilled water and drying the material thoroughly. For sample bars, saw cuts shall be made halfway across the bar from each side and staggered so that they are about ½ in. (12.7 mm) apart. The sawings so produced are treated in accordance with 9.3.3.1.

9.3.4 *Sample Size:*

9.3.4.1 For spectrographic analysis, three samples shall be prepared of a size and shape satisfactory for use by the laboratory at which the analysis is to be made.

9.3.4.2 For wet chemical analysis, each prepared sample (sawings, drillings, or granules) shall weigh at least 600 g.[4]

9.3.5 Aspects of sampling and sample preparation not specifically covered in this specification shall be carried out in accordance with Practice E 88.

10. Methods of Chemical Analyses

10.1 The chemical compositions enumerated in Table 1 of this specification shall, in case of disagreement, be determined by wet chemical or spectrographic methods mutually agreed upon by the supplier and the purchaser.

10.2 By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

11. Inspection

11.1 Inspection of the material shall be agreed upon between the purchaser and the supplier as part of the purchase contract.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the supplier promptly and in writing. In case of dissatisfaction with the results of the test, the supplier may make claim for a rehearing.

12.2 Rejection shall be considered as follows:

12.2.1 Variation of weight, quantity, dimensions, or workmanship.

12.2.2 Chemical composition.

12.2.2.1 In case of dispute, the material shall be sampled in the presence of both parties in accordance with 9.3.

12.2.2.2 The resulting sample (at least 1800 g) shall be mixed and separated into three equal parts, each of which shall be placed in a sealed package, one for the supplier, one for the purchaser, and one for the umpire if necessary, and analyzed in accordance with Test Methods E 37.

12.3 When the lead metal satisfies the chemical and physical requirements of this specification, it shall not be condemned for defects in manufacturing or for defects of alloys or products in which it is used.

13. Certification

13.1 When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been tested as directed in this specification and the requirements have been met. When specified in the purchase order or contract, a certified report of the test results shall be furnished.

14. Marking and Special Requirements

14.1 A brand, by which the supplier can be identified, shall be cast or marked legibly upon each pig, block, or hog. In addition, other markings shall identify the material by type and lot number.

14.2 (Any) special marking, color code, and other quality requirements not covered by this specification shall be agreed upon between the supplier and the purchaser.

15. Keywords

15.1 chemical-copper lead; lead; lead metal; pure lead; refined pure lead

[4] "Determination of As, Sb, and Te in Lead and Lead Alloys Using Hydride Generation Atomic Absorption Spectrometry," G.J. Fox, *Atomic Spectroscopy*, Vol 11, No.1, January 1990, p. 13.

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Chapter 9
Operating Procedures

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9 OPERATING PROCEDURES

This chapter provides general procedural guidance for the loading, unloading, and recovery of MAGNASTOR®. System user personnel shall use this information to prepare the detailed, site-specific procedures for loading, handling, storing, and unloading MAGNASTOR. Users may add, delete, or change the sequence of specific steps of the procedures to accommodate site-specific requirements provided that the general order of the tasks associated with TSC closure and storage is preserved and that the specific requirements for fastener torque values, temperature limits for operations, and other defined values in the procedure are also met. Specific optional operational sequences are identified herein to facilitate the fuel loading operations.

All facility-specific procedures prepared by users must fully comply with the MAGNASTOR Certificate of Compliance (CoC) and Technical Specifications, including the approved contents and design features.

Equipment and operating requirements will be established by the user prior to implementation. Refer to Table 9.1-1 for a listing of the major auxiliary equipment generally required by the user to load and close or to open and unload the system. MAGNASTOR provides effective shielding for operations personnel; however, the licensee/user may utilize supplemental shielding to further reduce operator radiation exposure. The planned location, type, and possible interactions of the temporary supplemental shielding with MAGNASTOR shall be appropriately evaluated by the licensee/user. MAGNASTOR, when operated by properly trained personnel in accordance with the generic procedures provided herein, will meet As Low As Reasonably Achievable (ALARA) guidance for personnel exposure control.

MAGNASTOR's design features minimize the potential for contamination of the TSC during fuel loading, canister preparation, and transfer. The TSC is loaded in the spent fuel pool, but the external surfaces of the canister are protected from contact with the contaminated pool water by clean water maintained in the annulus between the transfer cask and the TSC. For purposes of the operating procedures, clean water is defined as demineralized, processed, or filtered pool water, or any water external to the spent fuel pool that has water chemistry compatible for use in the spent fuel pool. During loading and/or cooling operations, the exterior surfaces of the TSC shell, bottom and closure lid can be exposed to spent fuel pool water, which may be contaminated. The smooth exterior surfaces of the TSC shell, bottom and closure lid can be readily decontaminated. Therefore, the TSC external surfaces are expected to be essentially free of removable contamination during long-term storage operations.

Tables in Chapter 3 provide the handling weights for the major components of MAGNASTOR and the loads to be lifted during various phases of the loading and unloading operations. Licensees/users must perform appropriate reviews and evaluations to ensure that the lifted loads do not exceed rated load limits of user-supplied lifting equipment and comply with the facility's heavy-load program.

Additional details and guidance on the operations of the MAGNASTOR System are provided in the MAGNASTOR Operations Manual, Document No. 71160-P-02, (or equivalent site-specific manuals prepared for individual Licensees/Users), including more detailed step-by-step operating procedures, and identification of Contingency Events and proposed corrective actions to ensure that FSAR and Technical Specification limits are not exceeded. The Operations Manual also contains additional information on the system design description, characteristics, ancillary equipment design and functions, and operational figures of the ancillary systems.

9.1 Loading MAGNASTOR

MAGNASTOR is used to load, transfer, and store spent fuel. The three principal components of the system are: the transportable storage canister (TSC), the transfer cask, and the concrete cask. The transfer cask contains and supports the TSC during fuel loading, lid welding and closure operations. The transfer cask, with the transfer adapter, is also used to move the TSC into position for placement in the concrete cask.

These loading procedures are based on three initial conditions.

- the transfer cask is located in a facility's designated workstation for cask preparation
- an empty TSC (properly receipt inspected and accepted) is located in the transfer cask cavity
- an accepted concrete cask is available to receive the TSC when loading and preparation activities are complete

The TSC is filled with clean or pool water and the transfer cask containing the TSC is lowered into the spent fuel pool for fuel assembly loading and verification. The user must identify and select the fuel assemblies to be loaded and ensure that all loaded fuel assemblies comply with the Approved Content provisions of the CoC. Up to four damaged fuel cans (DFCs) containing damaged or undamaged PWR fuel assemblies or PWR fuel debris may be loaded in a TSC with a DF Basket Assembly, as authorized in the Approved Contents provisions of the CoC. Undamaged fuel assemblies may be loaded directly (i.e., without a DFC) into DFC locations in the DF Basket Assembly.

Following fuel loading, the closure lid is installed and the transfer cask containing the loaded TSC is lifted from the bottom of the spent fuel pool. The TSC is partially drained and the closure lid is welded to the TSC shell. The closure lid-to-shell weld is visual and progressive dye penetrant examined. The cavity is refilled and the TSC is subjected to a hydrostatic pressure test with no loss in pressure or observable leakage allowed. Following hydrostatic pressure test acceptance, the closure ring, which provides the redundant confinement closure barrier, is installed, welded and inspected. The TSC cavity water is then drained and volumetrically measured. At the option of the user, the closure ring welding sequence can be completed later in the cask loading operational sequence following completion of vacuum drying and helium backfill.

The residual moisture in the TSC is then removed by vacuum drying techniques and the TSC dryness is verified. The TSC is then evacuated to ≤ 3 torr and backfilled with a known quantity of pressurized high-purity helium to provide an inert atmosphere and to establish the convective heat transfer flow for the safe long-term storage of the spent fuel contents. System connections to the vent and drain openings are removed and the inner port covers are installed, welded, dye

penetrant examined and helium leakage rate tested. The outer port covers, which provide the redundant sealing of the confinement boundary, are installed, welded and dye penetrant examined. Installation and welding of the TSC closure lid, shell, closure ring and port covers complete the assembly of the confinement boundary and redundant closure.

The concrete cask is positioned for the transfer of the TSC and the transfer adapter is installed. The transfer cask containing the loaded TSC is positioned on the transfer adapter on the top of the concrete cask. The TSC is lowered into the concrete cask and the transfer cask and transfer adapter are removed. The concrete lid assembly is installed and secured to complete the loading process.

The loaded concrete cask is moved to the ISFSI storage pad using the site-specific transporter and placed in its long-term storage location. Final radiation surveys are completed and the temperature monitoring system is installed, if used, which completes the MAGNASTOR loading and transfer sequence.

9.1.1 Loading and Closing the TSC

This section describes the sequence of operations to load and close the TSC in preparation for transferring the TSC to the concrete cask. The empty TSC is assumed to be positioned inside the transfer cask located at the designated workstation.

1. Visually inspect the TSC and basket internals for foreign materials or debris.
   Note: When BWR enrichments require the use of the 82-assembly basket configuration, verify the basket design blocks the five center fuel tube cell locations to assure that assemblies cannot physically be loaded in the five designated nonfuel locations.
2. Visually inspect the top of the TSC shell and closure lid weld preps.
3. Inflate the upper transfer cask annulus seal with air or nitrogen gas. Disconnect the gas supply.
   Note: Either the top or bottom upper annulus seal is used based on the length of the TSC to be loaded.
   Note: The sequence and use of upper and lower annulus seals are at the discretion of the Licensee/User based on selected in-plant operational procedures and approved site-specific TSC cooling methods to maintain TSC and fuel clad temperatures within FSAR limits.
   Note: Optional TSC annulus shims may be utilized at the discretion of the user to assist in centering the TSC in the MTC annulus.
4. Verify the three TSC retaining blocks (MTC1/MTC2) are pinned in the retracted position or the retaining ring (MTC2) is removed.
5. Verify that at least one lock pin is installed on each transfer cask shield door.

6. Fill the TSC with clean or pool water. For PWR spent fuel contents, the soluble boron concentration in the TSC shall be verified and monitored in accordance with the LCO 3.2.1.
7. Attach the lift yoke to a crane suitable for handling the loaded TSC, transfer cask and yoke. Position the lift yoke over the transfer cask and engage it with the two transfer cask trunnions.
   Note: The temperature of the transfer cask (surrounding ambient air temperature) must be verified to be at or above the minimum operating temperature of 0°F, per Section 4.3.1.f. of the Technical Specifications (not applicable to the stainless steel MTC2 design).
8. Lift the transfer cask containing the empty TSC and move it to the spent fuel pool following the prescribed load path.
   Note: An optional protective cover, attached to the bottom of the transfer cask, may be used to prevent imbedding contaminated particles in the shield doors and door rails.
9. Connect the clean water lines to the lower annulus fill ports of the transfer cask. Ensure that the unused ports are closed or capped to prevent pool water in-leakage.
10. Lower the transfer cask to the pool surface and turn on the clean water supply lines to the lower annulus fill ports to fill the transfer cask/TSC annulus.
    Note: Sequence on connection and filling/draining transfer cask/TSC annulus is at the discretion of the user based on approved site-specific procedures.
11. Spray the transfer cask and lift yoke with clean water to wet the exposed surfaces.
    Note: Wetting the components that enter the spent fuel pool and spraying the components leaving the pool will reduce the effort required to decontaminate the components.
12. Lower the transfer cask as the annulus fills with clean water until the upper annulus fill ports are accessible. Hold this position and connect the clean water annulus fill lines to the upper fill ports. Ensure the unused ports are closed or capped to prevent pool water in-leakage.
13. Lower the transfer cask to the bottom of the pool in the cask loading area.
14. Disengage the lift yoke and visually verify that the lift yoke is fully disengaged. Remove the lift yoke from the spent fuel pool while spraying the yoke and crane cables with clean water.
15. Load the previously selected fuel assemblies into the TSC basket.
    Note: The fuel assemblies shall be selected in compliance with the requirements of the approved contents specified in Appendix B of the Technical Specifications and the boron concentration limits of the Technical Specifications, including limitations on fuel assembly positions within the basket. Specific fuel assembly positions for preferential and zoned loading patterns shall be in full compliance with the requirements of Appendix B of the Technical Specifications. Assembly selection, placement and compliance with preferential zone loading patterns within the basket shall be independently verified.

Note: Up to four DFCs containing authorized PWR contents may be loaded in a TSC with a DF Basket Assembly. A DFC spacer is required to be positioned in the Designated DF Basket Assembly corner locations for the shorter length DFCs. Independently, visually verify proper placement and correct orientation of each required DFC spacer.

Note: At the option of the user, install fuel assembly spacers for the axial positioning of the PWR fuel assembly types to be loaded. Verify spacer identification and install fuel spacers in each intended fuel loading location based on the fuel spacer plan prepared, which is based on the fuel assembly inventory and nonfuel hardware to be loaded. Independently, visually verify proper placement and correct orientation of each required fuel spacer.

16. Visually verify the fuel assembly (and DFC, as applicable) identifications to confirm the serial numbers match the approved fuel-loading pattern.
17. Install three swivel hoist rings hand tight in the three closure lid lifting holes or in three of the six TSC lift holes. Install a three-legged sling set to the hoist rings and connect the sling set to the crane hook or the attachment point on the lift yoke.

    Note: At the discretion of the user, the closure lid can be attached to the lift yoke and the lid installed during the lowering of the lift yoke.
18. Raise the closure lid. Adjust closure lid rigging to level the closure lid.
19. Move the closure lid over the spent fuel pool and align the lift yoke (if used) to the transfer cask trunnions and align the closure lid to the match marks of the TSC.
20. Lower the closure lid until it enters the TSC and seats in the top of the TSC. Visually verify closure lid alignment using the match marks (± ½ inch).

    Caution: Following closure lid installation, there is a thermal time limit of 18 hours to begin the Annulus Circulating Water System (ACWS), or approved alternative annulus flow system operation, and to begin temperature measurement of the MTC annulus outlet flow to verify MTC outlet temperature is maintained < 113°F. If ACWS flow cannot be initiated in the time allowed, return the MTC to the spent fuel pool and remove the closure lid to allow cooling by the spent fuel pool water.
21. Allow sling cables to go slack and move the lift yoke into position to engage the transfer cask trunnions. Engage the lift yoke to the trunnions, apply a slight tension, and visually verify engagement.
22. Raise the transfer cask until its top clears the pool surface. Visually verify that the closure lid is properly seated. If necessary, lower the transfer cask and reinstall the closure lid. Rinse the lift yoke and transfer cask with clean water as the equipment is removed from the pool.
23. Rinse and flush the top of the transfer cask and TSC with clean water as necessary to remove any radioactive particles. Survey the top of the TSC closure lid and the top of the transfer cask to check for radioactive particles.

24. As the transfer cask is removed from the spent fuel pool, terminate the annulus fill water supply, remove the annulus fill system hoses, and allow annulus water to drain into the spent fuel pool.
25. Following the prescribed load path, move the transfer cask to the designated workstation for TSC closure operations.

    Note: At the option of the user, the TSC closure operations may be performed with the transfer cask partially submerged in the spent fuel pool, cask loading pit, or an equivalent structure. This operational alternative provides additional shielding for the cask operators.
26. Disengage the three-legged sling set from the closure lid and the lift yoke from the transfer cask trunnions. Place lift yoke and sling set in storage/lay-down area.
27. Inflate the transfer cask lower annulus seal with air or nitrogen. Disconnect the gas supply from the transfer cask.

    Note: The installation, use, and operational sequence of the lower annulus seal is at the discretion of the user based on approved site-specific procedures. At the option of the user, the gas supply can be maintained continuously to the annulus seals.
28. Install the Annulus Circulating Water cooling System (ACWS), or alternative annulus flush/cooling system, to the lower and upper annulus fill lines. Unused fill lines are to be closed or capped.

    Note: For TSCs prepared with the transfer cask partially submerged on an in-pool shelf, partially drained cask loading pit or equivalent partial submerged condition, alternative ACWS operations (e.g., reverse flow ACWS) may be utilized to maintain TSC and fuel clad temperatures within normal operational limits.

    Note: ACWS operation allows the vacuum drying and TSC transfer times in LCO 3.1.1 to be utilized.
29. Initiate clean water flow into the transfer cask lower fill lines with annulus water discharging through the upper fill lines. Ensure water flow is maintained to keep the outlet water temperature $\leq$ 113°F.

    Note: Analysis of alternative reverse flow ACWS operations are detailed in Chapter 4, demonstrating that the fuel clad and TSC temperatures are bounded by standard ACWS cooling operations for the following reverse flow limits:
    - A maximum inlet water temperature of $\leq$ 100°F, which requires a minimum inlet flow rate of $\geq$ 60 GPM
    - A minimum inlet flow rate of $\geq$ 40 GPM, which limits the maximum inlet water temperature of $\leq$ 70°F

Note: With the ACWS, or site-approved alternative ACWS, operating, there is no time limit through initiation of the draining of the TSC. However, if the circulating water cooling system is not utilized, or becomes nonoperational, measure the cavity water temperature every 2 hours. If TSC preparation operations through draining are not completed prior to the cavity water temperature reaching 200°F, a cooling water flow will be established through the cavity to lower the water temperature to < 130°F prior to the start of draining, or the TSC shall be returned to the spent fuel pool within 2 hours and maintained with the TSC submerged for a minimum cooling period of 24 hours, or until the ACWS operation is initiated.

30. Detorque and remove the lifting hoist rings from the closure lid.
31. Using a portable suction pump, remove any standing water from the closure lid weld groove, and the vent and drain ports.
32. Decontaminate the top of the transfer cask and TSC closure lid to allow installation of the welding equipment. Decontaminate external surfaces of the transfer cask and remove the bottom protective cover, if installed.
33. Insert the drain line with a quick-connector attached through the drain port opening and into the basket drain port sleeve. Remove the quick-disconnect and any contaminated water displaced from the cavity.
34. Torque the drain tube connector to the drain opening to the value specified in Table 9.1-2. Verify quick-disconnect is installed and properly torqued in the vent port opening.
35. Install a venting device to the vent port quick-disconnect to prevent combustible gas or pressure buildup below the closure lid.
36. Verify that the top of the closure lid is level (flush) with, or slightly above, the top of the TSC shell.
37. At the discretion of the user, establish foreign material exclusion controls to prevent objects from being dropped into the annulus or TSC.
38. Install the welding system, including supplemental shielding, to the top of the closure lid.

    Note: At the discretion of the user, supplemental shielding may be installed around the transfer cask to reduce operator dose. Use of supplemental shielding shall be evaluated to ensure its use does not adversely affect the safety performance of MAGNASTOR.
39. Connect a suction pump to the drain port quick-disconnect and verify venting through the vent port quick-disconnect.
40. Operate the suction pump to remove approximately 70 gallons of water from the TSC. Disconnect the suction pump.

    Note: The radiation level will increase as water is removed from the TSC cavity, as shielding material is being removed.

Note: Fuel rods shall not be exposed to air during the 70-gallon pump-down.

41. Attach a hydrogen detector to the vent line. Ensure that the vent line does not interfere with the operation of the weld machine.
42. Sample the gas volume below the closure lid and observe hydrogen detector for H_2 concentration prior to commencing closure lid welding operations. Monitor H_2 concentration in the TSC until the root pass of the closure lid-to-shell weld is completed.

    Note: If H_2 concentration exceeds 2.4% prior to or during root pass welding operations, immediately stop welding operations. Evacuate the TSC gas volume or purge the gas volume with helium. Verify H_2 levels are <2.4% prior to restarting welding operations.

    Note: In place of continuous H_2 monitoring, continuous gas purging of the volume below the lid may be used in concert with initial (prior to start of welding) and intermittent H_2 monitoring (upon termination of gas purging and prior to re-starting welding operations).
43. Install shims into the closure lid-to-TSC shell gap, as necessary, to establish a uniform gap for welding. Tack weld the closure lid and shims, as required.
44. Operate the welding equipment to complete the closure lid-to-TSC shell root pass weld in accordance with the approved weld procedure.
45. Perform visual and liquid penetrant (PT) examinations of the root pass and record the results.
46. Remove the H_2 detector from the vent line while ensuring the TSC cavity vent line remains installed and allows venting of gases from the cavity.
47. Operate the welding equipment to perform the closure lid-to-shell weld to the midplane between the root and final weld surfaces. Perform visual and PT examinations for the midplane weld pass, and record the results.
48. Complete welding through the completion of the final pass of the closure lid weld, perform final visual and PT examinations, and record the results.
49. Perform the hydrostatic test of the TSC as follows:
    a. Connect a drain line to the vent port and a pressure test system to the drain port.
    b. Refill the TSC with clean water until water is observed flowing from the vent port drain line. Close the vent line isolation valve. Ensure continuing compliance with the boron concentration requirements of LCO 3.2.1.
    c. Pressurize the TSC to 150 (+10, -0) psig and isolate the TSC.
    d. Maintain the TSC pressure for a minimum 10-minute hold period. At the end of the 10-minute hold period, visually examine the closure lid-to-TSC shell weld for leakage of water, while maintaining the test pressure. The test pressure shall be maintained until the completion of the visual inspection of the closure lid-to-TSC shell weld.

e. The hydrostatic test is acceptable if there is no visible water leakage from the closure lid-to-TSC shell weld based on a visual examination of the weld after a minimum 10-minute hold period, while maintaining the test pressure.

f. Vent the TSC cavity and remove the pressure test system from the drain port and the drain line from the vent line. Reinstall a vent line to the vent port to prevent pressurization of the TSC.

50. Install and tack the closure ring in position in the closure lid-to-TSC shell weld groove.

    Note: Depending on the operational loading procedure and intended minimum helium backfill time (per LCO 3.1.1) to be utilized, the closure ring installation, welding and NDE sequence can be performed following final helium mass backfill (i.e., after Step 60).

51. Weld the closure ring to the TSC shell and to the closure lid. Perform visual and PT examinations of the final surfaces of the welds and record the results.

    Note: At the option of the user and in order to facilitate the Maximum Transfer Time of Technical Specification LCO 3.1.1 the installation, welding, and NDE of the closure ring may be performed immediately after helium backfill (Step 61) or after completion of the welding, testing, and NDE of the vent and drain inner or outer port covers (Step 63 or 67).

52. Remove the water from the TSC using one of the following methods: drain down using a suction pump with a pressurized helium cover gas; or blow down using pressurized helium gas. Ensure the totalizer in the drain line is reset to zero prior to the start of draining.

    Note: Fuel rods shall not be exposed to air during canister draining operations. Record the start time of TSC draining operations. The maximum drying times of LCO 3.1.1 are based on the total time from start of the draining through completion of helium backfilling of the TSC cavity.

53. Connect a drain line with or without suction pump to the drain port connector.

54. Connect a regulated helium gas supply to the vent port connector.

55. Open gas supply valve and start suction pump, if used, and drain water from the TSC until water ceases to flow out of the drain line. Close gas supply valve and stop suction pump.

56. Record the time at the completion of the draining of the TSC. Record the volume of water drained from the TSC (V_{TSC}) as measured by the totalizer.

    At the option of the user, disconnect suction pump, close discharge line isolation valve, and open helium gas supply line. Pressurize TSC to approximately 25 psig and open discharge line isolation valve to blow down the TSC. Repeat blow down operations until no significant water flows out of the drain line. Note that time used for system draining and blow down is considered part of the vacuum drying time.

57. Disconnect the drain line and gas supply line from the drain and vent port quick-disconnects.
58. Dry the TSC cavity using vacuum drying methods as follows.

    Note: Ensure heat load dependent vacuum drying time limits are not exceeded so that fuel cladding temperatures are maintained below 752°F. Vacuum drying cycle time limits in LCO 3.1.1 are based on utilizing the ACWS, reverse flow ACWS or equivalent annulus cooling/flush system.

    Note: At the option of the user, the drain and/or vent port quick-disconnects can be removed and replaced temporarily with suitable straight-through fittings to increase flow area cross-section and to reduce resistance to gas flow. The quick-disconnect fittings must be reinstalled and torqued prior to final helium backfill.

    a. Connect the vacuum drying system to the vent and drain port openings.
    b. Operate the vacuum pump until a vapor pressure of ≤ 10 torr is achieved in the TSC. The time durations of the first vacuum drying cycle shall be in accordance with the time limits of LCO 3.1.1.
    c. Isolate the vacuum pump from the TSC and turn off the vacuum pump. Observe the vacuum gauge connected to the TSC for an increase in pressure for a minimum period of 10 minutes. If the TSC pressure is ≤ 10 torr at the end of 10 minutes, the TSC is dry of free water in accordance with LCO 3.1.1.

    Note: [redacted] After the cooling period, subsequent drying cycle operations can continue for the times indicated in LCO 3.1.1. Drying cycles and cooling periods may be continued until the TSC cavity passes the dryness verification per LCO 3.1.1. For fuel burnup greater than 45 GWd/MTU, the total number of cooling cycles is limited to ten, with cladding temperature variations more than 65 °C (149 °F).

59. Upon satisfactory completion of the dryness verification, evacuate the TSC cavity to a pressure of ≤ 3 torr. Isolate and turn off the vacuum pump, and backfill and pressurize the TSC cavity with 99.995% (minimum) pure helium as follows:
    a. Determine the free volume of the TSC (V_{TSC}) per Step 56.
    b. Multiply the V_{TSC} free volume by the helium loading value per unit volume (L_{helium}) to determine required helium mass (M_{helium}) to be backfilled into the cavity.
    c. Set the helium bottle regulator to 90 (+5,-0) psig.

d. Connect the helium backfill system to the vent port and reset the mass-flow meter to zero.
e. Slowly open the helium supply valve and backfill the TSC with the required helium mass (M_{helium}) in accordance with LCO 3.1.1.

60. Disconnect the vacuum drying helium backfill system from the vent and drain openings. Note the time the helium backfill is completed.

    Note: At the option of the user, Steps 50 and 51 can alternatively be performed at this point or immediately following Steps 63 or 67. The user to establish appropriate radiological controls to maintain operator dose ALARA.

61. Install and weld the inner port cover on the drain port opening.
62. Install and weld the inner port cover on the vent port opening.
63. Perform visual and PT examinations of the final surface of the port cover welds and record the results.
64. Perform helium leak test on each of the inner port cover welds to verify the absence of helium leakage past the inner port cover welds.
65. Install and weld the outer port cover on the drain port opening. Perform visual and PT examinations of the final weld surface and record the results.
66. Install and weld the outer port cover on the vent port opening. Perform visual and PT examinations of the final weld surface and record the results.
67. Using an appropriate crane, remove the weld machine and supplemental shield.
68. The ACWS, reverse flow ACWS or equivalent annulus cooling/flush system will be utilized throughout the TSC closing operations until the helium backfill time is satisfied (see LCO 3.1.1). Drain the TSC/transfer cask annulus by stopping ACWS flow to the annulus and connecting one or more drain lines to the lower annulus fill ports. Once the annulus is drained, deflate the top and bottom annulus seals. Note the time the MTC/TSC annulus cooling flow is terminated. Remove the temporary plugs or ensure that a minimum of four annulus fill lines are open in the base of the transfer cask.

    Note: The time duration of the sequence of operations from stopping the MTC/TSC annulus cooling, or completing the helium backfill if the annulus circulating water cooling system is not used, through completion of TSC transfer into the concrete cask shall not exceed the transfer time limits in LCO 3.1.1. If the TSC transfer to the concrete cask cannot be completed in the defined time period, the transfer operation will be suspended and the TSC shall be cooled by the ACWS, reverse flow ACWS or site-approved alternative cooling system for a minimum of 30 hours after steaming ceases prior to restarting TSC transfer operations. The second, and subsequent, minimum helium backfill time and maximum TSC transfer time shall be limited to the heat load specific cooling and specific transfer times in the maximum TSC transfer Tables 1.B

and 1.D of LCO 3.1.1. For PWR fuel, the 24-hour minimum helium backfill time is followed by a maximum TSC transfer time of 48 hours for heat loads ≤ 25 kW or 22 hours for heat loads ≤ 35.5 kW. For BWR fuel, the 24-hour minimum helium backfill time is followed by a maximum TSC transfer time of 65 hours for heat loads ≤ 25 kW or 32 hours for heat loads ≤ 33 kW.

69. If using MTC1 or MTC2 with retaining blocks, remove the lock pins and move the transfer cask retaining blocks inward into their functional position, and reinstall the lock pins. If using MTC2 with retaining ring, install the transfer cask retaining ring.
70. Install the six swivel hoist rings into the six threaded holes in the closure lid if TSC transfer is to be performed by two sets of redundant slings. Torque the hoist rings to the manufacturer's recommended value.

    Note: Utilize high temperature-resistant slings (≤ 350°F).

    Note: Alternative site-specific TSC lifting systems and equipment may be used for lowering and lifting the TSC in the transfer cask. The lifting system design must comply with the user's heavy load program and the applicable requirements of ANSI N14.6, NUREG-0612, and/or ASME/ANSI B30.1, as appropriate.
71. Complete final decontamination of the transfer cask exterior surfaces. Final TSC contamination surveys may be performed after TSC transfer following Step 21 in Section 9.1.2 when TSC surfaces are more accessible.
72. Proceed to Section 9.1.2.

9.1.2 Transferring the TSC to the Concrete Cask

This section describes the sequence of operations required to complete the transfer of a loaded TSC from the transfer cask into a concrete cask, and preparation of the concrete cask for movement to the ISFSI pad.

1. Position an empty concrete cask with the lid assembly removed in the designated TSC transfer location.

   Note: The concrete cask can be positioned on the ground, or on a deenergized air pad set, roller skid, heavy-haul trailer, rail car, or transfer cart. The transfer location can be in a truck/rail bay inside the loading facility or an external area accessed by the facility cask handling crane.

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the concrete cask, per Section 4.3.1.g. of the Technical Specifications.
2. Inspect all concrete cask openings for foreign objects and remove if present; install supplemental shielding in four outlets.

3. Install a four-legged sling set to the lifting points on the transfer adapter.
4. Using the crane, lift the transfer adapter and place it on top of the concrete cask ensuring that the guide ring sits inside the concrete cask lid flange. Remove the sling set from the crane and move the slings out of the operational area.
5. Connect a hydraulic supply system to the hydraulic cylinders of the transfer adapter.
6. Verify the movement of the connectors and move the connector tees to the fully extended position.
7. Connect the lift yoke to the crane and engage the lift yoke to the transfer cask trunnions. Ensure all lines, temporary shielding and work platforms are removed to allow for the vertical lift of the transfer cask.

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the transfer cask, per Section 4.3.1.f. of the Technical Specifications.
8. Raise the transfer cask and move it into position over the empty concrete cask.
9. Slowly lower the transfer cask into the engagement position on top of the transfer adapter to align with the door rails and engage the connector tees.
10. Following set down, remove the lock pins from the shield door lock tabs.
11. Install a stabilization system for the transfer cask, if required by the facility heavy load handling or seismic analysis programs.
12. Disengage the lift yoke from the transfer cask trunnions and move the lift yoke from the area.
13. As appropriate to the TSC lifting system being used, move the lifting system to a position above the transfer cask. If redundant sling sets are being used, connect the sling sets to the crane hook.
14. Using the TSC lifting system, lift the TSC slightly (approximately ½-1 inch) to remove the TSC weight from the shield doors.

    Note: The lifting system operator must take care to ensure that the TSC is not lifted such that the retaining blocks (MTC1/MTC2) or the retaining ring (MTC2) is engaged by the top of the TSC.
15. Open the transfer cask shield doors with the hydraulic system to provide access to the concrete cask cavity.
16. Using the cask handling crane in slow speed (or other approved site-specific handling system), slowly lower the TSC into the concrete cask cavity until the TSC is seated on the pedestal.

    Note: The transfer adapter and the standoffs in the concrete cask will ensure the TSC is appropriately centered on the pedestal within the concrete cask.

Note: The completion of the transfer of the TSC to the concrete cask (i.e., the top of the TSC is in the concrete cask cavity) completes the TSC transfer evolution time from Step 69 in Section 9.1.1.

17. When the TSC is seated, disconnect the slings (or other handling system) from the lifting system, and lower the sling sets through the transfer cask until they rest on top of the TSC.
18. Retrieve the lift yoke and engage the lift yoke to the transfer cask trunnions.
19. Remove the seismic/heavy load restraints from the transfer cask, if installed.
20. Close the shield doors using the hydraulic system and reinstall the lock pins into the shield door lock tabs.
21. Lift the transfer cask from the top of the concrete cask and return it to the cask preparation area for next fuel loading sequence or to its designated storage location.
22. Disconnect hydraulic supply system from the transfer adapter hydraulic cylinders.
23. Remove redundant sling sets, swivel hoist rings, or other lifting system components from the top of the TSC, if installed.
24. Verify all equipment and tools have been removed from the top of the TSC and transfer adapter.
25. Connect the transfer adapter four-legged sling set to the crane hook and lift the transfer adapter off the concrete cask. Place the transfer adapter in its designated storage location and remove the slings from the crane hook. Remove supplemental shielding from outlets.

    Note: If the optional low profile concrete cask is used, proceed to Step 26. If the standard concrete cask is provided, proceed to Step 38.

26. Install three swivel hoist rings and the three-legged sling set on the concrete cask shield ring.
27. Using the crane, lift the shield ring and place it into position inside of the concrete cask top flange.
28. Remove the three-legged sling and swivel hoist rings.
29. Using the designated transport equipment, move the loaded concrete cask out of the low clearance work area or truck/rail bay.
30. Install the three swivel hoist rings into the three threaded holes and attach the three-legged sling set to the shield ring.
31. Using an external or mobile crane, lift and remove the shield ring. Place the shield ring in position for the next loading sequence or return it to its designated storage location.
32. Install four swivel hoist rings in the threaded holes of the concrete cask extension using the manufacturer-specified torque.
33. Install the four-legged sling set and attach to the crane hook.

    Note: A mobile crane of sufficient capacity may be required for concrete cask extension and lid installations performed outside the building.

34. Perform visual inspection of the top of the concrete cask and verify all equipment and tools have been removed.

    Note: Take care to minimize personnel access to the top of the unshielded loaded concrete cask due to shine from the TSC.

35. Lift the concrete cask extension and move it into position over the concrete cask, ensuring alignment of the two anchor cavities with their mating lift anchor embedment.
36. Lower the concrete cask extension into position and remove the sling set from the crane hook.
37. Remove the four swivel hoist rings and cables from the concrete cask extension.

    Note: If concrete cask transport is to be performed by a vertical cask transporter, proceed to Step 38. If transport is to be performed using air pads in conjunction with a flat-bed transporter, proceed to Step 40.

38. Install the lift lugs into the anchor cavities of the concrete cask extension, or directly on top of the lifting embedment for the standard concrete cask, if applicable to the concrete cask design utilized.
39. Install the lift lug bolts through each lift lug and into the threaded holes in the embedment base. Torque each of the lug bolts to the value specified in Table 9.1-2.
40. Install three swivel hoist rings into the concrete cask lid and attach the three-legged sling set. Attach the lifting sling set to the crane hook.
41. At the option of the user, install the weather seal on the concrete cask lid flange. Lift the concrete cask lid and place it in position on the top of the flange.
42. Remove the sling set and swivel hoist rings and install the concrete cask lid bolts. Torque to the value specified in Table 9.1-2.
43. Move the loaded concrete cask into position for access to the site-specific transport equipment.
44. Proceed to Section 9.1.3.

9.1.3 Transporting and Placing the Loaded Concrete Cask

The section describes the general procedures for moving a loaded concrete cask to the ISFSI pad using either a vertical cask transporter (Step 1 through Step 9) or a flat-bed transport vehicle (Steps 10 through 17). Steps following Step 17 are performed for all concrete casks.

Vertical Cask Transporter

1. Using the vertical cask transporter lift fixture or device, engage the two concrete cask lifting lugs.
2. Lift the loaded concrete cask and move it to the ISFSI pad following the approved onsite transport route.

Note: Ensure vertical cask transporter lifts the concrete cask evenly using the two lifting lugs.

Note: Do not exceed the maximum lift height for a loaded concrete cask of 24 inches, per Section 4.3.1.h. of the Technical Specifications.

3. Move the concrete cask into position over its intended ISFSI pad storage location. Ensure the surface under the concrete cask is free of foreign objects and debris.

   Note: The spacing between adjacent loaded concrete casks must be at least 15 feet.
4. Using the vertical transporter, slowly lower the concrete cask into position.
5. Disengage the vertical transporter lift connections from the two concrete cask lifting lugs. Move the cask transporter from the area.
6. Detorque and remove the lift lug bolts from each lifting lug, if the lugs are to be reused.

   Note: At the option of the user, the lift lugs may be left installed during storage operations.
7. Lift out and remove the concrete cask lift lugs. Store the lift lugs for the next concrete cask movement.
8. Install the lug bolts through the extension base (or through the cover plate for the standard concrete cask) and into the threaded holes. Torque each bolt to the value specified in Table 9.1-2.
9. For the casks with extensions containing anchor cavities, install the weather seal and cover plates. Install the bolts and washers and torque to the value specified in Table 9.1-2.

Flat-bed Transport Vehicle Loaded with the Closed Concrete Cask

10. Move the transport vehicle with the closed concrete cask to a position adjacent to the ISFSI pad.
11. If required, install a bridging plate to cover the gap between the vehicle and the ISFSI pad.
12. If not already installed, insert four deflated air pads into the four inlets.
13. Attach a restraining device around the concrete cask and connect to a tow vehicle suitable for pushing or pulling the concrete cask off of the transport vehicle.
14. Using an air supply and an air pad controller, inflate the air pads.
15. Verify the ISFSI pad surface in the storage location is free of foreign objects and debris.
16. Using the tow vehicle, move the concrete cask into its position on the storage pad.

    Note: The center-to-center spacing of loaded concrete casks shall be a minimum of 15 feet.
17. Lower the concrete cask into position by deflating and removing the four air pads.

    Note: Ensure that air pads are not installed longer than eight hours to complete the concrete cask transfer.

All Concrete Casks

18. If optional temperature monitoring is implemented, install the temperature monitoring devices in each of the four outlets of the concrete cask and connect to the site's temperature monitoring system.
19. Install inlet and outlet screens to prevent access by debris and small animals.
    Note: Screens may be installed on the concrete cask prior to TSC loading to minimize operations personnel exposure.
20. Scribe and/or stamp the concrete cask nameplate to indicate the loading date. If not already done, scribe or stamp any other required information.
21. Perform a radiological survey of the concrete cask within the ISFSI array to confirm dose rates comply with ISFSI administrative boundary and site boundary dose limits.
22. Initiate a daily temperature monitoring program or daily inspection program of the inlet and outlet screens to verify continuing effectiveness of the heat removal system.

Table 9.1-1 Major Auxiliary Equipment

Item	Description
Air Pad Rig Set	A device consisting of four air pads, a controller, and an air supply source that lifts the concrete cask using air supplied at a high volume.
Annulus Fill System	System that supplies clean/filtered spent fuel pool water through the transfer cask/TSC annulus using the lower and upper transfer cask fill lines. The system maintains a positive clean water flow to minimize the exposure of the TSC external surfaces to contaminated spent fuel pool water.
Annulus Circulating Water Cooling System	The system provides a circulating water flow through the annulus to maintain the TSC shell temperature during TSC preparation and drying evolutions. The system includes appropriate circulating pump, pressure gauges, and inlet and outlet water thermometer.
Annulus Seals	Inflatable seals provided at the top and bottom of the transfer cask/TSC annulus for use with the annulus fill and annulus circulating water cooling systems.
Bottom Protective Cover	Optional plate temporarily attached to the base of the transfer cask to prevent particulate contamination of the transfer cask shield doors and rails.
Canister Upender	Lifting device used to upright a TSC from the horizontal position to a vertical orientation to allow vertical handling.
Cask Transporter	A heavy-haul trailer, a rail car, a vertical cask transporter, or other specially designed equipment used onsite to move the concrete cask. The loaded concrete cask is transported vertically resting on its base (requiring a flat-bed transporter) or it is transported vertically suspended from its lifting lugs (requiring a vertical cask transporter).
Closure Lid Lifting Sling System	Sling system used to install the closure lid into the TSC in the spent fuel pool. At the user's option, the sling system can be suspended from the lift yoke and used to install the lid and engage the yoke with one crane sequence.
Cooldown System (CDS)	Introduces nitrogen, helium, and cooling water to the TSC cavity to cooldown the TSC internals and stored spent fuel to allow the return of the TSC to the spent fuel pool for the unloading of the fuel assemblies. This system would only be required in the highly unlikely event that a loaded TSC had to be unloaded.

Table 9.1-1 Major Auxiliary Equipment (continued)

Drain and Blow Down System (DBS)	System used to pump out and/or blow down the water from the TSC cavity prior to the start of drying operations, and to refill the cavity and hydrostatic test the closure lid weld. The system includes the appropriate suction pump, piping/hoses, flow meter/totalizer, helium cover gas supply, pressure gauges, and valves to connect to the TSC vent and drain port connections to complete the draining and hydrostatic testing of the cavity.
Hydrogen Detection System	System that detects increased concentration of H_2 in the cavity resulting from material reactions during closure lid root pass welding operations and for closure lid weld removal operations.
Helium Mass Spectrometer Leak Detector (MSLD)	A system utilized to perform the helium leakage testing of the inner vent and drain port cover welds.
Lid Retention System	An optional component installed on top of the TSC closure lid to secure the lid during cask handling operations between the spent fuel pool and the workstation used to close the TSC.
Lift Yoke (with Crane Hook Extension, if required)	Device for lifting and moving MAGNASTOR transfer cask by engaging the lifting trunnions.
Loaded TSC Sling System	Redundant sling system (two 3-legged slings) used to transfer a TSC into a concrete cask or a transfer cask and meeting the requirements of ANSI N14.6 and the facility crane. Alternative TSC handling systems that meet site-specific or client requirements and comply with the facility's heavy lift program developed per NUREG-0612 may be utilized.
Remote/Robotic Welding System	System that completes the closure lid and port cover welds with minimal operator assistance. The system may include video cameras and a recording device to remotely observe the welding activities and to videotape the results of the closure lid PT examinations.
Supplemental Weld Shield	Optional steel plate installed on the closure lid to provide additional shielding to the cask operators during TSC welding, preparation, and test activities. The supplemental weld shield may be installed separately or as the base plate for the welding system.
Vacuum Drying and Helium Backfill System	The system used to vaporize and remove residual water, water vapor, and oxidizing gases from the TSC cavity prior to backfilling with helium. The system includes the appropriate vacuum pump(s), vacuum and pressure gauges, helium supply connections and valves, and hoses to connect the system to the vent and drain connections.

Table 9.1-1 Major Auxiliary Equipment (continued)

Weld Removal System and Port Cover Drill Fixture	Semiautomatic mechanical weld and/or TSC shell cutting system used to remove the closure lid and port cover welds in the unlikely event that a TSC needs to be unloaded. The Port Cover Drill Fixture is used to access the outer and inner vent port covers prior to TSC cavity gas sampling and venting in order to prevent an uncontrolled release of pressurized gas during the vent port cover removal process.
Gas Sampling and Pressure Measurement System	A system connected to the Port Cover Drill Fixture that allows the TSC cavity gas to be sampled and its pressure determined prior to venting of the TSC cavity gas without exposing operations personnel to any high pressure and temperature gas releases.

Table 9.1-2 Threaded Component Torque Values

Threaded Component	Torque Value (ft-lb)
Concrete Cask Lid Bolts	40 ± 5
Concrete Cask Body Extension	100 ± 10
Closure Lid Lifting Hoist Rings	
• Lid Handling Only	100, + 50, -0
• Loaded TSC Handling	100, + 50, -0
Drain Tube Connector	
• Viton, EDPM, or Elastomer Seal	200 ± 25
• Metallic Seal	200 ± 25
Vent Port Connector	
• Viton, EDPM, or Elastomer Seal	200 ± 25
• Metallic Seal	200 ± 25
Cover Plate Bolts	40 ± 5
Concrete Cask Lift Lug Bolts	115 ± 10 ft-lb
Concrete Cask Lid Lifting Hoist Rings	100, + 50, -0
Retaining Ring Bolts (MTC2 only)	30 (+0, -10) ft-lb

9.2 Removing the Loaded TSC from a Concrete Cask

This procedure assumes the loaded concrete cask is returned to the reactor loading facility for unloading. However, transfer of the TSC to another concrete cask can be performed at the ISFSI without the need to return to the loading facility, provided a cask transfer facility that meets the requirements specified in the Technical Specifications is available.

As the steps to move a loaded concrete cask are essentially the reverse of the procedures in Section 9.1.2 and Section 9.1.3, the procedural steps are only summarized here.

1. Remove inlet and outlet screens and temperature measuring equipment (if installed).
   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the concrete cask, per Section 4.3.1.g. of the Technical Specifications.
2. For concrete casks to be transported by a vertical cask transporter, remove anchor cavity cover plates, remove the lid assembly bolts, and install the lift lugs. Torque the lift lug bolts for each lift lug to the value specified in Table 9.1-2. Attach the concrete cask to the vertical cask transporter.
3. For concrete casks to be transported on a flat-bed vehicle, install an air pad rig set in the inlets. Inflate the air pads and move concrete cask onto the vehicle deck.
   Note: Ensure that air pads are not installed longer than eight hours to complete concrete cask transfer.
4. Move the loaded concrete cask to the facility.
5. Remove the concrete cask lid. Install concrete cask shield ring, if required.
6. Install the six hoist rings into the canister closure lid threaded holes. Remove shield ring, if installed.
   Note: Utilize high temperature-resistant slings (≤ 350°F)
7. Install transfer adapter on top of the concrete cask.
8. Place transfer cask onto the transfer adapter and engage the shield door connectors.
   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the transfer cask, per Section 4.3.1.f. of the Technical Specifications.
9. Open the shield doors, retrieve the lifting slings, and install the slings on the lifting system.
10. Slowly withdraw the TSC from the concrete cask. The chamfer on the underside of the transfer adapter assists in the alignment into the transfer cask.

11. Bring the TSC up to just below the retaining blocks (MTC1/MTC2) or the retaining ring (MTC2). Close the transfer cask shield doors and install the shield door lock pins.

12. Lift transfer cask off the concrete cask and move to the designated workstation.

After the transfer cask with the loaded TSC is in, or adjacent to, the facility, the operational sequence to load another concrete cask is performed in accordance with the procedures in Section 9.1.2. Note that the amount of time that a loaded TSC can remain in the transfer cask without cooling is limited to 11 hours from the time the TSC is removed from the concrete cask. Internal or external cooling of the TSC is required to be initiated within 11 hours as described in Section 9.3.

9.3 Wet Unloading a TSC

This section provides the basic operational sequence to prepare, open, and unload a TSC in a spent fuel pool. Due to the rugged design and fabrication of the TSC, users are not expected to perform this operational sequence. However, in accordance with the Technical Specifications, each user shall have the procedures and required equipment available, and perform a dry run of the unloading process.

The procedure that follows assumes that the TSC is in a transfer cask in the appropriate workstation.

1. If using MTC1 or MTC2 with retaining blocks, pull the lock pins and retract the retaining blocks in the transfer cask, and reinstall the lock pins. If using MTC2 with retaining ring, detach and remove the retaining ring.
2. Survey the TSC and transfer cask to establish radiation areas.
3. Install and secure by welding the Port Cover Drill Fixture to the outer vent port cover.
4. Install the Gas Sampling and Pressure Measurement System to the Port Cover Drill Fixture access port.
5. Operate the Port Cover Drill Fixture to remotely drill through the outer and inner vent port covers.
6. Measure cavity gas pressure utilizing the Gas Sampling and Pressure Measurement System.
7. Obtain a cavity gas sample from the Port Cover Drill Fixture connection.
8. Determine total gaseous inventory and connect a venting system to the Gas Sampling and Pressure Measurement System and route to the HEPA filters or to the off-gas system.
9. Vent the TSC cavity gas and reduce TSC pressure to atmospheric.
10. Remove the Port Cover Drill Fixture from the outer vent port cover.
11. Install the weld removal system on the closure lid and bolt the system to the closure lid threaded holes.
12. Establish appropriate airborne radiation controls.

    Note: Initial TSC cooling can be provided by an external TSC cooling system prior to port cover removal in order to satisfy the 11-hour maximum transfer time without cooling operations.
13. Using the weld removal system, remove the outer and inner port covers from the vent and drain ports.
14. Remove the weld removal system.
15. Using appropriate radiological controls, remove the vent and drain quick-disconnects and seals.

16. Replace the quick-connects and seals with approved spares, and torque them to the value specified in Table 9.1-2.
17. Attach the cooldown system to the vent and drain connections.
    Note: Cooling of the TSC using the ACWS or equivalent annulus cooling/flush system may be required to assure cavity water boiling will not occur during closure lid weld removal operations per Section 9.1.1.
18. Initiate nitrogen gas flow through the TSC to flush out residual radioactive gases. Continue nitrogen flow for a minimum of 10 minutes.
19. Initiate the controlled filling (5 +3/-0 gpm) of the TSC with clean water through the drain connector under controlled temperature (minimum 70°F) and pressure conditions (25 +10/-0 psig). Borated water shall be used as required for the PWR fuel contents in accordance with LCO 3.2.1.
20. Monitor steam/water temperature of the discharge from the vent connection.
21. Continue cooldown operations until the discharge water temperature is below 180°F.
22. Terminate cooling water flow and disconnect the cooldown system from the drain and vent ports. Install a vent line to the vent port.
    Note: Cooling of the TSC using the annulus circulating water system may be required to ensure cavity water boiling will not occur during closure lid weld removal operations per Section 9.1.1.
23. Connect a suction pump to the drain connector. Operate the pump and remove approximately 70 gallons of water from the cavity. Disconnect and remove the pump.
24. Remove the drain line from the closure lid.
25. Install the hydrogen detector to the vent line and verify hydrogen gas concentration in the gas volume in the cavity. If the concentration reaches 2.4%, stop all cutting activities and remove cavity gas using a vacuum pump.
26. Install the weld removal system on the closure lid. Operate the weld removal system to remove the closure ring-to-TSC shell and closure ring-to-closure lid welds. Remove the closure ring from the lid area.
27. Operate the weld removal system to remove the closure lid-to-shell weld.
28. Remove shims, if installed, to provide a suitable gap to be able to extract the closure lid under water.
29. Remove the weld removal system. Terminate annulus circulating water flow, if used.
30. Install three swivel hoist rings into the closure lid threaded holes. Attach three-legged sling set to the hoist rings and the lifting system (or, alternately, the transfer cask lifting yoke).
31. Engage the lift yoke to the transfer cask trunnions and bring the transfer cask over the spent fuel pool.

32. Install lower annulus fill lines and fill the annulus with clean water while lowering the transfer cask.
33. When the trunnions are near the pool surface, install upper annulus fill lines and start clean water flow.
34. Lower the transfer cask to the bottom of the pool. Disengage the lift yoke.
35. Slowly remove the closure lid and move the lid to an appropriate storage area.
    Note: The closure lid may be contaminated and slightly activated.
36. Following fuel unloading, reengage the lift yoke to the transfer cask trunnions and remove the transfer cask from the pool.
37. While the transfer cask is over the pool, stop the flow of water to the annulus, disconnect the upper and lower fill lines, and allow the water in the annulus to drain back into the pool.
38. Place transfer cask and empty TSC in the cask decontamination area or other workstation.
39. Using a suction pump, remove the water from the TSC and pump to radwaste drains or return the water to the spent fuel pool.
40. Remove and store the contaminated TSC until a determination is made regarding reuse or disposition of the closure lid and TSC.
41. As appropriate, the user may proceed with the loading of the removed fuel assemblies in a new TSC in accordance with the procedures in Section 9.1.

Chapter 10
Acceptance Criteria and Maintenance Program

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10 ACCEPTANCE CRITERIA AND MAINTENANCE PROGRAM

This chapter specifies the workmanship inspections, the acceptance test program, and the applicable inspection and test acceptance criteria to be implemented for the fabrication, use, and maintenance of the MAGNASTOR® system. The inspections and tests described in this chapter provide assurance that MAGNASTOR components are fabricated, inspected, tested, accepted for use, and maintained under the conditions specified in this Safety Analysis Report (SAR) and the Certificate of Compliance (CoC).

The controls, inspections, and tests set forth in this chapter ensure that the MAGNASTOR system will maintain the confinement of radioactive material under normal conditions or off-normal or accident events of storage; will maintain subcriticality control; will properly transfer the decay heat of the stored radioactive materials; and that the off-site radiation doses will comply with regulatory requirements.

The MAGNASTOR system is classified as important-to-safety and, therefore, the structures, systems, and components (SSCs) of the system are designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality assurance program. The application of the quality assurance program for the system's SSCs shall be commensurate with their defined safety category. The safety classifications of the major SSCs are provided in Chapter 2.

10.1 Acceptance Criteria

This section provides the workmanship and acceptance tests to be performed on the MAGNASTOR components and systems during their fabrication, as well as prior to and during loading of the system. These tests and inspections provide assurance that the components and systems have been procured, fabricated, assembled, inspected, tested, and accepted for use under the conditions and controls specified in this document and the Certificate of Compliance.

10.1.1 Visual Inspection and Nondestructive Examination

Fabrication, inspection, and testing are performed in accordance with the applicable design criteria, codes and standards specified in Chapter 2 and on the license drawings.

The following fabrication controls and inspections shall be performed to assure compliance with this document and the license drawings:

a) Materials of construction for the MAGNASTOR are identified on the license drawings and shall be procured with certification and supporting documentation as required by the ASME Code, Section II [1], when applicable; and the requirements of ASME Code, Section III, Subsection NB [2], Subsection NF [4] and Subsection NG [3], when applicable.

b) Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to the applicable Code specification and traceability markings, as applicable. Materials for the TSC confinement boundary (e.g., TSC shell plates, base plate, closure lid, and port covers) shall also be inspected per the requirements of ASME Code, Section III, Subsection NB-2500.

c) The confinement boundary shall be fabricated and inspected in accordance with ASME Code, Section III, Subsection NB, with the code alternatives as listed in Chapter 2, Table 2.1-2. The TSC fuel basket, damaged fuel cans (DFCs) and basket supports shall be fabricated and inspected in accordance with the ASME Code, Section III, Subsection NG, with the alternatives listed in Table 2.1-2.

d) The steel components of the transfer cask shall be in accordance with ASTM specifications and fabricated in accordance with ANSI N14.6 [11]. Inspections and NDE of the transfer cask shall be in accordance with ASME Code, Section III, Subsection NF.

e) The steel components of the concrete cask shall be in accordance with ASTM specifications and fabricated in accordance with ASME Code, Section VIII [6] (or fabrication may be in accordance with ANSI/AWS D1.1). Inspections of the welded steel components of the concrete cask shall be in accordance with ASME Code, Section VIII or ANSI/AWS D1.1.

f) ASME Code welding shall be performed using welders and weld procedures qualified in accordance with ASME Code, Section IX [7] and the ASME Code, Section III subsection applicable to the component (e.g., NB, NG or NF). ANSI/AWS code welding may be performed using welders and procedures qualified in accordance with the applicable AWS requirements or in accordance with ASME Code, Section IX.

g) Construction and inspections of the concrete component of the concrete cask shall be performed in accordance with the applicable sections and requirements of ACI-318 [8].

h) Visual examinations of the welds of the confinement boundary shall be performed in accordance with ASME Code, Section V, Articles 1 and 9 [9], with acceptance per Section III, Subsection NF, Article NF-5360. The final surface of TSC shell welds shall be dye penetrant examined (PT) in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance per Section III, Subsection NB, Article NB-5350. The TSC shell longitudinal and circumferential welds shall be radiographic examined (RT) in accordance with ASME Code, Section V, Articles 1 and 2, with acceptance per Section III, Subsection NB, Article NB-5320. The weld of the TSC baseplate to the TSC shell shall be ultrasonic examined (UT) in accordance with ASME Code, Section V, Articles 1 and 4, with acceptance per Section III, Subsection NB, Article NB-5330. In accordance with ISG-15 [14], the TSC closure lid to shell weld, performed following fuel loading, shall be dye penetrant (PT) examined at the root, mid-plane and final surface in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance per Section III, Subsection NB, Article NB-5350. The closure ring to TSC shell and the closure ring to closure lid welds shall be PT examined in accordance with the same code and acceptance criteria as the closure lid to TSC shell weld, except that only the weld final surface will be examined. The inner and outer (redundant) port covers to closure lid welds shall be PT examined at the final surface in accordance with the same code and acceptance criteria as for the closure lid to shell weld. Repairs to TSC vessel welds shall be performed in accordance with ASME Code, Section III, Subsection NB, Article NB-4450, and the welds reinspected per the original acceptance criteria applicable to the examination method.

i) Visual examinations of the welds of the fuel baskets, DFCs and basket supports shall be performed in accordance with ASME Code, Section V, Articles 1 and 9, with acceptance per Section III, Subsection NG, Article NG-5360. The fuel tube welds shall be magnetic particle examined (MT) in accordance with ASME Code, Section V, Articles 1, 7 and 25, with acceptance criteria per Section III, Subsection NG, Article NG-5340. Repairs to fuel basket welds shall be performed in accordance with ASME Code, Section III, Subsection NG, Article NG-4450, and the welds reinspected per the original acceptance criteria applicable to the examination method.

j) Visual examinations of the concrete cask structural steel weldments shall be performed in accordance with the ASME Code, Section V, Articles 1 and 9, or ANS/AWS D1.1, Section 6.9, with acceptance per Section VIII, Division 1, Part UW, Articles UW-35 and UW-36, or Table 6.1 of ANSI/AWS D1.1, respectively. Repairs to concrete cask structural weldment welds shall be performed in accordance with ANSI/AWS D1.1, and the welds reinspected per the original acceptance criteria.

k) Visual examination of the welds of the transfer cask shall be performed in accordance with ASME Code, Section V, Articles 1 and 9, or ANSI/AWS D1.1, Section 6.9, with acceptance per Section III, Subsection NF, Article NF-5360. Following structural load testing of the transfer cask, the final surface of all critical load-bearing welds shall be either dye penetrant (PT) or magnetic particle (MT) examined in accordance with ASME Code, Section V, Articles 1, 6 and 24 for PT and Articles 1, 7 and 25 for MT. The acceptance

criteria for the weld examinations shall be in accordance with Section III, Subsection NF, Article NF-5350 for PT and NF-5340 for MT. Repairs to the transfer cask vertical load-bearing welds shall be performed in accordance with ASME Code, Section III, Subsection NF, Article NF-4450 or ANSI/AWS D1.1. Repaired welds shall be reinspected per the original acceptance criteria applicable to the examination method.

l) Dimensional inspections of components shall be performed in accordance with written and approved procedures to verify compliance to the license drawings and fit-up of individual components. All dimensional inspections and functional fit-up tests shall be documented.

m) All components shall be inspected for cleanliness and proper packaging for shipping in accordance with written and approved procedures. All components will be free of any foreign material, oil, grease, and solvents.

n) Inspection and nondestructive examination personnel shall be qualified in accordance with the requirements of SNT-TC-1A [10].

10.1.2 Structural and Pressure Tests

10.1.2.1 Load Testing of Transfer Casks

The transfer cask is designed, fabricated, and tested to the requirements of ANSI N14.6 [11]. The transfer cask is provided with two lifting trunnions near the top of the cask for lifting and handling. The transfer cask shield doors and supporting door rails are designed to retain and support the maximum TSC loaded weight.

Following completion of fabrication, the load-bearing components of the transfer cask, including the lifting trunnions, shield doors, and rails, are load tested to verify their structural integrity to lift and retain the applicable loads.

The lifting and handling of the transfer cask and loaded TSC are defined as critical lifting loads per NUREG-0612 [12] at a number of nuclear facilities. In accordance with ANSI N14.6, special lifting devices for critical loads shall be provided with redundant lifting paths, or be designed and tested to higher safety factors. The transfer cask lifting trunnions, shield doors, and rails are designed to higher safety factors and are load tested to 300% of the maximum service load for each type of component.

The lifting trunnion pair shall have a load equal to three times their maximum service load applied for a minimum of 10 minutes. Likewise, the transfer cask shield doors and rails shall have a load equal to three times their maximum service load applied for a minimum of 10 minutes. After release of the test loads, the accessible portions of the trunnions and the adjacent areas, and the shield doors and rails and adjacent areas shall be visually examined to verify no

deformation, distortion, or cracking occurred. The critical load-bearing welds of the transfer cask shall be examined by the methods and acceptance criteria defined in Section 10.1.1, Item k).

Any evidence of deformation, distortion, or cracking of the loaded components, critical load-bearing welds or adjacent areas shall be cause for failure of the load test, and repair and/or replacement of the component. Following repair or replacement, the applicable portions of the load test shall be performed again and the components reexamined in accordance with the original procedure and acceptance criteria.

Load testing of the transfer cask shall be performed in accordance with written and approved procedures, and the test results shall be documented.

10.1.2.2 Load Testing of Concrete Cask Lifting Lugs and Anchors

The concrete cask is designed to be lifted and transported using one of two optional pin lift configurations. The optional pin lift configurations are two lifting anchors imbedded in the reinforced concrete shell or two lifting lugs bolted to anchors that are imbedded in the reinforced concrete shell. Either configuration provides a pin connection to a lifting system. The concrete lifting anchors, lifting lugs and attachment bolting are designed, fabricated, and tested in accordance with the requirements of ANSI N14.6 for lifts not made over safety-related equipment (noncritical lifts).

The concrete cask lifting lug load test shall be performed on the lugs independently of the concrete cask. The test will consist of applying a vertical load to the individual lugs at a value that is equal to one-half of 150% of the maximum concrete cask weight. The test load shall be applied for a minimum of 10 minutes. After the release of the test load, the accessible portions of the lifting anchors shall be visually examined to verify no deformation, distortion, or cracking occurred. Critical load-bearing welds of the lifting anchors shall be magnetic particle (MT) examined in accordance with ASME Code, Section V, Articles 1, 7 and 25, or liquid penetrant (PT) examined in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance criteria per Section III, Subsection NF, Article NF-5340 or NF-5350.

Any evidence of deformation, distortion, or cracking of the loaded components, critical load-bearing welds or adjacent areas shall be cause for failure of the load test, and repair and/or replacement of the affected component(s). Following repair or replacement, the applicable portions of the load test shall be reperformed and the components reexamined in accordance with the original procedure and acceptance criteria.

Load testing of the concrete cask lifting anchors and lifting lugs shall be performed in accordance with written and approved procedures, and the test results shall be documented.

10.1.2.3 Pressure Testing of the TSC

Following completion of the closure lid-to-TSC shell weld during the TSC preparation operations after fuel loading, the TSC shall be hydrostatically pressure tested at not less than 125% of the design pressure of 110 psig in accordance with ASME Code, Section III, Subsection NB, NB-6200 requirements as described and defined in Section 9.1.1. A bounding minimum test pressure of 150 psig shall be applied to the drain port connection for a minimum 10-minute hold period. There shall be no visible water leakage from the closure lid-to-TSC shell weld based on visual examination of the weld after a minimum 10-minute hold period, while maintaining the test pressure. Test pressure shall be maintained until the completion of the visual weld examination. The design pressure and minimum test pressure are identical for both PWR and BWR TSCs. The minimum test pressure conservatively exceeds the hydrostatic test pressure commitment stated in Table 2.1-2 (125% of MNOP).

10.1.2.4 Load Testing of Damaged Fuel Can (DFC)

To qualify the design of the MAGNASTOR DFC, the first DFC to be provided to a user shall be load tested to 150% of the total weight of the DFC plus the heaviest contents to be loaded in the DFC. The test load on the DFC shall be applied and held for a minimum of 10 minutes. Following completion of the load test, all load bearing welds and surfaces shall be visually inspected for permanent deformation, galling or cracking. Load bearing welds shall be inspected using liquid penetrant examination in accordance with ASME Code, Section V, Article 6. Acceptance criteria shall be in accordance with ASME Code, Section III, NG-5350.

Any evidence of permanent deformation, cracking or galling of load bearing surfaces, or unacceptable liquid penetrant examination results shall be cause for rejection, repair, reperformance of the load test and reexamination of the DFC.

10.1.3 Leakage Tests

The confinement boundary is defined as the TSC shell weldment, closure lid assembly, and vent and drain port covers. As described in Section 10.1.1, the confinement boundary is designed, fabricated, examined, and tested in accordance with the requirements of the ASME Code, Section III, Subsection NB, except for the code alternatives listed in Table 2.1-2.

At the completion of the TSC shell weldment confinement boundary welds (e.g., TSC shell seam and shell to bottom plate), the TSC shell weldment shall be leakage tested. The leakage test shall be performed in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14.5-1997 [20] to confirm the total leakage rate is less than, or equal to, 1×10^{-7} ref. cm^3/s (i.e., leaktight). The sensitivity of the test shall be one-half of the acceptance test criteria as specified in ANSI N14.5-1997.

The TSC shell weldment will be closed using a test lid installed over the top of the shell and the cavity evacuated. A test envelope will be installed around the TSC enclosing all of the TSC shell confinement welds and base metal plates, and filled with 99.995% (minimum) pure helium to an acceptable test concentration. The percentage of helium gas in the test envelope shall be accounted for in the determination of the test sensitivity. A mass spectrometer leak detector (MSLD) will be used to sample the evacuated volume for helium.

If helium leakage is detected, the area of leakage shall be identified, repaired and re-examined in accordance with the ASME Code, Section III, Subsection NB, NB-4450 or NB-4130, as appropriate. Following repair, the complete helium leakage test shall be re-performed to the original test acceptance criteria.

Leakage testing of the TSC shell weldment shall be performed in accordance with written and approved procedures, and the test results documented.

Based on the confinement system materials, welding requirements and inspection methods, shop helium leakage testing of the 9-inch thick closure lid is not required. However, due to the reduced thickness of the stainless steel closure lid (4-inch thick base material) of the composite closure lid assembly, and the presence of extended bolt holes for attachment of the shield plate assembly, a shop helium leakage test of the composite closure lid stainless steel plate shall be performed following fabrication. The leakage test shall be performed in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14.5-1997 to confirm the total leakage rate is less than, or equal to, 2×10^{-7} cm^3/s (helium). The sensitivity of the test shall be one-half of the acceptance test criteria as specified in ANSI N14.5-1997.

If leakage is detected, the area of leakage shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NB, NB-4130. Following repair and completion of required NDE, the helium leak test shall be re-performed to the original test acceptance criteria.

Leakage testing of the composite closure lid shall be performed in accordance with written and approved procedures, and the test results documented.

In order to ensure the integrity of the vent and drain inner port cover welds, a helium leakage test of each weld is performed following welding of the inner port covers to the closure lid assembly using the evacuated envelope method, as described in ASME Code, Section V, Article 10, and ANSI N14.5. The leakage test is to confirm that the leakage rate for each port cover is $\leq 2\times10^{-7}$ cm^3/s helium. Following inner port cover welding, a test bell is installed over the top of the port cover and the test bell volume is evacuated to a low pressure by a helium MSLD system. The

minimum sensitivity of the helium MSLD shall be $\leq 1\times10^{-7}$ ref. cm^3/s, helium, which is one-half of the allowable leakage criteria for leaktight.

If leakage is detected, the area of leakage shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NB, NB-4450. Following repair, the helium leak test shall be re-performed to the original test acceptance criteria.

10.1.4 Component Tests

10.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

The MAGNASTOR system design does not include any rupture discs or fluid transport devices. The closure lid vent and drain openings are each closed by valved quick-disconnect nipples. These nipples are recessed into the closure lid and are used during TSC preparation activities to drain, dry, and helium fill the TSC cavity. No credit is taken for the ability of the valved nipples to confine radioactive material. After completion of final helium backfill pressure adjustment, the port covers are welded in the vent and drain openings enclosing the valved nipples. The port covers provide the confinement boundary for the vent and drain openings.

10.1.4.2 Gaskets

The confinement boundary provided by the welded TSC has no mechanical seals or gaskets. The concrete cask includes optional weather seals at the concrete cask lid to cask interface. These gaskets do not provide a safety function and loss of the gaskets during operation would have no effect on the safe operation of the concrete cask. The gaskets are provided to facilitate concrete cask maintenance by minimizing water intrusion into the gasketed area.

10.1.5 Shielding Tests

The MAGNASTOR system design is analyzed based on the materials of fabrication and their thickness, using conservative shielding codes to evaluate system dose rates at the system's surface and at selected distances from the surface. The system shield design does not require performance of a shield test.

Following the loading of each MAGNASTOR and its movement to the ISFSI pad, radiological surveys are performed by the system user to establish area access requirements and to confirm that evaluated offsite doses will meet the applicable regulations. These tests are sufficient to identify any significant defect in the shielding effectiveness of the concrete cask.

10.1.6 Neutron Absorber Tests

NOTE

Sections 10.1.6.4.5, 10.1.6.4.6, 10.1.6.4.7 and 10.1.6.4.8 are incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in these four sections is shown in bold to distinguish it from other sections.

Neutron absorber materials are included in the design and fabrication of the MAGNASTOR fuel basket assemblies to assist in the control of reactivity, as described in Chapter 6. Criticality safety is dependent upon the neutron absorber material remaining fixed in position on the fuel tubes and containing the required amount of uniformly distributed boron. A neutron absorber material can be a composite of fine particles in a metal matrix or an alloy of boron compounds with aluminum. Fine particles of boron or boron-carbide that are uniformly distributed are required to obtain the best neutron absorption. Three types of neutron absorber materials are commonly used in spent fuel storage and transport cask fuel baskets: Boral (registered trademark), borated metal matrix composites (MMC), and borated aluminum alloy. The fabrication of the neutron absorber material is controlled to provide a uniform boron carbide distribution and the specified ^{10}B areal density.

10.1.6.1 Design/Performance Requirements

The MAGNASTOR system utilizes sheets of neutron absorber material that are attached to the sides of the spent fuel storage locations in the fuel baskets. The materials and dimensions of the neutron absorber sheets are defined on license drawings 71160-571 and 71160-572. The material is called out as a metallic composite (includes borated aluminum alloy, borated MMC, and Boral, which are available under various commercial trade names). Incorporating optional neutron absorber materials in the design provides fabrication flexibility for the use of the most economical and available neutron absorber material that meets the critical characteristics necessary to assure criticality safety. The critical design characteristics of the neutron absorber material are:

- A minimum "effective" areal density of 0.036 g/cm^2 ^{10}B for the PWR basket and 0.027 g/cm^2 ^{10}B for the BWR basket; and
- A uniform distribution of boron carbide; and
- A yield strength greater than or equal to that used in Section 10.1.6.4.4; and
- An effective thermal conductivity greater than or equal to that used in Section 10.1.6.4.4.

The required minimum actual ^{10}B loading in a neutron absorber sheet is determined based on the effectiveness of the material, i.e., 75% for Boral and 90% for borated aluminum alloys and for

borated metal matrix composites. Testing will be used to verify the areal density and the uniform distribution of ^{10}B in the neutron absorber materials. Section 8.8 presents a tabulation of the types of neutron absorber materials, the required minimum effective areal density of ^{10}B, and the required minimum as-fabricated areal density of ^{10}B.

The positions of the neutron absorber sheets with their attachments and retainers to the fuel tubes are shown on license drawings 71160-551 and 71160-591. The attachments and retainers ensure that the neutron absorber remains in place for all loading conditions for the lifetime of the canister.

10.1.6.2 Terminology

Applicable terminology definitions for the neutron absorber materials:

acceptance –	tests conducted to determine whether a specific production lot meets selected material properties and characteristics, or both, so that the lot can be accepted for commercial use.
areal density –	for sheets with flat parallel surfaces, the density of the neutron absorber times the thickness of the material.
designer –	the organization responsible for the design or the license holder for the dry cask storage system or transport packaging. The designer is usually the purchaser of the neutron absorber material, either directly or indirectly (through a fabrication subcontractor).
lot –	a quantity of a product or material accumulated under conditions that are considered uniform for sampling purposes.
neutron absorber –	a nuclide that has a large thermal or epithermal neutron absorption cross-section, or both.
neutron absorber material –	a compound, alloy, composite or other material that contains a neutron absorber.
neutron attenuation test –	a process in which a material is placed in a thermal neutron beam, and the number of neutrons transmitted through the material in a specified period of time is counted. The observed neutron counting rate may be converted to areal density by performing the same test on a series of calibration standards.

neutron cross-section –	a measure of the probability that a neutron will interact with a nucleus; a function of the neutron energy and the structure of the interacting nucleus.
packaging –	in transport of radioactive material, the assembly of components necessary to enclose the radioactive contents completely.
qualification –	the process of evaluating and testing, or both, a material produced by a specific manufacturing process to demonstrate uniformity and durability for a specific application.

10.1.6.3 Inspections

After manufacturing, each sheet of neutron absorber material will be visually and dimensionally inspected for damage, embedded foreign material, and dimensional compliance. The neutron absorber sheets are intended to be defect/damage free, but limited defects/damages are acceptable. Allowed defects are discussed in each material specification section that follows. Standard industrial inspections will be performed on the neutron absorber sheets to verify the acceptability of physical characteristics such as dimensions, flatness, straightness, tensile properties (if structural considerations are applicable) or other mechanical properties as appropriate, surface quality and finish. Inspection and testing of the neutron absorber materials will be performed in accordance with written procedures, by appropriately certified personnel, and the inspection and test results will be documented.

10.1.6.4 Specification

Three types of neutron absorber materials are permitted to augment criticality control in the MAGNASTOR fuel baskets – (1) Boral, a clad composite of aluminum and boron carbide, as specified in Section 10.1.6.4.1; (2) borated metal matrix composites (MMC), as specified in Section 10.1.6.4.2; and (3) borated aluminum alloy, as specified in Section 10.1.6.4.3. The required minimum "effective" areal density of ^{10}B in a neutron absorber is defined on license drawings 71160-571 and 71160-572, in Section 1.8, and is based on the fuel basket geometry and on the fuel assembly type and reactivity. The analyses of the fuel baskets do not consider the tensile strength of the neutron absorber material other than that it be sufficient to maintain its form, i.e., at least equivalent to the yield strength listed in Section 8.3. Environmental conditions encountered by the neutron absorber material may include:

- Immersion in water with the associated chemical, temperature and pressure concerns
- Dissimilar materials
- Gamma and neutron radiation fluence
- Dry heat-up rates
- Maximum temperatures

Except for materials for which validation has been completed, the durability of the neutron absorber materials is validated to demonstrate the following results:

- Neutron absorber materials will not incur significant damage due to the pressure, temperature, radiation, or corrosion environments that may be present in the loading and storage of spent fuel;
- Aluminum and boron carbide do not react with each other in the range of the maximum temperatures present in the fuel baskets;
- There are no significant changes in mechanical properties of the neutron absorber materials due to the fast neutron fluences experienced in spent fuel storage;
- General corrosion does not have time to affect the integrity of the neutron absorber material due to the very short time of immersion in spent fuel pool water.

Individual material types and process lots are tested to verify the presence, uniform distribution and minimum areal density (effectiveness) of ^{10}B specific to each type of neutron absorber material.

All neutron absorber materials are procured and qualified under a Quality Assurance/Quality Control program in conformance with the requirements of 10 CFR 72, Subpart G.

10.1.6.4.1 Boral

Boral is a composite core of blended boron carbide and aluminum powders between outer layers of aluminum. The core is slightly porous. Sheets of Boral are formed and mechanically bonded by hot-rolling ingots of the core material between aluminum sheets. Boral is credited with an effectiveness of 75% of the specified minimum areal density of ^{10}B in Boral based on testing of the material as described in Section 10.1.6.4.8.

Visual inspections of the Boral sheets will verify the presence of a full core and will identify any cladding damage, cracks or discontinuities, embedded foreign material, or peeled cladding.

Evidence of less than a full core, embedded foreign material, cracks or sharp burrs in the cladding shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Embedded pieces of B_4C matrix material are not considered foreign material, but such material shall be removed from the surface of the Boral. Scratches, creases or other surface indications are acceptable on the cladding of the Boral, but exposure of the core through the cladding surface of the sheet is not acceptable.

10.1.6.4.2 Borated Metal Matrix Composites - MMC

Borated metal matrix composite (MMC) material can be produced by powder metallurgy, casting or thermal spray methods and consists of fine boron carbide particles in a matrix of aluminum. Borated MMC material is a metallurgically bonded matrix, low porosity product. Borated metal matrix composites rely on a fine (average 10-40 micron) boron carbide particle size to achieve a uniform boron distribution. Specifications on the boron carbide particle size in MMCs are included in Section 10.1.6.4.7. MMCs are credited with an effectiveness of 90% of the specified minimum areal density of ^{10}B in the borated MMC material based on acceptance and qualification testing of the material as described in the Sections 10.1.6.4.4, 10.1.6.4.5 and 10.1.6.4.6. Visual inspections of the sheets of borated MMC material will be based on Aluminum Association recommendations, as applicable—i.e., blisters and/or widespread rough surface conditions such as die chatter or porosity shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores or discoloration are acceptable based on material neutron attenuation and thermal performance not being impacted by minor fabrication anomalies.

10.1.6.4.3 Borated Aluminum

Borated aluminum material is a direct chill cast metallurgy product with a uniform fine dispersion of discrete boron particles in a matrix of aluminum. Borated aluminum material is a metallurgically bonded matrix, low porosity product. Borated aluminum is credited with an effectiveness of 90% of the specified minimum areal density of ^{10}B in the borated aluminum material based on acceptance and qualification testing of the material as described in Sections 10.1.6.4.4, 10.1.6.4.5 and 10.1.6.4.6. Visual inspections of the sheets of borated aluminum material will be based on Aluminum Association recommendations, as applicable—i.e., blisters

and/or widespread rough surface conditions such as die chatter or porosity shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores or discoloration are acceptable based on material neutron attenuation and thermal performance not being impacted by minor fabrication anomalies.

10.1.6.4.4 Thermal Conductivity and Yield Strength Testing of Metal Matrix and Borated Aluminum Neutron Absorber Material

Thermal Conductivity Testing

Thermal conductivity qualification testing of the neutron absorber materials shall conform to ASTM E1225 [15], ASTM E1461 [16], or an equivalent method. The testing shall be performed on test coupons taken from production material. Note that thermal conductivity increases slightly with temperature increases.

- Sampling will initially be one test per lot and may be reduced if the first five tests meet the specified minimum thermal conductivity. Additional tests may be performed on the material from a lot whose test result does not meet the required minimum value, but the lot will be rejected if the mean value of the tests does not meet the required minimum value.
- Upon completion of 25 tests of a single type of neutron absorber material having the same aluminum alloy matrix and boron content (in the same compound), further testing may be terminated if the mean value of all of the test results minus two standard deviations meets the specified minimum thermal conductivity. Similarly, testing may be terminated if the matrix of the material changes to an alloy with a larger coefficient of thermal conductivity, or if the boron compound remains the same, but the boron content is reduced.

In the Chapter 4 thermal analyses, the neutron absorber is conservatively evaluated as a 0.125-in nominal thickness sheet for the PWR fuel basket and a 0.10-in nominal thickness sheet for the BWR fuel basket. The required minimum thermal conductivities for the MAGNASTOR absorbers are as follows.

Minimum Effective Thermal Conductivity - BTU/(hr-in-°F)

Fuel Basket Type	Radial		Axial	
	100°F	500°F	100°F	500°F
[redacted]				
BWR	1.503	1.972	3.295	3.669

The neutron absorber thermal acceptance criterion will be based on the nominal sheet thickness. Surface anomalies increase radiation heat transfer and have insignificant influence on thermal conductivity, permitting acceptance of minor surface defects without additional material testing.

Additional thermal conductivity qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum thermal conductivity are available as referenced documentation.

Yield Strength Testing

Yield strength qualification testing of the neutron absorber shall conform to ASTM Test Method B 557/B 557M, E 8 or E 21 [17, 18, 19].

Neutron absorber material yield strength must be equal to or greater than 1.6 ksi at 700°F. Per Section 8.3, a yield strength of 1.6 ksi is the material strength of the neutron absorber at 700°F and is applied as a temperature-independent value in the structural evaluations of the absorber. This yield strength assures that the material will maintain its form when subjected to normal, off-normal and accident condition loads.

The neutron absorber yield strength acceptance criterion will be based on the absorber meeting the specified nominal sheet thickness. Control and limitations on the neutron absorber boron content (primary driver to material structural performance) permits acceptance without additional material yield strength acceptance testing.

Additional yield strength qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum yield strength are available as referenced documentation.

10.1.6.4.5 Acceptance Testing of Borated Aluminum Alloy and Borated MMC Neutron Absorber Material by Neutron Attenuation

NOTE

Section 10.1.6.4.5 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Acceptance testing shall be performed to ensure that neutron absorber material properties for sheets in a given production run are in compliance with the materials requirements for the MAGNASTOR fuel baskets and that the process is operating in a satisfactory manner.

Statistical tests will be run to augment findings relating to isotopic content, impurity content or uniformity of the ^{10}B distribution.

- **Determination of neutron absorber material acceptance shall be performed by neutron attenuation testing. Neutron attenuation testing of the final product, or the coupons, shall compare the results with those for calibrated standards, which may be composed of homogeneous or heterogeneous materials. The heterogeneous standard will be calibrated to a recognized standard (e.g., homogeneous material such as ZrB_2 plate material or a NIST-produced standard) or by attenuation of a thermal neutron beam correlated to the known cross-section of ^{10}B at the beam energies. These tests shall include a statistical sample of finished product or test coupons taken from each lot of material to verify the presence, uniform distribution and the minimum areal density of ^{10}B.**

- **The ^{10}B areal density is measured using a collimated thermal neutron beam of up to 2.54 cm in diameter, with a tolerance of 10 percent.**

- Based on the MAGNASTOR required ^{10}B minimum effective areal densities for the PWR basket of 0.036, 0.030 or 0.027 g/cm^2, the ^{10}B minimum effective areal densities for the BWR basket of 0.027, 0.0225 or 0.020 g/cm^2 and the 90% credit applied for borated aluminum alloys and for borated metal matrix composites, a required minimum areal density for the as-manufactured neutron absorber sheets is established.
- Test locations/coupons shall be well distributed throughout the lot of material, particularly in the areas most likely to contain variances in thickness, and shall not contain unacceptable defects that could inhibit accurate physical and test measurements.
- The sampling plan shall require that each of the first 50 sheets of neutron absorber material from a lot, or a coupon taken therefrom, be tested. Thereafter, coupons shall be taken from 10 randomly selected sheets from each set of 50 sheets. This 1 in 5 sampling plan shall continue until there is a change in lot or batch of constituent materials of the sheet (i.e., boron carbide powder or aluminum powder) or a process change. A measured value less than the required minimum areal density of ^{10}B during the reduced inspection is defined as nonconforming, along with other contiguous sheets, and mandates a return to 100% inspection for the next 50 sheets. The coupons are indelibly marked and recorded for identification. This identification will be used to document the neutron absorber material test results, which become part of the quality record documentation package.
- The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level (also expressed as 95/95 level) or better. The following illustrates one acceptable method.

  The acceptance criterion for individual plates is determined from a statistical analysis of the test results for that lot. The minimum ^{10}B areal densities determined by neutron attenuation are converted to volume density, i.e., the minimum ^{10}B areal density is divided by the thickness at the location of the neutron attenuation measurement or the maximum thickness of the coupon. The lower tolerance limit of ^{10}B volume density is then determined—defined as the mean value of ^{10}B volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for a normal distribution with 95% probability and 95% confidence.

Finally, the minimum specified value of ^{10}B areal density is divided by the lower tolerance limit of ^{10}B volume density to arrive at the minimum plate thickness that provides the specified ^{10}B areal density.

Any plate that is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as nonconforming, with the following exception. Local depressions are acceptable, as long as they total no more than 0.5% of the area on any given plate and the thickness at their location is not less than 90% of the minimum design thickness.

- **All neutron absorber material acceptance verification will be conducted in accordance with the NAC International Quality Assurance Program. The neutron absorber material supplier shall control manufacturing in accordance with the key process controls via a documented quality assurance system (approved by NAC or NAC's approved fabricator), and the designer shall verify conformance by reviewing the manufacturing records.**
- **Nonconforming material shall be evaluated within the NAC International Quality Assurance Program and shall be assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted.**

10.1.6.4.6 Qualification Testing of Metal Matrix and Borated Aluminum Neutron Absorber Material

NOTE

Section 10.1.6.4.6 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Qualification tests for each MAGNASTOR System neutron absorber material and its set of manufacturing processes shall be performed at least once to demonstrate acceptability and durability based on the critical design characteristics, previously defined in this section.

The licensed service life will include a range of environmental conditions associated with short-term transfer operations, normal storage conditions, as well as off-normal and accident storage events. Additional qualification testing is not required for a neutron absorber material previously qualified, i.e., reference can be provided to prior testing with the same, or similar, materials for similar design functions and service conditions.

- Qualification testing is required for: (1) neutron absorber material specifications not previously qualified; (2) neutron absorber material specifications previously qualified, but manufactured by a new supplier; and (3) neutron absorber material specifications previously qualified, but with changes in key process controls. Key process controls for producing the neutron absorber material used for qualification testing shall be the same as those to be used for commercial production.
- Qualification testing shall demonstrate consistency between lots (2 minimum).
- Environmental conditions qualification will be verified by direct testing or by validation by data on the same, or similar, material, i.e., the neutron absorber material is shown to not undergo physical changes that would preclude the performance of its design functions. Conditions encountered by the neutron absorber material may include: short-term immersion in water, exposure to chemical, temperature, pressure, and gamma and neutron radiation environments. Suppliers' testing will document the durability of neutron absorber materials that may be used in the MAGNASTOR system by demonstrating that the neutron absorber materials will not incur significant damage due to the pressure, temperature, radiation, or corrosion environments or the short-term water immersion that may occur in the loading and storage of spent fuel.
- Thermal conductivity and yield strength qualification testing shall be as previously described in Section 10.1.6.4.4.
- The uniformity of the boron carbide distribution in the material shall be verified by neutron attenuation testing of a statistically significant number of measurements of the areal density at locations distributed throughout the test material production run, i.e., at a minimum from the ends and the middle of the run. The sampling plan must be designed to demonstrate 95/95 compliance with the absorber content requirements. Details on acceptable neutron attenuation testing are previously provided in this section for Acceptance Testing. Alternate test methods may be employed provided they are validated (benchmarked) to neutron attenuation tests.
- One standard deviation of the neutron attenuation test sampling results shall be less than 10% of the sample mean. This requirement provides additional assurance that a consistent product is achieved by the manufacturing process.
- A material qualification report verifying that all design requirements are satisfied shall be prepared.

- **Key manufacturing process controls in the form of a complete specification for materials and process controls shall be developed for the neutron absorber material by the supplier and approved by NAC to ensure that the product delivered for use is consistent with the qualified material in all respects that are important to the material's design function.**
- **Major changes in key manufacturing processes for neutron absorber material shall be controlled by mutually agreed-upon process controls established by the certificate holder/purchaser and the neutron absorber supplier. These process controls will ensure that the neutron absorber delivered will always be consistent with the qualification test material in any and all respects that are important to the neutron absorber's safety characteristics. Changes in the agreed-upon process controls may require requalification of those parts of the qualification that could be affected by the process changes. Typical changes covered by the agreed-upon process controls include:**
  - **Changes that could adversely affect mechanical properties (e.g., change in thermal conductivity, porosity, material strength, change of matrix alloy, boron carbide content, increase in the B_4C content above that used in previously qualified material, etc.);**
  - **Changes that could affect the uniformity of boron (e.g., change to mixing process for aluminum and boron carbide powders, change in stirring of melt, change in boron precipitate phase, etc.).**
- **Minor neutron absorber material processing changes, i.e., roller machine hardware or final sheet cutting methods, water jet, shear cut, etc., may be determined to be acceptable on the basis of engineering review without additional qualification testing, if such changes do not adversely affect the particle bonding microstructure, i.e., the durability or the uniformity of the boron carbide particle distribution, which is the neutron absorber effectiveness.**
- **Nonconforming material shall be evaluated within the NAC International Quality Assurance Program and shall be assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted.**

10.1.6.4.7 Additional Material Specifications

NOTE

Section 10.1.6.4.7 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Boron carbide particles for MMCs shall have an average size in the range 10-40 microns and no more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

Open porosity for borated aluminum and borated MMC neutron absorber material must be no greater than 0.5% unless qualification tests are performed to ensure that blisters are not produced under submerging and subsequent vacuum drying conditions.

Chemical composition of the boron carbide powder must meet the requirements of Table 1 of ASTM C 750-03, Type 3. Additional chemical requirements, applicable to a particular absorber material, may be placed on the boron carbide powder as a result of the "key manufacturing process controls" invoked by Section 10.1.6.4.6. Additional requirements may include, but are not limited to, upper limits on fluorine and chlorine content.

10.1.6.4.8 Boral Neutron Absorber Tests

NOTE

Section 10.1.6.4.8 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

The Boral neutron absorbing material is an aluminum matrix material formed from aluminum and boron-carbide. The mixing of the aluminum and boron-carbide powder forming the neutron absorber material is controlled to assure the required ^{10}B areal density. The constituents of the neutron absorber material shall be verified by chemical testing and by dimensional measurement to ensure the quality of the finished plate or sheet. The results of all neutron absorber material tests and inspections, including the results of

wet chemistry coupon testing, are documented and become part of the quality records documentation package for the fuel tube and basket assembly.

The manufacturing process of Boral consists of several steps. The initial step is the mixing of the aluminum and boron carbide powders that form the core of the finished material. The amount of each powder is a function of the desired ^{10}B areal density. The methods used to control the weight and blend the powders are proprietary processes of the manufacturer.

After manufacturing, test samples from each Boral batch of neutron absorber sheets shall be tested using wet chemistry techniques to verify the presence and minimum weight percent of ^{10}B. The tests shall be performed in accordance with approved written procedures.

The neutron absorber sampling plan is selected to demonstrate a 95/95 statistical confidence level in the neutron absorber sheet material in compliance with the specification. In addition to the specified sampling plan, each sheet of material is visually and dimensionally inspected using at least six measurements on each sheet. The sampling plan is supported by written and approved procedures.

The sampling plan requires that a coupon sample be taken from each of the first 100 sheets of absorber material. Thereafter, coupon samples are taken from 20 randomly selected sheets from each set of 100 sheets. This 1 in 5 sampling plan continues until there is a change in lot or batch of constituent materials of the sheet (i.e., boron carbide powder, aluminum powder, or aluminum extrusion) or a process change. If either of these circumstances occurs, the sampling plan reverts back to a coupon sample being taken from each of the first 100 sheets of absorber material, followed by the 20 randomly selected sheets from each set of 100 sheets. The sheet samples are indelibly marked and recorded for identification. This identification is used to document neutron absorber test results, which become part of the quality record documentation package.

Neutron Absorber Wet Chemistry Testing

Wet chemistry testing of the test coupons obtained from the sampling plan is used to verify the ^{10}B content of the neutron absorber material. Wet chemistry testing is applied because it provides an accurate and practical direct measurement of the boron and B_4C content of metal materials.

An approved facility with chemical analysis capability, which could include the neutron absorber vendor's facility, shall be selected to perform the wet chemistry tests. Personnel

performing the testing shall be trained and qualified in the process and in the test procedure.

Wet chemistry testing is performed by dissolving the aluminum in the matrix, including the powder and cladding, in a strong acid, leaving the B_4C material. A comparison of the amount of B_4C material remaining to the amount required to meet the ^{10}B content specification is made using a mass-balance calculation based on sample size.

A statistical conclusion about the neutron absorber sheet from which the sample was taken and that batch of neutron absorber sheets may then be drawn based on the test results and the controlled manufacturing processes.

The adequacy of the wet chemistry method is based on its use to qualify the standards employed in neutron blackness testing. The neutron absorption performance of a test material is validated based on its performance compared to a standard. The material properties of the standard are demonstrated by wet chemistry testing. Consequently, the specified test regimen provides adequate assurance that the neutron absorber sheet thus qualified is acceptable.

Acceptance Criteria

The wet chemistry test results shall be considered acceptable if the ^{10}B areal density is determined to be equal to, or greater than, that specified on the fuel tube License Drawings. Failure of any coupon wet chemistry test shall result in 100% sampling, as described in the sampling plan, until compliance with the acceptance criteria is demonstrated.

Yield Strength Testing

Yield strength qualification testing of the neutron absorber shall conform to ASTM Test Method B 557/B 557M, E 8 or E 21 [17, 18, 19]. For Boral, a laminated absorber, yield strength credited in the structural analysis was limited to the outer aluminum cover sheets. Therefore, only the cover sheet must be shown to meet the required strength.

10.1.7 Thermal Tests

Thermal acceptance testing of the MAGNASTOR system following fabrication and construction is not required. Continued effectiveness of the heat-rejection capabilities of the system may be monitored during system operation using a remote temperature-monitoring system.

The heat-rejection system consists of convection air cooling where air flow is established and maintained by a chimney effect, with air moving from the lower inlets to the upper outlets.

Since this system is passive, and air flow is established by the decay heat of the contents of the TSC, it is sufficient to ensure by inspection that the inlet and outlet screens are clear and free of debris that could impede air flow. Because of the passive design of the heat-rejection system, no thermal testing is required.

10.1.8 Cask Identification

Each TSC and concrete cask shall be marked with a model number and an identification number. Each concrete cask will additionally be marked for empty system weight and date of loading. Specific marking instructions are provided on the license drawings for these system components.

10.2 Maintenance Program

A generic maintenance program is defined in an operations manual, which will be provided to system users. The operations manual will provide instructions for the inspection, testing, and component replacements required to ensure continued safe and effective operation and handling of the MAGNASTOR system. System users will develop site-specific maintenance programs and documents.

The MAGNASTOR is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions during storage operations. This results in a minimal inspection and maintenance program for the lifetime of the system. The routine maintenance requirements and schedule are shown in Table 10.2-1. As shown in the table, the requirements include concrete surface condition inspections and repairs, and reapplication of corrosion-inhibiting coatings on accessible external carbon steel surfaces.

Maintenance activities for the MAGNASTOR shall be performed under the user's approved quality assurance (QA) program. Maintenance activities shall be administratively controlled and the results documented, as required by the QA program.

10.2.1 Structural and Pressure Tests

As described and analyzed in this document, there is no credible event leading to the structural failure of the TSC resulting in the loss of radioactive material confinement. Therefore, periodic structural or pressure tests on the TSC following initial acceptance and loading are not required.

The transfer cask shall be maintained, tested, and inspected in accordance with the routine inspection, maintenance, and annual testing requirements of ANSI N14.6. Prior to each use of the transfer cask, the trunnions and shield door assembly will be inspected for gross damage, adequate lubrication, and proper function. On a maintenance schedule established by the user, the transfer cask corrosion-inhibiting coating will be inspected and repaired in accordance with the coating supplier application procedures. Areas of minor scratching or damage to the coating of the transfer cask found during use may be temporarily repaired using a nuclear grade, pool-compatible grease.

10.2.2 Leakage Tests

The TSC confinement boundary is provided by a welded vessel and, as described in Chapters 3 and 12, no credible normal conditions or off-normal or accident events result in a loss of confinement. Therefore, maintenance leakage testing of the TSC is not required.

10.2.3 Subsystem Maintenance

The MAGNASTOR does not include any active subsystems that provide safety functions during storage operations. Therefore, no subsystem maintenance is required.

Auxiliary systems used during operations, such as equipment, rigging, and instrumentation used to handle, prepare, and weld the TSC or concrete cask, are maintained and calibrated by the users in accordance with their QA program and the safety importance of the auxiliary system, equipment, instrument, or rigging.

10.2.4 Shielding Tests

The shielding materials of the TSC, concrete cask, and transfer cask are designed for long-term use with negligible degradation over time as a result of normal operations. Chipping, spalling, or other defects of the concrete cask surface shall be identified by annual visual inspection. Repairs to defects larger than approximately one-inch deep or square shall be performed using grout repair materials applied in accordance with the manufacturer's instructions. Accessible external carbon steel surfaces are inspected annually to verify the integrity of corrosion-inhibiting coatings. Coatings are reapplied as necessary for the repair of the coating in accordance with manufacturer's instructions.

Table 10.2-1 MAGNASTOR Maintenance Program Schedule

Task	Frequency
Visual inspection and repair or recoating of concrete cask concrete and accessible coated carbon steel surfaces	Annually during storage operations
Visual inspection of concrete cask identification markings	Annually
Load testing and/or visual and dimensional inspection of the transfer cask	Annually while transfer cask is in operation, or prior to returning to service
Visual inspection and repair or recoating of MTC1 transfer cask exposed carbon steel surfaces, except on sliding surfaces (does not apply to MTC2)	Annually while transfer cask is in operation, or prior to returning the transfer cask to service
Visual inspection of MTC1 transfer cask exposed carbon steel surfaces and temporary repair of coating surfaces using site-approved materials (does not apply to MTC2)	Quarterly while transfer cask is in operation, or prior to returning the transfer cask to service
Functional check of transfer cask sliding parts to verify adequate lubrication	Each use
Functional check of transfer cask inflatable seals to confirm operability	Each use
Visual inspection of the concrete cask lift lug bolts – if applicable	Prior to each installation

10.3 References

1. ASME Boiler and Pressure Vessel Code, Section II, Part A & Part B, "Materials," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
2. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, "Class 1 Components," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
3. ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, "Core Support Structures," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
4. ASME Boiler and Pressure Vessel Code, Section III, Subsection NF, "Supports," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
5. ANSI/AWS D1.1, "Structural Welding Code – Steel," American National Standards Institute, Inc., Washington, DC, 1998.
6. ASME Boiler and Pressure Vessel Code, Section VIII, Part UW, "Pressure Vessels Fabricated by Welding," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
7. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
8. ACI 318-95 and (ACI 318R-95), "Building Code Requirements for Structural Concrete," and Commentary, American Concrete Institute, Farmington Hills, MI, October 1995.
9. ASME Boiler and Pressure Vessel Code, Section V, "Nondestructive Examination," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
10. Recommended Practice SNT-TC-1A, "Nondestructive Testing", American Society for Nondestructive Testing, Columbus, OH, edition as invoked by the applicable ASME Code.
11. ANSI N14.6-1993, "American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More," American National Standards Institute, Inc., Washington, DC, June 1993.
12. NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," US Nuclear Regulatory Commission, Washington, DC, July 1980.
13. TR-017218-R1, EPRI Guideline for Sampling in the Commercial Grade Item Acceptance Process, Final Report, January 1999.
14. ISG-15, "Materials Evaluation," US Nuclear Regulatory Commission, Washington, DC, Revision 0, January 10, 2001.

15. ASTM Standard E1225[a], "Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."
16. ASTM Standard E1461[a], "Test Method for Thermal Diffusivity of Solids by the Flash Method."
17. ASTM Standard B 557/B 557M[a], "Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products."
18. ASTM Standard E8[a], "Test Methods for Tension Testing of Metallic Materials."
19. ASTM Standard E21[a], "Test Methods for Elevated Temperature Tension Tests of Metallic Materials."
20. ANSI N14.5-1997, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," American National Standards Institute, Washington, DC, 1997.

[a] Current edition of testing standards at time of testing is to be used.

Chapter 11
Radiation Protection

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11 RADIATION PROTECTION

MAGNASTOR® is provided in PWR and BWR fuel assembly configurations. The PWR system is designed to store up to 37 PWR spent fuel assemblies and associated nonfuel hardware. The BWR system is designed to store up to 87 BWR spent fuel assemblies with or without zirconium-based alloy channels. The radiation protection features and analysis presented in this chapter apply to both fuel assembly configurations. The estimated exposures for operations and storage are based on the PWR or BWR contents that result in the highest dose rates. Transfer cask exposures are based on the cask configuration documented in Section 5.1.1 and, as such, rely on a dry canister cavity with a supplemental (weld) shield in place.

11.1 Ensuring that Occupational Radiation Exposures Are As Low As Reasonably Achievable (ALARA)

MAGNASTOR provides appropriate radiation protection features for cask system operations to minimize the exposure of operations personnel to radiation or radioactive materials. The components of the system that require operation, maintenance, and inspection are designed to minimize radiation exposure to personnel.

11.1.1 Policy Considerations

MAGNASTOR is designed so that operation, inspection, repair, and maintenance can be carried out while maintaining occupational exposure As Low As Reasonably Achievable (ALARA) [1,2].

11.1.2 Design Considerations

When used in accordance with its design, MAGNASTOR maintains occupational radiation exposures as low as reasonably achievable while meeting overall system performance objectives. The following specific design features demonstrate the ALARA philosophy.

- Material selection and surface preparation that facilitate decontamination.
- Basket configurations that allow spent fuel loading using accepted standard practices.
- Positive clean water flow in the transfer cask/TSC annulus to minimize the potential for contamination of the TSC surfaces during in-pool loading.
- Passive confinement, thermal, criticality, and shielding systems that require no maintenance.
- Thick steel and concrete shells in the storage system, and a steel/lead/neutron shield/steel configuration in the transfer system.
- Nonplanar cooling air pathways with respect to the spent fuel assembly source regions to minimize radiation streaming at the concrete cask inlets and outlets.
- Provision of shield blocks below the vent and drain openings in the closure lid to minimize streaming.
- Provision of quick-release devices for use on the transfer cask doorstops and retaining blocks.
- Optional use of remote, automated outlet air temperature measurement to reduce surveillance time.

11.1.3 Operational Considerations

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

- Use of a prefabricated weld shield as a base for the welding system during welding equipment setup, removal, welding, and weld inspection of the closure lid, closure ring, and port covers. The weld shield is used during the TSC closing and sealing operations.
- Use of remote manual or automatic equipment for welding the closure lid and closure ring.
- Decontamination of the exterior surface of the transfer cask and welding of the closure lid while the TSC remains filled with water. (Personnel exposures reported in this chapter are based on a conservative dry TSC shielding evaluation.)
- Use of quick-disconnect fittings at vent and drain port penetrations to facilitate auxiliary system connections.
- Use of remote handling equipment, where practicable, to reduce radiation exposure.

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

11.2 Radiation Protection Design Features

The detailed description of the MAGNASTOR radiation shielding design is provided in Chapter 5. The principal radiation protection design features are the shielding necessary to meet the design objectives, the placement of penetrations near the edge of the TSC lid to reduce operator exposure and improve access, and the use of the weld shield for work on and around the closure lid. Use of the weld shield reduces operator exposure during the welding, inspection, draining, drying and helium backfilling operations.

Radiation exposure rates at various work locations were determined with the MCNP5 code within the vicinity of a single transfer and concrete cask and the NAC-CASC (a modified SKYSHINE-III version) code for the concrete cask array. These codes generated bounding dose rate profiles at various distances from the transfer and concrete cask, which are used to estimate the operator exposures for loading and routine operations.

11.3 Estimated Onsite Collective Dose Assessment

Operations personnel exposure estimates are based on identifying the operational cask sequence, estimating the duration and number of personnel required to perform the tasks, determining the location of the personnel in relation to the cask, and multiplying the dose rates at the particular task location by the number of personnel and the task duration. The operational tasks identified are based on the MAGNASTOR operating procedures provided in this document and operational experiences in loading other canister-based systems.

A collective dose estimate is provided for placing a single MAGNASTOR on the ISFSI, and for exposures related to routine storage operations of a 20-cask (2×10 array) ISFSI. Each cask in the array is assumed to be loaded with the contents that produce the maximum dose rate.

The personnel exposure estimates associated with loading and routine operations are presented in Table 11.3-1 through Table 11.3-4. The estimated durations, task sequences, and personnel requirements are based on the MAGNASTOR design features, operational experiences in loading systems of similar design, and operational and equipment improvements based on previous experience. These estimates are provided to allow the user to perform ALARA evaluations on MAGNASTOR implementation and use, and to establish personnel exposure guidelines for operating personnel. For each user, the site-specific design features, location and configuration of work stations, equipment staging, standard practices, operating crew size, use of temporary shielding, etc., will result in personnel exposures that may be higher or lower than those presented.

11.3.1 Estimated Dose Due to Loading Operations

The estimated dose due to loading operations considers the collective dose due to the loading, closure, transfer, and placement of a single TSC containing bounding fuel assembly contents. This analysis assumes that the exposure incurred by the operators is independent of background radiation, as background will vary with site conditions. A two mrem/hr dose rate is assigned to tasks not performed within four meters of the equipment or component surface. An example for these tasks is the monitoring of the operation of the welding system using cameras. This task may be performed at more than four meters from the cask body, and behind significant auxiliary shielding. The number of persons allocated to task completion is generally the minimum number of actual operators required for the task and excludes supervisory, health physics, security, and other nonoperating personnel.

Area dose rates are assigned based on the orientation of the worker(s) with respect to the source for a given operational task or sequence. Exposure estimates for the PWR and BWR systems are shown in Table 11.3-1 and Table 11.3-2. The number of individual tasks required for loading and transfer of the TSCs is collapsed to eight groups for this presentation. Dose rates shown are time-averaged values across the individual subtasks. Activities 7 and 8 of Table 11.3-1 and Table 11.3-2 include a crane operator who is considered to be outside of the radiation zone around the cask. Exposures due to loading operations are based on design basis casks conservatively loaded with 37 kW PWR and 35 kW BWR heat loads. Because the PWR exposures are based on a 37 kW cask heat load and a hybrid CC1/CC2 model and MTC1, they bound exposures calculated at 35.5 kW for any of the three concrete casks and either of the transfer casks. Similarly, PWR exposures presented for undamaged fuel bound those of damaged fuel due to the negligible contribution from damaged fuel to cask surface dose rates near the top of the cask, which is the predominant exposure location for accumulation of occupational dose.

11.3.2 Estimated Dose Due to Routine Operations

Once the MAGNASTOR is in storage at the ISFSI, limited ongoing maintenance and surveillance will be required. The annual dose evaluations presented herein consider the tasks that are anticipated to be representative of an operational facility. Exposure due to certain events, such as clearing the material blocking the air vents, is taken into account.

Routine operations may include the following.

- An optional daily electronic measurement of ambient air and outlet air temperatures for each TSC in service. Outlet temperature measurements are recorded at a location away from the cask array, and operators are not expected to incur dose as a result of the temperature measurement.
- An optional inspection of the concrete cask inlet and outlet screens to verify that they are unobstructed. The time required to perform the inspection, and the expected dose, will be site-specific due to ISFSI pad dimensions and configurations, the concrete cask array, distance of the inspector, etc.
- A daily inspection of the security fence and equipment surrounding the ISFSI storage area. This surveillance is assumed to require 15 minutes and is performed by one security officer.
- Radiological surveillance. The surveillance consists of a radiological survey comprised of a surface radiation measurement on each cask, the determination and/or verification of general area exposure rates and radiological postings. This surveillance is assumed to require 30 minutes, and be performed quarterly by one health physics technician.

- Annual visual inspection of the general condition of the concrete casks. This inspection is estimated to require 10 minutes per cask and require one technician. For each cask, three minutes of health physics support is also included.
- Corrective maintenance. As the MAGNASTOR is a passively cooled and shielded system, no significant maintenance is expected over the lifetime of the IFSFI. To account for activities such as minor concrete repairs, air inlet and outlet cleaning, or temperature-monitoring equipment replacement, 10% of the array is assumed to require maintenance each year. Maintenance exposure is evaluated based on two operators for 30 minutes each and one health physics technician for 10 minutes.
- Grounds maintenance performed twice a month by one maintenance technician. Grounds maintenance is assumed to require 60 minutes.

Storage operation exposures for a 2×10 array of either PWR or BWR concrete casks loaded with TSCs containing bounding fuel assembly sources are presented in Table 11.3-3 and Table 11.3-4. ISFSI exposures are based on design basis casks conservatively loaded with 40 kW PWR and 38 kW BWR heat loads. Because the PWR exposures are based on a 40 kW cask heat load and a hybrid CC1/CC2 model, they bound the exposures calculated at 35.5 kW for any of the three concrete casks. Similarly, PWR exposures presented for undamaged fuel are applicable to casks containing damaged fuel as there is only a minor contribution from damaged fuel to the cask surface average dose rate.

Table 11.3-1 Estimated Person-mrem Exposure for Loading Operations of the PWR System

	Description	# of Subtasks	Exposure Duration (min)	Average Dose Rate (mrem/hr)	Exposure (mrem)
1	Fuel Assembly Loading and Transfer Cask Removal from Pool	4	908	2.7	83
2	HP Survey and Decon Top of TSC/Transfer Cask	3	30	26.0	13
3	Install Weld Shield/Weld Machine, and Perform Partial Drain of TSC	4	45	20.0	15
4	Perform Closure Lid and Ring Welding and PT Exams, Hydrostatically Test TSC	16	480	24.6	197
5	Drain TSC and Decontaminate Transfer Cask	5	230	32.3	124
6	Dry TSC Cavity, Backfill/Pressure TSC, Install Port Covers, Weld and Inspect Covers, Remove Weld Shield/Weld Machine, and Survey Cask/TSC Surfaces	13	475	7.2	57
7	Install Hoist Rings, Place Transfer Cask on Concrete Cask, Transfer TSC, Install Concrete Cask Lid, and Perform HP Survey	17	220	42.0	154
8	Move Concrete Cask to ISFSI, Position Concrete Cask on ISFSI Pad, and Install/Connect Screens and Temperature Measuring System	11	180	23.0	69
	Total				**712**

Table 11.3-2 Estimated Person-mrem Exposure for Loading Operations of the BWR System

	Description	# of Subtasks	Exposure Duration (min)	Average Dose Rate (mrem/hr)	Exposure (mrem)
1	Fuel Assembly Loading and Transfer Cask Removal from Pool	4	2033	2.3	159
2	HP Survey and Decon Top of TSC/Transfer Cask	3	30	36.0	18
3	Install Weld Shield/Weld Machine, Connect Drain System, and Perform Partial Drain of TSC	4	45	22.7	17
4	Perform Closure Lid and Ring Welding and PT Exam, Hydrostatically Test TSC	16	480	31.3	250
5	Drain TSC and Decontaminate Transfer Cask	5	230	35.0	134
6	Dry TSC Cavity, Backfill/Pressure TSC, Install Port Covers, Weld and Inspect Covers, Remove Weld Shield/Weld Machine, and Survey Cask/TSC Surfaces	13	475	13.5	107
7	Install Hoist Rings, Place Transfer Cask on Concrete Cask, Transfer TSC, Install Concrete Cask Lid and Perform HP Survey	17	220	45.8	168
8	Move Concrete Cask to ISFSI, Position Concrete Cask on ISFSI Pad, and Install/Connect Screens and Temperature Measuring System	11	180	20.0	60
	Total				**913**

Table 11.3-3 Estimate of Annual Exposures Due to Routine Operations for a PWR 20-Cask Array

Activity	Location	# of Casks	Frequency (/year)	Time (min)	Dose Rate (mrem/hr)	# of Personnel	Exposure (mrem)
Security Surveillance	Outside Fence	Array	365	15	< 2	1	183
Radiological Surveillance	4 m	Array	4	30	30.4	1	61
Annual Inspection	1 m	20	1	10	54.8	1	183
Radiological Support	1 m	20	1	3	54.8	1	55
Corrective Maintenance	1 ft	2	1	30	67.0	2	134
Radiological Support	1 m	2	1	10	54.8	1	18
Grounds Maintenance	Outside Fence	Array	26	60	< 2	1	52
Total Person-mrem for the Array							686
Total Person-mrem - Average Dose Per Cask							**34**

Table 11.3-4 Estimate of Annual Exposures Due to Routine Operations for a BWR 20-Cask Array

Activity	Location	# of Casks	Frequency (/year)	Time (min)	Dose Rate (mrem/hr)	# of Personnel	Exposure (mrem)
Security Surveillance	Outside Fence	Array	365	15	< 2	1	183
Radiological Surveillance	4 m	Array	4	30	27.6	1	55
Annual Inspection	1 m	20	1	10	49.4	1	165
Radiological Support	1 m	20	1	3	49.4	1	49
Corrective Maintenance	1 ft	2	1	30	61.9	2	124
Radiological Support	1 m	2	1	10	49.4	1	16
Grounds Maintenance	Outside Fence	Array	26	60	< 2	1	52
Total Person-mrem for the Array							644
Total Person-mrem - Average Dose Per Cask							**32**

11.4 Exposures to the Public

Chapter 5 presents the detailed controlled area boundary evaluations. The MAGNASTOR dose contribution to public exposure at the controlled area boundary is due to direct gamma and neutron radiation emitted from the cask surfaces. When assembled in accordance with the operating procedures, the TSC is leaktight and, therefore, does not release radionuclides from the TSC interior. External surface contamination limits applied to the system assure that no significant public exposure results from particulate release from the system surfaces.

11.5 References

1. 10 CFR 72, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste," US Nuclear Regulatory Commission, Washington, DC.
2. 10 CFR 20, "Standards for Protection Against Radiation," Code of Federal Regulations, US Nuclear Regulatory Commission, Washington, DC

Chapter 12
Accident Analyses

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12 ACCIDENT ANALYSES

The results of the analyses of the off-normal and accident events, including those identified by ANSI/ANS 57.9-1992 [1], are presented in this chapter. Section 12.1 describes the off-normal events that could occur during the use of MAGNASTOR®, possibly as often as once per calendar year. Section 12.2 addresses very low probability events that might occur once during the lifetime of MAGNASTOR or hypothetical events that are postulated because their consequences may result in the maximum potential effect on the surrounding environment. The detailed analysis of each evaluated event is presented in the appropriate technical chapters – structural, thermal, shielding, criticality, confinement, or radiation protection. In the analyses in those chapters, the bounding parameters (i.e., maximum concrete cask weight and center of gravity) are conservatively used, as appropriate, to determine the capability of MAGNASTOR to withstand the effects of the analyzed events.

The load conditions imposed on the TSCs and the fuel baskets by the design basis normal, off-normal and accident events of storage are less severe than those imposed by the transport conditions–including the 30-foot drop impacts and the fire accident (10 CFR 71) [2]. Consequently, the evaluation of the TSCs and the fuel baskets for transport conditions bounds the storage condition results reported in this chapter.

This chapter demonstrates that MAGNASTOR is in compliance with the requirements of 10 CFR 72.24 and 10 CFR 72.122 [3] for off-normal and accident events. The evaluations provided are based on conservative assumptions and demonstrate that MAGNASTOR will provide safe storage of spent fuel during all analyzed off-normal and accident events.

12.1 Off-Normal Events

This section evaluates postulated off-normal events that might occur once during any calendar year of operations. The actual occurrence of any of these events is, therefore, infrequent.

12.1.1 Severe Ambient Temperature Events (106°F and -40°F)

This section provides the results of the evaluation of MAGNASTOR for the steady-state effects of severe ambient temperature events (106°F and -40°F).

12.1.1.1 Cause of Severe Ambient Temperature Event

Large geographical areas of the United States are subjected to sustained summer temperatures in the 90°F to 100°F range and winter temperatures that are significantly below zero. To bound the expected steady-state temperatures of the TSC and storage cask during severe ambient temperature events, analyses are performed to calculate the steady-state concrete cask, TSC, fuel basket, and fuel cladding temperatures for a 106°F ambient temperature and solar loads. Similarly, winter weather analyses are performed for a -40°F ambient temperature with no solar load. Neither ambient temperature event is expected to last longer than several days.

12.1.1.2 Detection of Severe Ambient Temperature Event

Detection of off-normal ambient temperatures would occur during measurement of ambient temperature.

12.1.1.3 Analysis of Severe Ambient Temperature Event

The analysis for the off-normal temperature events is presented in Chapter 4. Two-dimensional axisymmetric models are used to determine the temperatures of the concrete, the TSC, fuel basket, and fuel cladding. Steady-state conditions are considered in all analyses. Based on the analysis, the calculated principal component temperatures for each of the ambient temperature conditions and the allowable temperatures are summarized in Section 4.5.1. The calculated component temperatures are less than the allowable temperatures.

Table Deleted via 10 CFR 72.48

As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons, the temperature results for the severe ambient temperature events are also bounded.

The thermal stress evaluations for the concrete cask for these off-normal events are bounded by those for the accident event of "Maximum Anticipated Heat Load (133°F Ambient Temperature)" as presented in Section 12.2.7. Thermal stress analyses for the TSC and the basket components are performed using ANSYS finite element models as described in Section 3.6. A bounding thermal gradient is applied to the TSC and fuel baskets to bound the severe ambient temperature conditions. Factors of safety for off-normal events are presented in Section 3.6.

12.1.1.4 Corrective Actions

No corrective actions are required for these off-normal events.

12.1.1.5 Radiological Impact

There is no radiological impact due to these off-normal events.

12.1.2 Blockage of One-Half of the Air Inlets

This section provides the results of the evaluation of MAGNASTOR for the steady-state effects of a blockage of one-half of the air inlets at the normal ambient temperature (76°F).

12.1.2.1 Cause of Blockage of One-Half of the Air Inlets Event

Although unlikely, blockage of one-half of the air inlets may occur due to blowing debris, snow, intrusion of a burrowing animal, etc. The screens over the inlets are expected to minimize any blockage of the inlet channels and expedite recovery by restricting the blockage to the exterior of the concrete cask.

12.1.2.2 Detection of One-Half of the Air Inlets Blockage Event

The blockage of one-half of the air inlet screens would be detected visually by persons performing a daily surveillance of the ISFSI or observing an increase in the concrete cask outlet temperature if measured, which would result from the reduced airflow caused by the blockage. The air inlet screens blockage event may also be detected by security forces, or other operations personnel, engaged in other routine activities such as fence inspection or grounds maintenance.

12.1.2.3 Analysis of One-Half of the Air Inlets Blockage Event

Using the same methods and the same thermal models for the severe ambient temperature events, thermal evaluations are performed for the concrete cask and the TSC and its contents for the one half air inlet blockage event. The boundary condition of the two-dimensional axisymmetric concrete cask and TSC model is modified to allow only one-half of the airflow into the air inlet to simulate the one-half of the air inlets blocked condition. The detailed analysis is provided in Section 4.5.

The calculated maximum component temperatures are compared to the allowable component temperatures as presented in Section 4.5.1. The calculated component temperatures are less than the component allowable temperatures.

Table Deleted via 10 CFR 72.48

As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons, the temperature results for the blockage of one-half of the air inlets event are also bounded.

The thermal stress evaluation for the concrete cask for the one-half of the air inlets blocked event is bounded by those for the accident event of "Maximum Anticipated Heat Load (133°F Ambient Temperature)" as reported in Section 12.2.7. Thermal stress analyses for the TSC and the basket components are performed using ANSYS finite element models as described in Section 3.6. For the TSC and baskets, bounding temperature gradients are used to bound the one-half of the air inlets blocked condition. A summary of thermal stresses is presented in Section 3.6.

12.1.2.4 Corrective Actions

The debris blocking the air inlet screens will be manually removed. The nature of the debris may indicate that other actions are required to prevent recurrence of the blockage.

12.1.2.5 Radiological Impact

There are no significant radiological consequences for the one-half of the air inlets blocked event. Personnel will be subject to an estimated maximum contact dose rate of 448 mrem/hr when clearing the inlet screens of a concrete cask containing a conservative 37 kW payload of PWR fuel. If it is assumed that a worker kneeling, with his hands at the inlet screens, would require 15 minutes to clear the screens, the estimated maximum extremity dose is 112 mrem. For clearing the inlet screens of a concrete cask containing a conservative 35 kW payload of BWR fuel, the maximum contact dose rate and the maximum extremity dose are estimated to be 364 mrem/hr and 91 mrem, respectively. The whole body dose in both the PWR and the BWR cases will be significantly less than the extremity doses.

Because the PWR dose rates are based on a 37 kW cask heat load and a hybrid CC1/CC2 model, they bound dose rates calculated at 35.5 kW for any of the three concrete casks.

12.1.3 Off-Normal TSC Handling Load

This section reports the results of the evaluation of the consequences of off-normal handling loads on the TSC during the installation of the TSC in the concrete cask, or removal of the TSC from the concrete cask or from the transfer cask. The TSC is handled vertically in the transfer cask.

12.1.3.1 Cause of Off-Normal TSC Handling Load Event

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

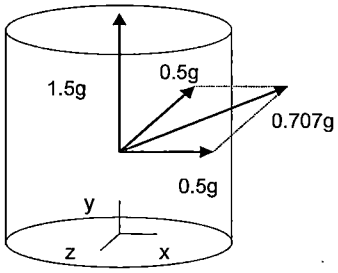
12.1.3.2 Detection of Off-Normal TSC Handling Load Event

The off-normal TSC-handling event can be detected visually during the handling of the TSC, or audibly by hearing a banging or scraping noise associated with TSC movement. The event is expected to be obvious to the operators at the time of occurrence.

12.1.3.3 Analysis of Off-Normal TSC Handling Load Event

The TSC off-normal handling analysis is performed using an ANSYS finite element model described in Chapter 3. The model is used to evaluate the TSCs for both PWR and BWR fuel types by modeling the longest TSC with the heaviest fuel/fuel basket weight. The material stress allowables used in the analysis consider the higher component temperatures that occur during transfer operations.

The off-normal TSC handling loads are defined as 0.5g applied in all directions (i.e., in the global x, y, and z directions) in addition to a 1g lifting load applied in the vertical direction. The resulting off-normal handling accelerations are 0.707g in the lateral direction and 1.5g (0.5g + 1g) in the vertical direction.



The resulting maximum TSC stresses for combined off-normal handling, maximum internal pressure and thermal stress loads are summarized in Section 3.6.

The structural evaluation of the PWR and BWR fuel basket tubes and support weldments for off-normal events is also presented in Section 3.6.

The TSCs and fuel baskets are shown to be structurally adequate for the off-normal handling condition.

12.1.3.4 Corrective Actions

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

12.1.3.5 Radiological Impact

There are no radiological consequences associated with this off-normal TSC handling event.

12.1.4 Failure of Instrumentation

MAGNASTOR may use a temperature-sensing system to measure the outlet air temperature at each of the four air outlets on each concrete cask. The air temperature at the outlets may be recorded and reviewed daily.

12.1.4.1 Cause of Instrumentation Failure Event

The temperature instrumentation failure event could occur as a result of instrumentation component failure, or as a result of any event that interrupted power or altered temperature sensor output.

12.1.4.2 Detection of Instrumentation Failure Event

The temperature instrumentation failure event may be identified by the lack of, or an inappropriate, reading at the temperature reader terminal. The event could also be identified by disparities between outlet temperatures in a cask or between similar casks.

12.1.4.3 Analysis of Instrumentation Failure Event

For concrete casks incorporating daily temperature-monitoring systems, the maximum time period during which an increase in the outlet air temperatures may go undetected is 24 hours. The principal condition that could cause an increase in temperature is the blockage of the air inlets. Section 12.2.13 shows that even if all of the air inlets of a single cask are blocked immediately after a temperature measurement, it would take longer than 24 hours before any component approaches its allowable temperature limit. Therefore, there will be sufficient time to identify and correct temperature instrumentation failure events prior to critical system components reaching the temperature limits. During the period of loss of instrumentation, no significant change in TSC temperature will occur under normal conditions. Therefore, instrument failure would be of no consequence when the affected storage cask continues to operate in a normal storage condition.

Because the TSC and the concrete cask are a large heat sink, and because there are few conditions that could result in an outlet temperature increase, the temporary loss of the optional remote sensing and monitoring of the outlet air temperature is not a major concern. No applicable regulatory criteria are violated by the failure of the temperature instrumentation system.

12.1.4.4 Corrective Actions

This event requires that the temperature-monitoring equipment be either replaced or repaired or otherwise returned to operable, or that the concrete cask air inlet screens be visually inspected daily for blockage.

12.1.4.5 Radiological Impact

There are no radiological consequences for this event.

12.1.5 Small Release of Radioactive Particulate From the TSC Exterior

The procedures for loading the TSC provide for operations and measures to minimize TSC exterior surface contact with contaminated spent fuel pool water, and the TSC external surfaces are surveyed, to the extent practical, to verify removable contamination is within allowable limits. The external surfaces of the TSC are rolled or flat stainless steel plates, and the presence of excessive removable contamination on the external surfaces is unlikely. Therefore, radioactive particulate release from the TSC exterior surface is not expected to occur during normal storage operations.

12.1.5.1 Cause of Radioactive Particulate Release Event

The most likely cause of a radioactive particulate release event is air passing over the external surfaces of a contaminated TSC. In spite of precautions taken to preclude contamination of the external surface of the TSC, it is possible that a portion of the TSC surface may become contaminated during fuel loading by the spent fuel pool water and that the removable contamination in excess of allowable limits may go undetected. Subsequently, surface contamination could become airborne and be released as a result of the airflow over the TSC surfaces.

12.1.5.2 Detection of Radioactive Particulate Release Event

The release of small amounts of radioactive contamination particulates over time is difficult to detect. Any release is likely to be too low to be detected by any of the normally employed long-term radiation dose monitoring methods (such as TLDs) normally located at the ISFSI perimeter fence. It is possible that a suspected release could be verified by a smear survey of the air outlets.

12.1.5.3 Analysis of Radioactive Particulate Release Event

The analysis presented in Section 5.6.5 calculates a total dose of less than 0.1 mrem at 100 meters from a design basis concrete cask based on removable contamination levels of 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α.

The method for determining the dose is based on the plume dispersion calculations presented in U.S. NRC Regulatory Guides 1.109 [4] and 1.145 [5] and is highly conservative. The analysis demonstrates that the offsite radiological consequences from the release of TSC surface contamination is negligible, and all applicable regulatory criteria are met for an ISFSI array. ISFSI-specific allowable dose rates will be calculated on a site-specific basis to conform to 10 CFR 72.

12.1.5.4 Corrective Actions

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

12.1.5.5 Radiological Impact

As previously shown, the potential offsite radiological impact due to the release of TSC surface contamination is negligible.

12.1.6 Crane Failure During Loaded Transfer Cask Movements

Before the TSC is placed into the concrete cask, it is handled using the transfer cask. If the crane used to lift and maneuver the transfer cask failed during a lift operation (e.g., moving the transfer cask from the spent fuel pool to the decon pit/work area or from the work area to the VCC), it

would not be possible to submerge the transfer cask and TSC in the spent fuel pool, and it might be difficult to initiate cooling with the ACWS. This off-normal event does not result in the loss of load carrying capability of the crane.

12.1.6.1 Cause of Crane Failure During Loaded Transfer Cask Movements

The transfer cask handling crane may become inoperable due to a mechanical or electrical malfunction of the crane or its supporting equipment.

12.1.6.2 Detection of Crane Failure During Loaded Transfer Cask Movements

Crane failure would be identified immediately by the crane operators.

12.1.6.3 Analysis of Crane Failure During Loaded Transfer Cask Movements

[redacted]

12.1.6.4 Corrective Actions

The required corrective action for this event depends on the heat load of the TSC. Depending on the heat load, cooling flow may be required to be established to maintain fuel temperatures, basket temperatures, and TSC pressure below off-normal allowable limits. Regardless of heat load, the crane would need to be repaired and returned to an operable condition before loading operations could continue.

12.1.6.5 Radiological Impact

The radiological consequences for this event include the additional personnel dose resulting from the need to repair the crane, and to potentially perform additional annulus cooling operations prior to proceeding with the TSC transfer.

12.1.7 Crane/Hoist Failure During TSC Transfer to VCC

During transfer of the TSC from the transfer cask into the VCC, the transfer cask is positioned on top of the VCC and its doors are opened. The TSC is then lowered into the VCC using a crane or equivalent lifting device. A failure of the crane/lifting device during this operation would strand the TSC within the transfer cask/VCC cavity until the crane is repaired. This condition would severely limit the options for cooling the TSC should the crane be inoperable for a period extending beyond the established normal transfer time. This condition is only valid if the transfer cask doors are open; if they are unable to be opened, the condition and results discussed in Section 12.1.6 apply.

12.1.7.1 Cause of Crane/Hoisting Failure During TSC Transfer to VCC

The TSC handling crane/lifting device may become inoperable due to a mechanical or electrical malfunction of the crane or its supporting environment.

12.1.7.2 Detection of Crane/Hoist Failure During TSC Transfer to VCC

Crane failure would be identified immediately by the crane operators.

12.1.7.3 Analysis of Crane/Hoist Failure During

The analysis of the condition using a two-dimensional FLUENT model is presented in Chapter 4, Section 4.4.1.5, for PWR fuel. The analysis results show that for heat loads less than or equal to 33 kW, the calculated steady state temperatures for the TSC are below the off-normal temperature allowables, so there is no time requirement for establishing cooling flow once the normal transfer time is exceeded. Furthermore, the analysis results show that for heat loads less than or equal to 28 kW, the calculated steady state temperatures for the TSC are below normal temperature allowables. The analysis results show that for PWR heat loads greater than 33 kW, the off-normal temperature allowables for the TSC are reached 11 hours after the established normal transfer time limit is reached.

12.1.7.4 Corrective Actions

The required corrective action for this event depends on the heat load of the TSC. Depending on the heat load, cooling flow may be required to be established to maintain fuel temperatures, basket temperatures, and TSC pressure below off-normal allowable limits. Regardless of heat load, the crane would need to be repaired and returned to an operable condition before loading operations could continue.

12.1.7.5 Radiological Impact

The radiological consequences for this event include the additional personnel dose resulting from the need to repair the crane/lifting device, and to potentially perform additional annulus cooling operations prior to proceeding with the TSC transfer.

12.2 Accidents and Natural Phenomena

This section presents the results of analyses of the design basis and hypothetical accident events evaluated for MAGNASTOR. In addition to design basis accidents, this section addresses very low-probability events, including natural phenomena that might occur once over the lifetime of the ISFSI, or hypothetical events that are postulated to occur because their consequences may result in the maximum potential effect on the immediate environment.

MAGNASTOR includes TSCs of two different lengths to accommodate two lengths of PWR fuel or two lengths of BWR fuel. In the accident analyses of this section, the bounding cask parameters (such as weight and center of gravity) are conservatively used, as appropriate, to determine the cask's capability to withstand the effects of the accidents. The results of these analyses show that any credible potential accident will result in a dose of ≤5 rem beyond the postulated controlled area. Consequently, MAGNASTOR is demonstrated to have a substantial design margin of safety, and will provide protection to the public and to site operations personnel during storage of spent fuel.

12.2.1 Accident Pressurization

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

The results of analysis of this event demonstrate that the TSC is not significantly affected by the increase in internal pressure that results from the hypothetical rupture of all (PWR or BWR) fuel rods and burnable absorbers contained within the TSC.

12.2.1.1 Cause of Pressurization

The hypothetical failure of all of the fuel rods in a TSC would release the fill and fission gases contained within the fuel and cladding to the TSC cavity, resulting in an increase in internal TSC pressure.

12.2.1.2 Detection of Accident Pressurization

The rupture of fuel rods within the TSC is unlikely to be detected by any measurement or inspection that could normally be undertaken from the exterior of the TSC or the concrete cask.

12.2.1.3 Analysis of Accident Pressurization

Analysis of this accident involves calculation of the maximum TSC internal pressure and the resulting stresses. The maximum TSC pressure is calculated by adding the releasable quantity of fill and fission gas in the fuel assemblies, BPRA gases, and the subsequent calculation of the pressure in the TSC, if these gases are added to the helium backfill pressure already present in the TSC (see Section 4.6). The analysis shows that the maximum TSC pressures for the 100% fuel failure assumption are 221 psig (PWR) and 159 psig (BWR). The pressure for both PWR and BWR configurations is less than the design pressure of 250 psig for the accident event. As presented in Section 3.7.1.1, a structural evaluation is performed for the TSC for the internal pressure of 250 psig using the ANSYS finite element model that envelops both PWR and BWR configurations. The minimum factor of safety for the TSC stresses is calculated to be 1.59.

Consequently, there is no adverse consequence to the TSC as a result of the maximum accident internal pressure.

12.2.1.4 Corrective Actions

No recovery or corrective actions are required for this hypothetical accident.

12.2.1.5 Radiological Impact

There are no dose consequences due to this accident.

12.2.2 Failure of All Fuel Rods With a Ground-level Breach of the TSC

Since no mechanistic failure of the TSC occurs and since the TSC is leaktight, this potential accident condition is not evaluated.

12.2.3 Fresh Fuel Loading in the TSC

This section evaluates the effects of an inadvertent loading of up to 37 fresh, unburned PWR fuel assemblies or up to 87 fresh, unburned BWR fuel assemblies in a TSC. In-plant operational procedures and engineering and quality control programs are expected to preclude occurrence of this event. Nonetheless, it is evaluated here to demonstrate the adequacy of the TSC design for accommodating fresh fuel without a resulting criticality event. There are no adverse effects on the TSC due to this event since the criticality control features of MAGNASTOR ensure that the k_{eff} of the fuel is less than 0.95 for all loading conditions of fresh fuel.

12.2.3.1 Cause of Fresh Fuel Loading

The cause of this event is operator and/or procedural error.

12.2.3.2 Detection of Fresh Fuel Loading

This event is expected to be identified immediately by observation of the identification of the fuel installed in the TSC prior to closure lid installation, or by a review of the fuel handling records.

12.2.3.3 Analysis of Fresh Fuel Loading

The criticality analysis presented in Chapter 6 evaluates the loading of up to 37 PWR or up to 87 BWR fresh fuel assemblies having no burnup. The maximum k_{eff} for the accident events remains below the upper subcritical limit (USL) and the k_{eff} of MAGNASTOR is less than 0.95 for fresh fuel loading conditions. Therefore, there is no adverse impact on MAGNASTOR due to this event.

12.2.3.4 Corrective Actions

This event requires that the TSC be unloaded when the incorrect fuel loading is identified. The root cause for the fuel misloading error should be identified and procedural actions implemented to preclude recurrence.

12.2.3.5 Radiological Impact

There are no dose impacts due to this event, as MAGNASTOR remains subcritical.

12.2.4 24-Inch Drop of the Concrete Cask

This section provides a summary of the results of the structural evaluation of a loaded concrete cask for a 24-inch drop onto a concrete storage pad. The concrete cask may be lifted using lifting lugs in the top of the cask. The concrete cask containing the heaviest TSC is used in the analysis as the bounding case. The evaluation shows that neither the concrete cask nor the TSC experiences significant adverse effects due to the drop accident. Lifting of the concrete cask to a height greater than 24 inches is precluded by the Technical Specifications.

12.2.4.1 Cause of 24-Inch Cask Drop

The concrete cask may be lifted and moved by a transport frame, which may be self-propelled or towed. The transport frame raises the cask using a lifting attachment that connects to the two lifting lugs. The failure of one or more of the lifting lugs, or the failure of the lifting frame, could result in a drop of the cask.

12.2.4.2 Detection of 24-Inch Cask Drop

The operators will visually detect this event as it occurs.

12.2.4.3 Analysis of 24-Inch Cask Drop

The detailed analyses of the cask drop event are provided in Chapter 3. A bottom-end impact is assumed to occur on the concrete cask bottom surface, transmitting the maximum load to the concrete cask and the TSC. The energy absorption is computed as the product of the compressive force acting on the concrete cask and its displacement. Conservatively assuming that the storage pad surface impacted is an infinitely rigid surface, the concrete cask body will crush until the impact energy is absorbed.

The TSC rests upon a base weldment designed to support and facilitate cooling of the TSC. Following the initial impact, the air inlet system will partially collapse, providing an energy-absorption mechanism that somewhat reduces the deceleration force on the TSC.

As described in Section 3.7.3, the accelerations of the concrete cask and TSC and the deformation of the base weldment are determined using a LS-DYNA model. The maximum accelerations of the TSC during the bottom-end impact are 25.2g. The LS-DYNA analyses show that the maximum deformation of the base weldment is about 2.9 inches. This deformation reduces the air inlet to approximately 66% of the original height. This condition is bounded by the consequences of the loss of one-half of the air inlets evaluated in Section 12.1.2.1.

The TSC stress evaluation for the concrete cask 24-inch bottom-end-drop accident is performed using a conservative g-load of 60g. This evaluation bounds the 25.2g load that is calculated for the 24-inch bottom-end-drop event as previously determined. This TSC evaluation is performed using the ANSYS finite element program. The analyses show that the structural components of the TSC (shell, bottom plate, and closure lid) satisfy the allowable stress intensity limits. The results of the bounding TSC analysis for the 60g bottom-end impact loading are discussed in Section 3.7.1.2.1. The minimum margin of safety for the stresses in the TSC shell, bottom plate and closure lid is 3.71. The minimum margin of safety for stress in the TSC shield plate and associated attachment bolts is 1.14.

Classical theory and empirical buckling formula are used to evaluate buckling of the TSC shell for the 60g bottom-end impact. The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are satisfied by the results of the buckling interaction equation calculations. The maximum stress components used in the evaluation are provided in Section 3.7.1. The factor of safety against buckling is 3.7; therefore, buckling of the canister shell does not occur during the 24-inch drop.

Stresses in the basket are calculated using classical hand calculations, as described in Section 3.7.2. Conservatively, an inertia load of 60g is applied in the axial direction. The stress evaluation of the basket is performed using the Level D allowable stresses according to ASME Code, Section III, Subsection NG. The stress evaluation results are presented in Section 3.7.2 for both the PWR and BWR baskets. The fuel baskets are shown to be structurally adequate for the 24-inch drop accident condition.

12.2.4.4 Corrective Actions

Although the concrete cask remains functional following this event and no immediate recovery actions are required, the TSC should be inspected and transferred to an undamaged concrete cask as soon as practicable. The damaged cask should be inspected and repaired as required prior to continued use. Prior to transferring the TSC from the damaged concrete cask, temperature-monitoring or inlet and outlet screen inspection frequencies should be evaluated for an increase based on the damaged cask's air flow path restrictions.

12.2.4.5 Radiological Impact

There are no radiological consequences for this accident.

12.2.5 Explosion

The analysis of a design-basis flood presented in Section 12.2.9 shows that the flood exerts a pressure of 22 psig on the TSC, and that MAGNASTOR experiences no adverse effects due to this pressure. The pressure of 22 psig is considered to bound any pressure due to an explosion occurring in the vicinity of the ISFSI.

12.2.5.1 Cause of Explosion

An explosion affecting MAGNASTOR may be caused by industrial accidents or the presence of explosive substances in the vicinity of the ISFSI. However, no flammable or explosive substances are stored or used at the storage facility. In addition, site administrative controls exclude explosive substances in the immediate vicinity of the ISFSI. Therefore, an explosion affecting MAGNASTOR is extremely unlikely. This accident is evaluated in order to provide a bounding pressure that could be used in the event that the potential effects of an explosion require consideration at a given site.

12.2.5.2 Analysis of Explosion

Pressure due to an explosion event is bounded by the pressure effects of a flood having a depth of 50 feet. The TSC shell is evaluated in Chapter 3 for the effects of the flood having a depth of 50 feet, and the results are summarized in Section 12.2.9.

There is no adverse consequence to the TSC as a result of the 22 psig pressure exerted by a design basis flood. This pressure conservatively bounds an explosion event.

12.2.5.3 Corrective Actions

In the unlikely event of a nearby explosion, inspection of the concrete casks is required to ensure that the air inlets and outlets are free of debris, and to ensure that any monitoring system and inlet and outlet screens are intact. No further recovery or corrective actions are required for this accident.

12.2.5.4 Radiological Impact

There are no radiological consequences for this accident.

12.2.6 Fire Accident

This section provides the results of the evaluation of the effects of a bounding condition hypothetical fire accident, although a fire accident is a very unlikely occurrence in the storage lifetime of MAGNASTOR. The evaluation demonstrates that for the hypothetical thermal accident (fire) event, the cask meets its storage performance requirements.

12.2.6.1 Cause of Fire

A fire may be caused by flammable material at the ISFSI or by transport equipment fuel. While it is possible that a transport vehicle could cause a fire while transferring a loaded storage cask at the ISFSI, this fire will likely be confined to the vehicle and will be rapidly extinguished by the persons performing the transfer operations or by the site fire crew. The maximum permissible quantity of fuel in the transport vehicle or prime mover is the only means by which fuel (maximum 50 gallons of flammable liquid) would be next to a cask, and potentially at, or above, the elevation of the surface on which the cask is supported.

The fuel carried by other onsite vehicles or by other equipment used for ISFSI operations and maintenance, such as air compressors or electrical generators, is considered not to be within the proximity of a loaded cask on the ISFSI pad. Site-specific analysis of fire hazards will evaluate the specific equipment used at the ISFSI and determine any additional controls required.

12.2.6.2 Detection of Fire

A fire in the vicinity of MAGNASTOR will be detected by observation of the fire or smoke.

12.2.6.3 Analysis of Fire

The detailed analysis of the fire event is provided in Chapter 4. The analysis uses a two-dimensional axisymmetric finite element model to perform a transient analysis for the

bounding configuration of PWR fuel. The initial condition of the analysis is based on the steady-state results for the normal condition of storage that correspond to an ambient temperature of 100°F with solar insolation, which envelopes the 76°F ambient used in Chapter 4. The fire condition is implemented by constraining the nodes at the inlet to be 1,475°F for 8 minutes, applied as a stepped boundary condition. At the end of the 8 minutes, the temperature of the node at the inlet is reset to the ambient temperature of 100°F. The maximum fuel cladding temperature for the fire accident is only 3°F higher than that for the normal condition of storage. The maximum temperature of the TSC shell increases to 512°F due to the fire condition - well below the accident condition allowable temperature of 800°F.

As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons, the temperature results for the fire accident condition are also bounded.

The limited duration of the fire and the large thermal capacitance of the concrete cask maintained the cask temperatures above 300°F to a region less than 10 inches above the top surface of the air inlets, which does not adversely affect the safe operation of the cask. Therefore, the operation of the concrete cask is not adversely affected by the fire accident event.

12.2.6.4 Corrective Actions

Immediately upon detection of the fire, appropriate actions should be taken by site personnel to extinguish the fire. The exterior surfaces of the concrete cask should then be visually inspected for general deterioration of the concrete, loss of shielding (spalling of concrete), exposed reinforcing bar, and surface discoloration that could affect heat rejection. This inspection will be the basis for the determination if any repair activities are necessary to maintain or return the concrete cask to its design basis configuration.

12.2.6.5 Radiological Impact

There are no significant radiological consequences for this accident. There may be local spalling of concrete during the fire event, which could lead to some minor reduction in shielding effectiveness and an insignificant increase in radiation dose rates on the cask surface.

12.2.7 Maximum Anticipated Heat Load (133°F Ambient Temperature)

This section evaluates MAGNASTOR response to storage operation at an ambient temperature of 133°F. The event is analyzed in accordance with the requirements of ANSI/ANS 57.9 to evaluate a credible worst-case thermal loading. A steady-state condition is considered in the thermal evaluation of the system for this accident event.

12.2.7.1 Cause of Maximum Anticipated Heat Load

This condition results from a weather event that causes the concrete cask to be subject to a 133°F ambient temperature with full insolation.

12.2.7.2 Detection of Maximum Anticipated Heat Load

Detection of the high ambient temperature condition will be by observation of ambient temperature.

12.2.7.3 Analysis of Maximum Anticipated Heat Load

Using the same methods and thermal models described in Section 12.1.1 for the off-normal events of severe ambient temperatures (106°F and -40°F), thermal evaluations are performed for the concrete cask and the TSC with its contents for this accident condition. The principal PWR and BWR cask component temperatures for this ambient condition and the allowables are summarized in Section 4.6.1. The calculated component temperatures are less than the allowable temperatures.

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

As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons, the temperature results for the maximum anticipated heat load event are also bounded.

Thermal stress evaluations for the concrete cask are presented in Section 12.1.1. The concrete temperature results obtained from the thermal analysis for this accident condition are applied to the structural model for stress calculation. The stresses are used in the loading combination (Table 2.3-1) for the concrete cask evaluation. The maximum stress, 22.0 ksi in the reinforcing steel, occurs in the vertical direction. The factor of safety is 2.45. The maximum compressive stress is 1.46 ksi in the concrete. The factor of safety is 1.82. The maximum tensile stress in the concrete is 0.13 ksi. The factor of safety is 1.62.

12.2.7.4 Corrective Actions

The high ambient temperature event is a natural phenomenon, and no recovery or corrective actions are required.

12.2.7.5 Radiological Impact

There are no radiological consequences for this accident.

12.2.8 Earthquake Event

This section provides the results of the evaluation of the response of the concrete cask to an earthquake imparting horizontal accelerations of 0.37g at the top surface of the concrete storage pad. This evaluation shows that the loaded or empty concrete cask does not tip over in this earthquake event. The vertical acceleration is defined as two-thirds of the horizontal acceleration in accordance with ASCE 4-86 [16].

12.2.8.1 Cause of the Earthquake Event

Earthquakes are natural phenomena to which the storage system might be subjected at any U.S. site. Earthquakes are detected by the ground motion and by seismic instrumentation onsite and offsite.

12.2.8.2 Earthquake Event Analysis

The evaluation of the concrete cask for the earthquake event is presented in Section 3.7.3. In the event of an earthquake, there exists a base shear force or overturning force due to the horizontal acceleration ground motion and a restoring force due to the vertical acceleration ground motion. To maximize the overturning moment, the dimensions for the longer PWR configuration, which has the highest center of gravity, are used in the evaluation. As shown in Section 3.7.3, the natural frequency of the structure is greater than 33 cycles per second (Hz).

The results of the tip-over evaluation show that the minimum ground acceleration that may cause a tip-over of a loaded concrete cask is 0.41g. ANSI/ANS-57.9 requires a factor of safety of 1.1 against tip-over; therefore the maximum allowable ground acceleration for the MAGNASTOR system is 0.37g. Since the 0.25g design basis earthquake ground acceleration for MAGNASTOR is less than 0.37g, the storage cask will not tip over. The analysis conservatively assumes that the TSC is in the maximum off-center position.

The analyses in Section 3.7.3 conservatively apply seismic loads of 0.5g in the horizontal direction and 0.5g in the vertical direction to evaluate concrete cask stress. These accelerations reflect a more rigorous seismic loading and, therefore, bound the design basis earthquake event. The maximum compressive stresses are calculated to be –147 psi at the outer surface and –114 psi at the inner surface, with no credit taken for the steel inner liner. These compressive stresses

are used in the load combinations for the concrete cask as also shown in Section 3.7.3, and the combined stress results meet stress criteria for the accident events.

12.2.8.3 Corrective Actions

Visual inspection of the array of concrete casks is required following an earthquake event. The positions of the concrete casks should be verified to ensure they meet the minimum center-to-center spacing requirements. The functions of the temperature-monitoring system, if used, should be verified.

12.2.8.4 Radiological Impact

There are no radiological consequences for this accident.

12.2.9 Flood

This section reports the results of the evaluation of a 50-foot depth of water having a velocity of 15 ft/second. This flood depth would fully submerge MAGNASTOR. Analysis demonstrates that the concrete cask does not overturn when exposed to the design basis rate of water flow. The hydrostatic pressure exerted by the 50-foot depth of water does not produce significant stress in the TSC. The design basis flood, therefore, does not adversely affect MAGNASTOR.

Small floods may lead to a blockage of concrete cask air inlets. Full blockage of air inlets is evaluated in Section 12.2.13.

12.2.9.1 Cause of Flood

The probability of a design-basis flood event at a given ISFSI site is unlikely because geographical features and environmental factors specific to that site are considered in the site selection process. Some possible sources of a flood are:

- 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)
- high tides produced by a hurricane
- tsunami (tidal wave) caused by an underwater earthquake or volcanic eruption

12.2.9.2 Analysis of Flood

The analysis of the flood event is presented in Section 3.7.3. The coefficient of friction between carbon steel and concrete used in the analysis is 0.35 [6,8].

Based on minimum cask weight and maximum projected area, the analysis shows that a water flow rate of 21.9 ft/second is required to overturn the concrete cask. This is greater than the design basis floodwater velocity of 15 ft/second. Therefore, cask tip-over does not occur. The analysis shows that a flood depth of 50 feet exerts a hydrostatic pressure on the TSC and the

concrete cask of 22 psi, which results in stresses in the TSC shell. The TSC structural evaluation for the increased external pressure due to flood conditions is presented in Section 3.7.1. The evaluation shows that there is no adverse consequence to the TSC as a result of the hydrostatic pressure due to the flood condition.

The concrete cask is a thick monolithic structure and is not affected by the hydrostatic pressure due to the design-basis flood. Compressive stresses in the concrete cask are included in Section 3.7.3. The maximum combined stresses for the load combination due to dead, live, thermal and flood loading are less than the allowable stress.

12.2.9.3 Corrective Actions

Inspection of the array of concrete casks is required following a flood. While the cask does not tip over, a potential exists for collection of debris or accumulation of silt at the base of the cask, which could clog or obstruct the air inlets or outlets. Blocked inlets require removal of the debris, silt, excessive standing water, etc. Verify proper operation of the temperature monitoring system, if used, as flood conditions may have impaired its operation.

12.2.9.4 Radiological Impact

There are no dose radiological consequences for this event.

12.2.10 Lightning Strike

This section reports the results of the evaluation of the impact of a lightning strike on the concrete cask. The evaluation shows that the cask does not experience adverse effects due to a lightning strike.

12.2.10.1 Cause of Lightning Strike

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

12.2.10.2 Detection of Lightning Strike

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

12.2.10.3 Analysis of the Lightning Strike Event

The analysis assumes that the lightning strikes the upper-most metal surface and proceeds through the concrete cask liner to the ground. The integrated maximum current for a lightning strike is a peak current of 250 kiloamps over a period of 260 microseconds, and a continuing current of up to 2 kiloamps for 2 seconds in the case of severe lightning discharges [9]. Due to the extremely short time for the duration, the lack of conductivity of the concrete, and its large thermal mass, the only area affected will be the surface of the concrete cask. Therefore, the increase in concrete cask bulk temperature attributed to Joulean heating is not significant.

12.2.10.4 Corrective Actions

The array of the concrete casks should be visually inspected for any damage following the lightning event and actions taken as appropriate.

12.2.10.5 Radiological Impact

There are no dose radiological consequences due to this event.

12.2.11 Tornado and Tornado-Driven Missiles

This section provides the results of the evaluation of the strength and stability of the concrete cask for a maximum tornado wind loading and for the impacts of tornado-generated missiles. The design basis tornado characteristics are selected in accordance with NRC Regulatory Guide 1.76 [10].

The evaluation demonstrates that the concrete cask remains stable in tornado wind loading in conjunction with impact from a high-energy tornado missile. The performance of the cask is not significantly affected by the tornado event.

12.2.11.1 Cause of Tornado and Tornado-Driven Missiles

A tornado is a random weather event. Probability of its occurrence is dependent upon the time of the year and geographical areas. Wind-loading and tornado-driven missiles have the potential for causing damage from pressure differential loading and from impact loading.

12.2.11.2 Detection of Tornado and Tornado-Driven Missiles

A tornado event is expected to be visually observed. Advance warning of a tornado and of tornado sightings may be received from the National Weather Service, local radio and television stations, local law enforcement personnel, and site personnel.

12.2.11.3 Analysis of Tornado and Tornado-Driven Missiles

The detailed analysis of the effects of tornado winds and tornado driven-missiles is provided in Section 3.7.3. Classical techniques are used to evaluate the loading conditions based on

NUREG-0800 [11]. The concrete cask stability is evaluated based on the design wind pressure calculated in accordance with ANSI/ASCE 7-93 [12] and using classical free body stability analysis methods. Local damage to the concrete shell is assessed using a formula developed in NSS 5-940.1 [13]. The local shear strength of the concrete shell is evaluated on the basis of ACI 349-85 [14], Section 12.12.2.1, without considering the reinforcing and the steel internal shell. The concrete shell shear capacity is also evaluated for missile loading using ACI 349-85, Section 12.7.

The cask configuration used in the analysis combines the height of the tallest (Group 2 PWR) cask with the weight and center of gravity of the lightest (Group 1 PWR) cask. This configuration bounds all other configurations for cask stability.

Tornado Wind Loading (Concrete Cask)

To evaluate concrete cask wind loading, the tornado wind velocity (360 mph) is transformed into an effective pressure applied to the cask using procedures delineated in ANSI/ASCE 7-93. From Section 3.7.3, comparison of the calculated pressure to the overturning moment shows that the minimum factor of safety against overturning is 2.44.

The calculated stresses in the concrete due to the tornado wind load are included in the load combination for the concrete evaluation. As shown in Section 3.7.3, the maximum combined stresses for the load combination of dead, live, thermal, and tornado winds are less than the allowable stress.

Tornado Missile Loading (Concrete Cask)

The concrete cask is designed to withstand the effects of impacts associated with postulated tornado-generated missiles identified in NUREG-0800, Section 3.5.1.4.III.4, Spectrum I missiles. These missiles consist of the following.

- massive high kinetic energy missile (4,000 lb automobile, with a frontal area of 20 square ft that deforms on impact)
- 280 lb, 8-inch-diameter armor piercing artillery shell
- one-inch diameter solid steel sphere

All of these missiles are assumed to impact in a manner that produces the maximum damage at a velocity of 126 mph (35% of the maximum tornado wind speed of 360 mph). The concrete cask has no openings except for the four outlets at the top and four inlets at the bottom. The upper openings are configured such that a one-inch diameter solid steel missile cannot directly impact the TSC. The TSC is protected from small missiles entering the lower inlets by a steel pedestal

(bottom plate). Therefore, a detailed analysis of the impact on the TSC of a 1-inch diameter steel missile is not required.

Concrete Shell Local Damage Prediction (Penetration Missile)

Local damage to the cask body is assessed using the NSS 5-940.1 [13] formula as the basis for predicting depth of penetration and minimum concrete thickness requirements to prevent scabbing. The minimum concrete shell thickness required to prevent scabbing is three times the predicted penetration depth of 5.82 inches based on the NSS 5-940.1 formula, or 17.46 inches. The concrete cask wall thickness includes a minimum of 25.25 inches of concrete, which is more than the thickness required to prevent damage due to the penetration missile.

Closure Plate Local Damage Prediction (Penetration Missile)

The concrete cask is closed with a 6.8-inch thick (CC1, CC2 and CC4) or 12.8-inch thick (CC3) concrete and steel lid that is bolted in place. The penetration thickness is evaluated using the methodology in Topical Report BC-TOP-9A [15], as presented in Section 3.7.3. The calculated penetration thickness is 0.65 inch. Taking credit for only the 0.75-inch steel plate, the factor of safety against penetration is 1.15. Therefore, the concrete cask closure can sustain penetration missile impact without the additional protection provided by the concrete.

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

The concrete cask is a free-standing structure. Therefore, the principal consideration in overall damage response is the potential of upsetting or overturning the cask as a result of the impact of a high-energy missile. Based on the detailed analysis presented in Section 3.7.3, it is concluded that the cask can sustain an impact from the defined massive high kinetic energy missile and does not overturn since the energy of the missile is less than that required to overturn the cask. The minimum factor of safety against overturning is 3.48.

Combined Tornado Wind and Missile Loading (High-Energy Missile)

The cask rotation due to the heavy missile impact is calculated in Section 3.7.3. This analysis compares the total energy available for overturning to the energy required for overturning and shows that the minimum factor of safety against overturning is 2.06.

Local Shear Strength Capacity of the Concrete Shell (High-Energy Missile)

The shear strength of the concrete at the top edge of the concrete shell due to a high-energy missile impact, based on ACI 349-85, is determined in Section 3.7.3. In the analysis, the force developed by the massive high kinetic energy missile having a frontal area of 20 sq ft, is evaluated using the methodology presented in Topical Report, BC-TOP-9A [15]. The required

missile contact area based on the concrete punching shear strength (neglecting reinforcing) is calculated as 1.8 sq ft for the governing CC3 configuration, which is much less than 20 sq feet. Thus, the concrete shell alone, based on the concrete conical punching strength and discounting the steel reinforcement and shell, has sufficient capacity to react to the high-energy missile impact force.

The effects of tornado winds and missiles are considered both separately and combined in accordance with NUREG-800, Section 3.3.2 II.3.d. For the case of tornado wind plus missile loading, the stability of the cask is assessed and found to be acceptable. Therefore, overturning of the cask under the combined effects of tornado winds, plus tornado-generated missiles, does not occur.

Tornado Effects on the TSC

The postulated tornado wind loading and missile impacts are not capable of overturning the cask, or penetrating the protective boundary established by the concrete cask. Consequently, there is no effect on the TSC. Stresses resulting from the tornado-induced decreased external pressure are bounded by the stresses due to the accident internal pressure discussed in Section 12.2.1.

12.2.11.4 Corrective Actions

A tornado is not expected to result in the need to take any corrective action other than an inspection of the concrete cask array at the ISFSI. This inspection would be directed at ensuring that air inlets and outlets had not become blocked by wind-blown debris and at checking for obvious (concrete) surface damage.

12.2.11.5 Radiological Impact

Damage to the concrete cask after a design-basis tornado accident will not result in radiation exposure at the controlled area boundary in excess of 5 rem to the whole body or any organ. The penetrating missile impact is estimated to reduce the concrete shielding thickness, locally at the point of impact, by approximately six inches. Cask surface dose rates are recalculated for the highest normal condition dose rate PWR and BWR payloads with a cask model that reduces the concrete radius by 6 inches over the entire cask height. This evaluation resulted in maximum localized surface dose rates of less than 600 mrem/hr for both the PWR and BWR configurations.

Because the PWR dose rates are based on a 40 kW cask heat load and a hybrid CC1/CC2 model, they bound the dose rates calculated at 35.5 kW for any of the three concrete casks.

As the potential high dose rate areas at the top of the concrete cask incorporate a 0.75-inch steel plate, which is not penetrated by missile impact loadings, the top axial post-accident dose rates are bounded by the previously presented post-accident radial dose rates.

12.2.12 Tip-Over of Concrete Cask

Tip-over of the concrete cask is a nonmechanistic, hypothetical accident that presents a bounding case for evaluation. There are no design basis accidents that result in the tip-over of the cask.

Functionally, the cask does not suffer significant adverse consequences due to this event. The concrete cask, TSC, and basket maintain performance requirements for design basis structural integrity, shielding, geometry, criticality control of the contents, and content confinement.

Results of the evaluation show that supplemental shielding at the bottom of the concrete cask may be necessary, following the tip-over, until the cask can be uprighted. The potential for increased dose rates is due to the design of the concrete cask, which provides significantly less shielding to the bottom, as these surfaces are not normally accessible or contributing to the off-site dose.

12.2.12.1 Cause of Cask Tip-Over

A tip-over of the cask is possible in an earthquake that significantly exceeds the design basis described in Section 12.2.8. No events related to the defined design bases will result in a cask tip-over.

12.2.12.2 Detection of Cask Tip-Over

The tipped-over configuration of the concrete cask will be obvious during site inspection following the initiating event.

12.2.12.3 Analysis of Cask Tip-Over

The detailed analyses of the tip-over event are presented in Section 3.7.3 for the bounding PWR and BWR configurations. This section presents a summary of the results of the analyses. For a tip-over event to occur, the center of gravity of the concrete cask and loaded TSC must be displaced beyond its outer radius, i.e., the point of rotation. When the center of gravity passes beyond the point of rotation, the potential energy of the cask and TSC is converted to kinetic energy as the cask and TSC rotate toward a horizontal orientation on the ISFSI pad. The subsequent motion of the cask is governed by the structural characteristics of the cask, the ISFSI pad and the underlying soil.

The objective of the evaluation of the response of the concrete cask in the tip-over event is to determine the maximum acceleration to be used in the structural evaluation of the loaded TSC and basket.

The MAGNASTOR system includes a concrete cask design, which holds canisters of two different heights, loaded with either PWR or BWR fuel baskets. The concrete cask is analyzed with conservative fuel heights, canister lengths, concrete pad thicknesses, and soil densities. To bound a range of ISFSI geometries, standard pad and oversized pad configurations are evaluated. The accelerations are evaluated at the inner surface of the cask liner, which physically corresponds to the interface of the liner and the loaded TSC nearest the plane of impact. The following table is a summary of accelerations for both pad configurations.

	Position Measured from the Bottom of the Concrete Cask (inches)		Acceleration (g)	
	PWR Group 1	PWR Group 2	PWR Group 1	PWR Group 2
Top of the TSC closure lid	197.9	214.6	32.8	35.70

The BWR finite element model and methodology is similar to that for the PWR configuration. The maximum accelerations at key locations of the concrete cask liner that are required in the evaluation of the loaded BWR TSC/basket model are listed as follows.

Location	Acceleration Standard Pad (g)	Acceleration Oversized Pad (g)
Top of Basket	26.4	26.6
Top of Canister Closure Lid	29.5	29.6

12.2.12.4 Analysis of TSC and Basket for Cask Tip-Over Event

The detailed structural evaluations for the TSC and basket are provided in Section 3.7.1 and Section 3.7.2, respectively. ANSYS finite element models are used to evaluate the side impact loading condition. A 40g inertial load for the canister and 35g for the baskets is conservatively considered. Comparison of maximum stress results to the allowable stress intensities shows that the TSC and fuel tubes are structurally adequate for the concrete cask tip-over condition and satisfy the stress criteria in accordance with the ASME Code, Section III, Division I, Subsection NB and NG, respectively.

For the TSC stress evaluation, the minimum factor of safety is calculated to be 1.24, which occurs in the TSC shell at the lower termination point of the concrete cask standoffs. The minimum factor of safety for the TSC closure weld, which includes a 0.8 weld quality factor, is 1.20. For the PWR and BWR basket stress evaluation, the following table is a summary of the worst case stress results and the factors of safety (FS) for both the PWR and BWR basket configurations.

Stress Location	P_m (ksi)			$P_m + P_b$ (ksi)		
	S_{int}	S_{allow}	FS	S_{int}	S_{allow}	FS
PWR Fuel Tube	41.2	46.8	1.14	44.8	60.2	1.34
PWR Corner Weldment	23.6	47.9	2.03	37.3	61.6	1.65
PWR Side Weldment	8.6	47.9	5.57	30.0	61.6	2.05
BWR Fuel Tube	44.40	47.35	1.07	50.46	60.88	1.21
BWR Corner Weldment	41.27	47.88	1.16	44.2	61.56	1.39
BWR Side Weldment	7.64	47.88	6.27	20.24	61.56	3.04

As the table shows, the minimum factors of safety are 1.14 and 1.07 for the PWR and BWR baskets, respectively. These results indicate that the basket structural integrity is maintained during the tip-over event.

Retainer strips are used to support and protect the neutron absorber in the fuel tubes. The retainer strip assembly consists of retainer and corner clips made of Type 304 stainless steel fixed to the fuel tube using welded posts and plug welds. For the tip-over, the PWR fuel tube neutron absorber is analyzed with the support of weld posts. The BWR fuel tube neutron absorber is analyzed without the support of weld posts. The neutron absorber, retainer strip, and corner clips are analyzed using LS-DYNA models and classical hand calculations. Results of the LS-DYNA analysis show the permanent deformation of the PWR neutron absorber is less than the thickness of the retainer strip, 0.015 inch. The BWR neutron remains elastic during impact. Additionally, the weld post, retainer, corner clips, and associated welds have a sufficient factor of safety. Therefore, the neutron absorber and retainer strip are acceptable in accordance with established criteria.

12.2.12.5 Corrective Actions

The most important recovery action required following a concrete cask tip-over is the shielding, or uprighting, of the cask to minimize the personnel exposure from the exposed bottom end. The uprighting operation will require a heavy lift capability and rigging expertise. The concrete cask must be returned to the vertical position by rotation around a convenient bottom edge using a method and rigging that controls the rotation to the vertical position.

The surface and top and bottom edges of the concrete cask are expected to exhibit cracking and possibly loss of concrete down to the layer of the external reinforcing bar cage. If only minor damage occurs, the concrete may be repairable by using grout. Otherwise, it may be necessary to remove the TSC, at the earliest possible time, for installation in an undamaged concrete cask.

If required, the storage pad should be repaired to preclude the intrusion of water that could cause further deterioration of the pad in freeze-thaw cycles.

12.2.12.6 Radiological Impact

There is a potential for an adverse radiological consequence in the hypothetical tip-over event, as the bottom end of the concrete cask and the TSC have significantly less shielding than in the radial direction. However, due to the small surface area exposed, relative to the size of the ISFSI, the dose rate at the site boundary will not exceed 5 rem/hour. Following a tip-over event, personnel access to the bottom area of the cask should be restricted, and supplemental shielding may be used until the concrete cask can be uprighted.

Damage to the edges or surface of the concrete cask may occur following a tip-over, which could result in a minor increase in localized dose rates.

12.2.13 Full Blockage of the Concrete Cask Air Inlets

This section presents the results of the evaluation of the concrete cask for the steady-state effects of full blockage of the air inlets at the normal ambient temperature (76°F). The analysis conservatively used 100°F. The evaluation estimates the duration of the event that would result in the fuel cladding, the fuel basket or the concrete cask components reaching their design basis limiting temperatures (see Chapter 4 for the allowable temperatures for accident conditions), or the TSC reaching its accident internal pressure limit. The evaluation demonstrates that there are no adverse consequences due to this accident, provided that blockage of the concrete cask air inlets is cleared within 58 hours.

12.2.13.1 Cause of Full Blockage

The likely cause of complete cask air inlet blockage is the covering of the base of the cask with snow, water, or earth in a catastrophic event that is significantly beyond the design basis earthquake or a landslide. This hypothetical event is a bounding accident and is not considered credible.

12.2.13.2 Detection of Full Blockage

Blockage of the cask air inlets will be visually detected during the general site inspection following an earthquake, landslide, or other events with a potential for such blockage. In addition, the cask inlets and outlets will be visually inspected to verify their unblocked condition, or the concrete temperature differential measured every 24 hours, limiting the potential for a full blockage event to go undetected.

12.2.13.3 Analysis of Full Blockage

The evaluation of this event is presented in Section 4.6.3. The evaluation assumes initial normal storage conditions, with the sudden loss of convective cooling of the TSC in the concrete cask (simulating the full blockage of the air inlets and outlets). The loss of convective cooling results in the fairly rapid and sustained heat-up of the TSC and the concrete cask. Transient analysis is performed using the two-dimensional concrete cask and TSC thermal model. The spent fuel cladding, fuel basket and concrete cask component temperatures do not reach their accident condition limits for a time period of approximately 72 hours after initiation of the event. The TSC internal pressure will reach the analyzed maximum pressure in approximately 58 hours after a complete blockage occurs. The calculation of the maximum TSC internal pressure considers a helium temperature of 677°F and 100% failure of the fuel rods. Therefore, at least two of the air inlets are required to be cleared of blockage within 58 hours of the initiation of the event.

As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons, the temperature results for the full blockage of the concrete cask air inlets event are also bounded.

12.2.13.4 Corrective Actions

The obstruction(s) blocking two of the air inlets must be removed within 58 hours, and all blockage should be removed at the earliest possible date. The nature of the obstruction may indicate that other actions are required to prevent recurrence of the blockage.

12.2.13.5 Radiological Impact

There are no significant radiological consequences for this event, as the concrete cask retains its shielding performance. Dose to personnel may result from opening of the concrete cask, if access is required to clear the inlets of debris. The higher dose rates at the air inlets (448 mrem/hr for a 37 kW payload) will result in an increase in operator dose as a result of clearing the inlets. If it is assumed that a worker kneeling with his hands on the inlets requires 15 minutes to clear each inlet, the estimated extremity dose is a total of 448 mrem for clearing four air inlets. The whole body dose will be slightly less. In addition, some dose will be incurred clearing debris away from the concrete cask body. This dose is estimated at less than 50 mrem per cask, assuming one hour is spent near each concrete cask's exterior surface.

Because the PWR dose rates are based on a 37 kW cask heat load and a hybrid CC1/CC2 model, they bound the dose rates calculated at 35.5 kW for any of the three concrete casks.

12.3 References

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Chapter 13
Operating Controls and Limits

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13 OPERATING CONTROLS AND LIMITS

This chapter identifies operating controls and limits, technical parameters and surveillance requirements imposed to ensure the safe operation of the MAGNASTOR® SYSTEM.

Appendix A includes the Technical Specifications for the MAGNASTOR SYSTEM.

- Use and Application
- Limiting Condition for Operation (LCO) Applicability
- Surveillance Requirement (SR) Applicability
- Design Features
- Administrative Controls and Programs

Appendix B presents the Approved Contents for the MAGNASTOR SYSTEM.

Appendix C defines the Technical Specifications Bases for the MAGNASTOR SYSTEM.

APPENDIX A

TECHNICAL SPECIFICATIONS FOR THE MAGNASTOR SYSTEM

The Technical Specifications for the MAGNASTOR SYSTEM, including the Use and Application, Limiting Condition for Operation (LCO) Applicability, Surveillance Requirement (SR) Applicability, Design Features, and Administrative Controls and Programs, are incorporated in Appendix A of Certificate of Compliance No. 1031.

APPENDIX B

APPROVED CONTENTS
FOR THE MAGNASTOR SYSTEM

The MAGNASTOR SYSTEM Approved Contents are incorporated in Appendix B of Certificate of Compliance No. 1031.

Appendix C
Technical Specification Bases for the MAGNASTOR® SYSTEM

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1.0 INTRODUCTION

This Appendix presents the design or operational condition, or regulatory requirement, which establishes the bases for the Technical Specifications provided in Appendix A and the approved contents provided in Appendix B.

The section and paragraph numbering used in this Appendix is consistent with the numbering used in Appendix A, Technical Specifications for the MAGNASTOR SYSTEM, and Appendix B, Approved Contents for the MAGNASTOR SYSTEM.

2.0 APPROVED CONTENTS

2.1 Fuel Specifications and Loading Conditions

BASES

BACKGROUND	The system is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR Basket Assembly or up to 87 undamaged BWR fuel assemblies in the 87 BWR Basket Assembly. The system is also designed to store up to 4 damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies including 4 DFC locations. DFCs may be placed in up to 4 of the DRC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR FUEL DEBRIS equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF basket assembly. The MAGNASTOR SYSTEM design requires specifications for the spent fuel to be stored, such as the type of spent fuel, minimum and maximum allowable enrichment prior to irradiation, maximum burnup, minimum acceptable post-irradiation cooling time prior to storage, maximum decay heat, and condition of the SPENT NUCLEAR FUEL (SNF) assemblies (e.g., UNDAMAGED FUEL; DAMAGED FUEL, etc.). Other important limitations are the dimensions and weight of the SNF assemblies. The approved contents, which can be loaded into the MAGNASTOR SYSTEM, are specified in Section 2.0 of Appendix B. Specific limitations for the MAGNASTOR SYSTEM are specified in Tables B2-1 through B2-24 of Appendix B. These limitations support the assumptions and inputs used in the thermal, structural, shielding, and criticality evaluations performed for the MAGNASTOR SYSTEM.
APPLICABLE SAFETY ANALYSES	To ensure that the closure lid is not placed on a TSC containing an unauthorized SNF assembly, facility procedures require verification of the loaded fuel assemblies to ensure that the correct SNF assemblies have been loaded in the TSC.

(continued)

BASES (continued)

APPROVED CONTENTS	2.1.1 Tables B2-1 and B2-9 in Appendix B define the specific fuel assembly characteristics for the PWR and BWR fuel assemblies authorized for loading into the MAGNASTOR SYSTEM. These fuel assembly characteristics include parameters such as cladding material, minimum and maximum enrichment, decay heat generation, post-irradiation cooling time, burnup, and fuel assembly length, width, and weight. The fuel assembly and nonfuel assembly hardware characteristic limits of Tables B2-2 through B2-8 and Tables B2-10 through B2-14 in Appendix B must be met to ensure that the thermal, structural, shielding, and criticality analyses supporting the MAGNASTOR SYSTEM Safety Analysis Report are bounding. 2.1.2 Approved Contents section B2.0 in Appendix B authorizes the loading of up to four DAMAGED FUEL CANS (DRCS) into the DF Basket Assembly in the MAGNASTOR System. Table B2-1(II.) describes the Allowable DF Basket Assembly and DFC contents.
APPROVED CONTENT LIMITS AND VIOLATIONS	If any Approved Contents limits of Section 2.0 in Appendix B are violated, the limitations on SNF assemblies to be loaded are not met. Action must be taken to place the affected SNF assembly(ies) in a safe condition. This safe condition may be established by returning the affected SNF assembly(ies) to the spent fuel pool. However, it is acceptable for the affected fuel assemblies to temporarily remain in the MAGNASTOR SYSTEM, in a wet or dry condition, if that is determined to be a safe condition. NRC Operations Center notification of the Approved Contents limit violation is required within 24 hours. A written report on the violation must be submitted to the NRC within 60 days. This notification and written report are independent of any reports and notification that may be required by 10 CFR 72.216.
REFERENCES	FSAR, Sections 2.1 and Chapter 6.

3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs	LCO 3.0.1, 3.0.2 and 3.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.
LCO 3.0.1	LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the system is in the specific conditions of the Applicability statement of each Specification).
LCO 3.0.2	LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS condition is applicable from the point in time that an ACTIONS condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that: a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and, b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified. There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. Whether stated as a Required Action or not, correction of the entered condition is an action that may always be considered upon entering ACTIONS. The second type of Required Action specifies the remedial measures that permit continued operation that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation. Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications. The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

(continued)

BASES (continued)

LCO 3.0.3	This specification is not applicable to the MAGNASTOR SYSTEM.
LCO 3.0.4	LCO 3.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the facility in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following conditions exist: a. Facility conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and, b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in being required to exit the Applicability desired to be entered to comply with the Required Actions. Compliance with Required Actions that permit continued operation of the system for an unlimited period of time in a specified condition provides an acceptable level of safety for continued operation. That is without regard to the status of the system. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability. The provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS, or that are related to the unloading of a TSC. Exceptions to LCO 3.0.4 are stated in the individual Specifications. Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.
LCO 3.0.5	This specification is not applicable to the MAGNASTOR SYSTEM, as there is no provision for a return to service under administrative control for testing.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs	SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.
SR 3.0.1	SR 3.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify that systems and components meet the LCO and variables are within specified limits. Failure to complete Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO. Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when: a. The systems or components are known to not meet the LCO, although still meeting the SRs; and, b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances. Surveillances do not have to be performed when the system is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified. Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning the equipment to service. Upon completion of maintenance, appropriate post-maintenance testing is required. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2. Post-maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary system parameters not having been established. In these situations, the equipment may be considered to meet the LCO, provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function. This will allow operations to proceed to a specified condition where other necessary post-maintenance tests can be completed.

(continued)

BASES (continued)

SR 3.0.2	SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per ..." interval. SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers system conditions that may be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities). The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications as a Note in the Frequency stating, "SR 3.0.2 is not applicable." As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per ..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the affected equipment in an alternative manner. The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals or periodic Completion Time intervals beyond those specified.
SR 3.0.3	SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

(continued)

SR 3.0.3 (continued)

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of Surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance.

The basis for this delay period includes consideration of system conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements. When Surveillance with a Frequency based not on time intervals, but upon specified system conditions, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by the Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility, which is not intended to be used as an operational convenience to extend Surveillance intervals.

If Surveillance is not complete within the allowed delay period, then the equipment is considered to not meet the LCO, or the variable is considered outside the specified limits, and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If Surveillance is failed within the delay period, then the equipment does not meet the LCO, or the variable is outside the specified limits, and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance.

Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4

SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry into specified conditions in the Applicability for which these systems and components ensure safe operation of the system.

(continued)

SR 3.0.4 (continued)

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified condition. When a system, subsystem, division, component, device, or variable is outside the specified limits, the associated SR(s) are not required to be performed per SR 3.0.1, which states that Surveillances do not have to be performed on equipment that has been determined to not meet the LCO. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

The provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that is required to comply with ACTIONS.

In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that is related to the unloading of the MAGNASTOR SYSTEM.

The precise requirements of performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met.

Alternately, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further, discussion of the specific formats of SRs annotation is found in Technical Specification Section 1.4, Frequency.

3.1 MAGNASTOR SYSTEM Integrity

3.1.1 Transportable Storage Canister (TSC)

BASES

BACKGROUND

A TRANSFER CASK with an empty TSC is placed into the spent fuel pool and loaded with SNF assemblies and other approved contents meeting the requirements of Appendix B, Approved Contents. A closure lid is then placed on the TSC, and the TRANSFER CASK containing the TSC is removed from the pool and placed in the cask preparation area or prepared in a partially submerged condition. Cooling water flow to the TRANSFER CASK annulus shall be provided to assist in limiting the MAGNASTOR SYSTEM component temperatures during TSC preparation and closure activities. The closure lid is welded to the TSC shell and the weld is examined by dye penetrant examination methods (i.e., root, mid-plane and final surface). A hydrostatic pressure test of the weld is performed at a minimum of 125% of the TSC maximum normal operating pressure. The TSC cavity water is removed by pumping and/or blow down while backfilling the cavity with helium, and the free volume of the TSC is determined by measuring the volume of water removed.

TSC cavity moisture removal is performed using vacuum drying methods following draining of the bulk cavity water. TSC cavity dryness is confirmed by ensuring that any pressure rise in the isolated TSC cavity with the vacuum pump turned off and isolated is less than the acceptance criteria.

Upon verification of the dryness of the TSC cavity following vacuum drying operations, the TSC is further evacuated using the vacuum pumping system to a vacuum pressure that excludes significant quantity of oxidizing gases (i.e., < 1 mole). The TSC cavity is then backfilled with high purity helium (≥ 99.995% purity) until the required helium mass density is established. Drying and backfilling the TSC cavity with helium provides the capability to remove the contents decay heat by convective and conductive heat transfer and minimizes any oxidizing gases to below a significant value. Establishment of the inert helium atmosphere protects the fuel cladding from degradation. The backfilling and resulting pressurization of the cavity with helium to an established helium mass density will provide the required helium mass and pressure to ensure the operation of the heat transfer design of the MAGNASTOR SYSTEM, and will eliminate the possibility of air in-leakage over the storage period.

The closure ring is installed in the closure lid-to-TSC shell weld groove, welded to the shell and to the closure lid, and the final weld surface examined by dye penetrant methods. The inner port covers of the vent and drain openings are installed, welded and the final weld surface examined by final surface dye penetrant methods. The vent and drain inner port covers are then helium leak tested to verify the absence of helium leakage to a minimum sensitivity of 1.0×10^{-7} cm^3 / sec (helium).

(continued)

BASES (continued)

BACKGROUND (cont.)

The outer port covers are then installed, welded and the final weld surface examined by dye penetrant methods.

The TSC weldment is designed, analyzed, and tested to meet the leaktight criteria of ANSI N14.5. In addition, the closure lid-to-TSC shell weld is hydrostatically pressure tested and examined by multi-pass dye penetrant examination following fuel loading. The closure lid, closure ring and inner and outer port covers provide redundant closures to ensure confinement boundary integrity. Therefore, leakage of radioactive materials from the TSC and loss of helium and possible in-leakage of air are not considered credible.

APPLICABLE SAFETY ANALYSIS

The confinement of the radioactive materials contents in the TSC is ensured by the multiple confinement boundaries, including the fuel pellet matrix, the fuel rod cladding, and the pressure boundary provided by the TSC. Long-term integrity of the spent fuel contents is ensured by the inert helium atmosphere of the TSC, which is accomplished by the removal of free water, elimination of residual oxidizing gases, and backfilling with a measured mass of high purity helium. The pressurized helium atmosphere in the TSC ensures that the MAGNASTOR SYSTEM convective heat transfer thermal design will perform as analyzed. The measurement of the helium backfill mass ensures that the TSC internal pressure does not exceed the TSC's design pressure under design storage operating conditions.

LCO

A dry pressurized, helium filled and sealed TSC establishes the inert environment that will ensure the integrity of the fuel cladding and proper performance of the MAGNASTOR SYSTEM thermal design, while precluding air in-leakage and out-leakage of radioactive materials.

The Section 1 Tables of the LCO specify the limits for both PWR and BWR SNF contents (based on the decay heat load of the TSC contents) for Maximum Vacuum Drying Times; Minimum Helium Backfill Time (i.e., minimum time period the TSC is allowed to soak with annulus cooling system in operation following completion of the helium mass backfill prior to the initiation of the TSC transfer to the CONCRETE CASK in the TRANSFER CASK); and the Maximum TSC Transfer Time available to complete the transfer of the TSC to the CONCRETE CASK.

The Section 2 Table in the LCO provides the Maximum Drying Time Limit for the second and subsequent vacuum drying cycles following a minimum of 24 hours of either in-pool cooling or annulus circulating water system (ACWS) cooling with the TSC backfilled to 75 psig (+10, -0) with high purity helium, if the TSC dryness criteria were not met on the first vacuum drying cycle (this Table is not applicable to PWR contents with decay heat loads of ≤ 20 kW, which has unlimited vacuum drying time, no minimum helium backfill time and 600-hour TSC transfer time).

(continued)

BASES (continued)

LCO (cont.)

The Section 2 Table in the LCO provides the Maximum Drying Time Limit for the second and subsequent vacuum drying cycles following a minimum of 24 hours of either in-pool cooling or annulus circulating water system (ACWS) cooling with the TSC backfilled to 75 psig (+10, -0) with high purity helium, if the TSC dryness criteria were not met on the first vacuum drying cycle.

A Note in Section 2 refers the Licensee to use Table 1.B and 1.D following the additional drying cycle(s) to determine the Minimum Helium Backfill Time and Maximum TSC Transfer Time applicable for the second TSC transfer cycle. Note that the helium backfill (soak) and transfer times in Tables 1.B and 1.D would also be applicable for a second cycle of TSC transfer to the CONCRETE CASK if the first transfer cycle was not completed in the allowed time. The minimum 24-hour helium soak would lower and reset the TSC and SNF content temperatures to a value corresponding to the temperatures used in the determination of the Table 1.B and 1.D values for maximum transfer time limits.

Each temperature transient, either resulting from additional water cooling and vacuum drying cycles, or from additional helium soak and TSC transfer cycles, would need to be accounted for in the 10 allowable thermal transients for SNF assemblies with burnups exceeding 45,000 MWd/MTU.

APPLICABILITY

The sealed TSC with a dry measured helium mass cavity atmosphere is required to be established prior to TRANSPORT OPERATIONS to ensure integrity of the fuel contents and the effectiveness of the heat dissipation capability during LOADING OPERATIONS and STORAGE OPERATIONS.

ACTIONS

A note has been added to the ACTIONS, which states that, for this LCO, separate Condition entry is allowed for each TSC. This is acceptable as the Required Actions for each Condition provide appropriate compensatory measures for each TSC not meeting the LCO. Subsequent TSCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the cavity vacuum drying pressure with the vacuum pump isolated and turned off is not met prior to TRANSPORT OPERATIONS, an engineering evaluation is necessary to determine the potential quantity of moisture left in the TSC. Since moisture remaining in the cavity during TRANSPORT and STORAGE OPERATIONS may represent a long-term degradation issue, immediate action is not required. The Completion Time is sufficient to complete an engineering evaluation of the safety significance of the Condition.

(continued)

BASES (continued)

ACTIONS (cont.)

AND

A.2

Upon determination of the mass of water potentially contained in the TSC, a corrective action plan shall be developed and actions initiated, as required, in a timely manner to return the TSC to an analyzed condition.

B.1

If a determination is made that the helium backfill mass or purity requirements are not met prior to TRANSPORT OPERATIONS, an engineering evaluation shall be performed to establish the mass of helium in the TSC. As high or low helium mass values could result in TSC over-pressurization or reduced effectiveness of the TSC heat rejection capability, respectively, the engineering evaluation shall be performed in a timely manner. The Completion Time is sufficient to complete an engineering evaluation of the safety significance of the Condition.

AND

B.2

When the mass of helium in the TSC is determined, a corrective action plan shall be developed and actions implemented, as required, in a timely manner to return the TSC to an analyzed condition.

C.1

If the TSC cannot be returned to an analyzed safe condition, the TSC contents are required to be placed in a safe condition in the spent fuel pool. The Completion Time is reasonable based on the time required to plan, train and perform UNLOADING OPERATIONS in an orderly manner.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS	SR 3.1.1.1, and SR 3.1.1.2 The long-term integrity of the TSC and stored contents is dependent on a dry and pressurized helium cavity environment. The dryness of the TSC cavity is demonstrated by evacuation by a vacuum pump to a low vacuum and monitoring the rise in pressure over a specified period with the vacuum pump isolated and turned off. The establishment of the required helium backfill mass and corresponding operating pressure at operating temperature will ensure the effectiveness of the TSC capability to reject the contents decay heat to the fuel basket and TSC structure. The decay heat will subsequently be rejected by the cooling air flows provided by the CONCRETE CASK during STORAGE OPERATIONS. These two surveillances shall be performed once prior to TRANSPORT OPERATIONS. Successful completion will ensure that the appropriate conditions have been established for long-term storage in compliance with the analyzed design bases.
REFERENCES	1. FSAR Sections 4.4 and 9.1.

3.1 MAGNASTOR SYSTEM Integrity

3.1.2 CONCRETE CASK Heat Removal System

BASES

BACKGROUND

The heat removal system for the CONCRETE CASK containing a loaded TSC is a passive, convective air-cooled heat transfer system that ensures that the decay heat emitted from the TSC is transferred to the environment by the upward flow of air through the CONCRETE CASK annulus. During STORAGE OPERATIONS, ambient air is drawn into the CONCRETE CASK annulus through the four air inlets located at the base of the CONCRETE CASK. The heat from the TSC surfaces is transferred to the air flow via natural circulation. The buoyancy of the heated air creates a chimney effect forcing the heated air upward and drawing additional ambient air into the annulus through the air inlets. The heated air flows back to the ambient environment through the four air outlets located in the CONCRETE CASK lid.

APPLICABLE SAFETY ANALYSIS

The thermal analyses of the MAGNASTOR SYSTEM take credit for the decay heat from the TSC contents being transferred to the ambient environment surrounding the CONCRETE CASK. Transfer of heat from the TSC contents ensures that the fuel cladding and TSC component temperatures do not exceed established limits. During normal STORAGE OPERATIONS, the four air inlets and four air outlets are unobstructed and full natural convection heat transfer occurs (i.e., maximum heat transfer for a given ambient temperature and decay heat load). Vent obstruction can be any type of accumulation within the vent that restricts airflow.

Analyses have been performed for two scenarios corresponding to the complete obstruction of what is equivalent to two and four air inlets. Blockage of the equivalent area of two air inlets reduces the convective air flow through the CONCRETE CASK/TSC annulus and decreases the heat transfer from the TSC surfaces to the ambient environment. Under this off-normal event, no CONCRETE CASK or TSC components or fuel cladding exceed established short-term temperature limits, and the TSC internal pressure does not exceed the analyzed maximum pressure.

The complete blockage of all four air inlets effectively stops the transfer of the decay heat from the TSC due to the elimination of the convective air flow. The TSC will continue to radiate heat to the liner of the CONCRETE CASK. Upon loss of air cooling, the MAGNASTOR SYSTEM component temperatures will increase toward their respective established accident temperature limits. The spent fuel cladding and fuel basket and CONCRETE CASK structural component temperatures do not reach their accident limits for a time period of approximately 72

(continued)

BASES (continued)

APPLICABLE SAFETY ANALYSIS (cont.)

hours. The internal pressure in the TSC cavity will not reach the analyzed maximum pressure condition for approximately 58 hours after a complete blockage condition occurs.

Therefore, following the identification of a reduction in the heat dissipation capabilities of the CONCRETE CASK by the temperature-monitoring program or the visual inspection of the air inlet and outlet screens, actions are to be taken immediately to restore at least partial convective airflow (i.e., a minimum area of what is equivalent of two air inlet and all four air outlets are unobstructed). Once partial airflow is established, the fuel cladding and the TSC and component temperatures will not exceed normal STORAGE OPERATIONS limits. Efforts to reestablish full OPERABLE status for the CONCRETE CASK can then be undertaken in a controlled manner. If necessary, the TSC may be transferred into the TRANSFER CASK to permit full access to the base of the CONCRETE CASK for repairs with minimal radiological effects.

LCO

The CONCRETE CASK heat removal system is to be verified to be OPERABLE to preserve the applicability of the design bases thermal analyses. The continued operability of the heat removal system ensures that the decay heat generated by the TSC contents is transferred to the ambient environment to maintain the fuel cladding and CONCRETE CASK and TSC temperatures within established limits.

APPLICABILITY

The LCO is applicable during STORAGE OPERATIONS. Once the CONCRETE CASK lid is installed following transfer of a loaded TSC, the heat removal system is required to be OPERABLE to ensure adequate heat transfer.

ACTIONS

A Note has been added to the Actions that states for this LCO, separate condition entry is allowed for each CONCRETE CASK. This is acceptable, as the Required Actions for each Condition provide appropriate compensatory measures for each CONCRETE CASK not meeting the LCO. Other CONCRETE CASKs that do not meet the LCO are addressed by independent Condition entry and application of the associated Required Actions.

A.1

If the CONCRETE CASK heat removal system has been determined to be inoperable, full operability is to be restored, or at a minimum, adequate heat removal must be restored or verified to prevent exceeding fuel cladding and critical component temperatures for accident events. Adequate heat removal capability is ensured by

(continued)

BASES (continued)

ACTIONS (cont.)

having at least the equivalent area of two CONCRETE CASK air inlets and all four air outlets unobstructed, which is consistent with the analyzed off-normal event. Alternatively, adequate heat removal can be verified by measuring the exit air temperature from the four air outlets and determining the temperature rise over the ISFSI ambient air temperature.

This verification must be completed immediately where "immediately" is defined as "the required action should be pursued without delay in a controlled manner". Restoration of adequate heat removal must be completed within 58 hours of the last operability determination to ensure the TSC internal pressure limit is not exceeded per the analysis in FSAR Section 12.2.13.3, which is the most restrictive time limit.

Thermal analyses of a fully blocked CONCRETE CASK air inlet condition show that fuel cladding and critical basket material accident temperatures and internal pressure limits could be exceeded over time. As a result, requiring immediate verification, or restoration, of adequate heat removal capability will ensure that accident temperature and pressure limits are not exceeded. Once adequate heat removal has been reestablished or verified, the additional actions required to restore the CONCRETE CASK to OPERABLE status can be completed under A.2.

AND

A.2

In addition to Required Action A.1, efforts are required to be continued to restore the CONCRETE CASK heat removal system to OPERABLE.

As long as adequate heat removal capability has been verified to exist, restoring the CONCRETE CASK heat removal system to fully OPERABLE is not an immediate concern. Therefore, restoring it to OPERABLE within 30 days is a reasonable Completion Time.

SURVEILLANCE REQUIREMENTS

SR 3.1.2.1

The long-term integrity of the stored spent fuel is dependent on the continuing ability of the CONCRETE CASK to reject decay heat from the TSC to the ambient environment. Routine verification that the four air inlets and four air outlets are unobstructed and intact ensures that convective airflow through the CONCRETE CASK/TSC annulus is occurring and performing effective heat transfer. Alternatively, the Surveillance Requirement can be fulfilled by measuring the exit air temperature from the four air outlets and determining the temperature rise over the ISFSI ambient air temperature. As long as the temperature increase of the convective airflow is less than the surveillance limits, adequate heat transfer is occurring to maintain

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS (continued)	SR 3.1.2.1 (continued) CONCRETE CASK, TSC, and spent fuel cladding temperatures below long-term limits. If partial or complete blockage of the CONCRETE CASK air inlets occurs, the heat rejection system will be rendered inoperable and this LCO is not met. Immediate corrective actions are to be taken to remove the obstructions from at least two air inlets and all four air outlets, or equivalent area, to restore partial air flow, and additional corrective actions are to be taken to remove all air inlet and outlet obstructions and return the CONCRETE CASK to a fully OPERABLE status. The Frequency of 24 hours is reasonable based on the time necessary for the spent fuel cladding and CONCRETE CASK and TSC component temperatures to reach their short-term temperature limits and the internal pressure to increase to the accident condition pressure limit. The Frequency will allow appropriate corrective actions to be completed in a timely manner.
REFERENCES	FSAR Section 4.4.

3.2 MAGNASTOR SYSTEM Criticality Control for PWR Fuel

3.2.1 Dissolved Boron Concentration

BASES

BACKGROUND	A TRANSFER CASK with an empty TSC is placed into a spent fuel pool and loaded with fuel assemblies and associated NONFUEL HARDWARE meeting the requirements of Appendix B, Approved Contents for the MAGNASTOR SYSTEM. After loading the TSC, a closure lid is installed on the TSC, the closure lid is welded to the TSC shell, and the water in the cavity is drained. For those TSCs to be loaded with PWR fuel assemblies, credit is taken in the criticality analyses for boron dissolved in the water within the TSC cavity during the loading and TSC preparation up through the draining of the cavity water. To preserve the analyses bases, the dissolved boron concentration of the TSC cavity water must be verified to meet specified limits when there are fuel assemblies and water in the TSC. This may occur during LOADING OPERATIONS and UNLOADING OPERATIONS.
APPLICABLE SAFETY ANALYSIS	The spent fuel stored in the MAGNASTOR SYSTEM is required to remain subcritical ($k_{eff} < 0.95$) under all conditions of storage. The MAGNASTOR SYSTEM is analyzed to safely store a wide variety of spent fuel assembly types with differing initial enrichments and associated nonfuel hardware. For PWR SNF assemblies to be loaded in the TSCs, credit has been taken in the criticality analyses for neutron poison in the form of soluble boron in the water in the TSC cavity. Compliance with this LCO preserves the assumptions made in the criticality analyses and ensures that the stored PWR SNF assemblies will remain subcritical with a $k_{eff} < 0.95$ while water is in the TSC.
LCO	Compliance with this LCO ensures that the stored PWR SNF will remain subcritical with a $k_{eff} < 0.95$ while water is in the TSC. The LCO provides the minimum concentration of soluble boron required to be in the TSC cavity water based on the type, initial enrichment, and contained nonfuel hardware of the PWR fuel assembly. All UNDAMAGED SNF ASSEMBLIES loaded into the TSC are limited by analysis to the maximum enrichments of 5.0 wt% ^{235}U.

(continued)

BASES (continued)

APPLICABILITY	The dissolved boron concentration LCO is applicable whenever a TSC has at least one PWR SNF assembly in a storage location and water in the TSC.
ACTIONS	A Note has been added to the Actions that states for this LCO, separate condition entry is allowed for each TSC. This is acceptable since the Required Actions for each condition provide appropriate compensatory measures for each TSC not meeting the LCO. Subsequent TSCs being loaded or unloaded will be controlled by subsequent condition entry and application of associated Required Actions. A.1 and A.2 Continuation of LOADING OPERATIONS, UNLOADING OPERATIONS or positive reactivity additions (including actions to reduce dissolved boron concentration) is contingent upon maintaining the TSC in compliance with the LCO. Determination of a measurement of soluble boron below the required concentration for the limiting SNF assembly parameters, LOADING OPERATIONS, UNLOADING OPERATIONS, and any positive reactivity additions are to be immediately suspended and placed in a safe condition. <u>AND</u> A.3 Immediate actions are to be taken to restore the dissolved boron concentration in the TSC cavity water to within the established limits. One method of complying with the action is to initiate direct boration of the TSC water immediately in a controlled manner. Alternatively, the direct boration of the spent fuel pool water can be performed. Once initiated, the addition of boron to the TSC or spent fuel pool are to continue until the required soluble boron concentration is restored. The time to complete restoration will depend on the amount of boron required to be added and the capacity of the available boron addition equipment.
SURVEILLANCE REQUIREMENTS	SR 3.2.1.1 When the TSC is placed in the spent fuel pool for loading of PWR SNF assemblies, the dissolved boron concentration in the TSC water must be verified by two independent measurements to be within the applicable limit within four hours prior to entering the applicability of the LCO. For LOADING OPERATIONS, this means within four hours prior to loading any approved content into the TSC.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS (cont.)	The use of two independent measurements provides assurance that the dissolved boron concentration limit is met and maintained. The period of four hours prior to fuel loading for the surveillance frequency is reasonable based on the potential for boron dilution to occur prior to the start of loading without limiting operational flexibility. Following the verification of the boron concentration, there is no credible unplanned event that would change the concentration. During the period between the completion of boron concentration verification and commencement of loading operations, possible methods to change the boron concentration will be administratively controlled. If actions are taken that could result in a reduction in the boron concentration within the four-hour period, the surveillance will be performed again. While the TSC is in the spent fuel pool or while water is in the TSC, the boron concentration will be verified every 24 hours. Facility procedures will specifically ensure that any water to be added to, or recirculated through, the TSC will have a boron concentration greater than or equal to the minimum boron concentration specified by the LCO. For UNLOADING OPERATIONS, the dissolved boron concentration in water to be used to reflood a TSC containing PWR SNF will be verified within four hours of initiating TSC reflooding operations. This ensures that when the LCO is applicable, the LCO will be met. The boron concentration shall be verified every 24 hours until all PWR SNF assemblies are removed from the TSC during wet unloading operations.
REFERENCES	FSAR Chapter 6

3.3 MAGNASTOR SYSTEM Radiation Protection

3.3.1 CONCRETE CASK Maximum Surface Dose Rates

BASES

BACKGROUND	The regulations governing the operation of an ISFSI set limits on the control of occupational radiation exposure and radiation doses to the general public (Ref. 1). Radiation doses to the public are limited for both normal and accident conditions in accordance with 10 CFR 72 and 10 CFR 20. Occupational radiation exposure should be kept as low as reasonably achievable (ALARA) and within the limits of 10 CFR 20. Unexpected high dose rates may also lead to the identification of a fuel misload exceeding CoC Fuel Content limitations.
APPLICABLE SAFETY ANALYSIS	The CONCRETE CASK maximum surface dose rates are not an assumption in any accident analysis, but are used to ensure compliance with regulatory limits on dose to the public and occupational dose, and to potentially identify a misloaded spent fuel assembly.
LCO	The limits on CONCRETE CASK maximum neutron and gamma surface dose rates are based on the Safety Analysis Report shielding analysis of the MAGNASTOR System (Ref. 2). The limits are selected to minimize radiation exposure to the public, as determined in accordance with 10 CFR 72 and 10 CFR 20, and to maintain occupational dose ALARA to personnel working in the vicinity of the MAGNASTOR SYSTEM. The LCO specifies sufficient locations for taking dose rate measurements to ensure the dose rates measured are indicative of the effectiveness of the shielding materials.
APPLICABILITY	The CONCRETE CASK maximum neutron and gamma surface dose rates apply immediately prior to the start of STORAGE OPERATIONS. The selected limits ensure that the CONCRETE CASK surface dose rates during STORAGE OPERATIONS are bounded by the shielding safety analyses. Radiation doses during STORAGE OPERATIONS are monitored by the MAGNASTOR SYSTEM user in accordance with the plant-specific radiation protection program as required by 10 CFR 72.212(b)(6) and 10 CFR 20 (Ref. 1).
ACTIONS	A note has been added to the ACTIONS, which states that for this LCO, separate Condition entry is allowed for each loaded CONCRETE CASK. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each CONCRETE CASK not meeting the LCO. Subsequent MAGNASTOR SYSTEMs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

(continued)

BASES (continued)

ACTIONS (continued)

A.1

If the CONCRETE CASK maximum surface dose rates are not within limits, it could be an indication that a SNF assembly that did not meet the Approved Contents Limits in Section B2.0 of Appendix B was inadvertently loaded into the TSC. Administrative verification of the TSC SNF loading, by means such as review of video recordings and records of the loaded SNF assembly serial numbers, can establish whether a misloaded SNF assembly is the cause of the out-of-limit condition. The Completion Time is based on the time required to perform verification.

AND

A.2

If the CONCRETE CASK maximum surface dose rates are not within limits and it is determined that the CONCRETE CASK was loaded with the correct SNF assemblies, an analysis may be performed. This analysis will determine if the CONCRETE CASK would result in the ISFSI offsite or occupational calculated doses exceeding regulatory limits in 10 CFR 72 or 10 CFR 20, respectively. If it is determined that the measured maximum surface dose rates do not result in the regulatory limits being exceeded, STORAGE OPERATIONS may proceed.

B.1

If it is verified that the fuel was misloaded, or that the ISFSI offsite radiation protection requirements of 10 CFR 20 or 10 CFR 72 will not be met with the CONCRETE CASK maximum surface dose rates above the LCO limit, the performance of the CONCRETE CASK shall be assessed and a safe configuration established. The Completion Time is reasonable, based on the time required to perform an engineering evaluation and safety assessment of the CONCRETE CASK, to implement corrective actions such as augmented shielding applied to the CONCRETE CASK, repositioning the CONCRETE CASK in the cask array at the ISFSI to reduce the offsite dose impact of the CONCRETE CASK, or to off-load the affected TSC.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS	SR 3.3.1.1 This SR ensures that the CONCRETE CASK maximum neutron and gamma surface dose rates are within the LCO limits after transfer of the TSC into the CONCRETE CASK and prior to the commencement of STORAGE OPERATIONS. This Frequency is acceptable, as corrective actions can be taken before offsite dose limits are compromised. The surface dose rates are measured approximately at the locations indicated on Figure 3-1 of Appendix A of the Technical Specifications.
REFERENCES	1. 10 CFR Parts 20 and 72 2. SAR Section 5.1

3.3 MAGNASTOR SYSTEM Radiation Protection

3.3.2 TSC Surface Contamination

BASES

BACKGROUND	A TRANSFER CASK containing an empty TSC is immersed in the spent fuel pool in order to load the spent fuel assemblies. The external surfaces of the TSC are maintained clean by the application of clean water to the annulus of the TRANSFER CASK. However, there is potential for the surface of the TSC to become contaminated with the radioactive material in the spent fuel pool water. Contamination exceeding LCO limits is removed prior to moving the CONCRETE CASK containing the TSC to the ISFSI in order to minimize the radioactive contamination to personnel or the environment. This allows the ISFSI to be entered without additional radiological controls to prevent the spread of contamination and reduces personnel dose due to the spread of loose contamination or airborne contamination. This is consistent with ALARA practices.
APPLICABLE SAFETY ANALYSIS	The radiation protection measures implemented at the ISFSI are based on the assumption that the exterior surfaces of the TSC are not significantly contaminated. Failure to decontaminate the surfaces of the TSC to below the LCO limits could lead to higher-than-projected occupational dose and potential site contamination.
LCO	Removable surface contamination on the exterior surfaces of the TSC is limited to 10,000 dpm/100 cm^2 from beta and gamma sources and 100 dpm/100 cm^2 from alpha sources. Only loose contamination is controlled, as fixed contamination will not result from the TSC loading process. Experience has shown that these limits are low enough to prevent the spread of contamination to clean areas and are significantly less than the levels that could cause significant personnel skin dose.

(continued)

LCO (continued)	LCO 3.3.2 requires removable contamination to be within the specified limits for the exterior surfaces of the TSC. Compliance with this LCO may be verified by direct and/or indirect methods. The location and number of TSC and TRANSFER CASK surface swipes used to determine compliance with this LCO are determined based on standard industry practice and the user's plant-specific contamination measurement program for objects of this size. The objective is to determine a removable contamination value representative of the entire TSC surface area while implementing sound ALARA practices. Swipes and measurements of removable surface contamination levels on the interior surfaces of the TRANSFER CASK may be performed to verify the TSC LCO limits following transfer of the TSC to the CONCRETE CASK. These measurements will provide indirect indications regarding the removable contamination on the exterior surfaces of the TSC.
APPLICABILITY	Verification that the exterior surface contamination of the TSC is less than the LCO limits is performed during LOADING OPERATIONS. This occurs before TRANSPORT OPERATIONS and STORAGE OPERATIONS. Measurement of the TSC surface contamination is unnecessary during UNLOADING OPERATIONS, as surface contamination would have been measured prior to moving the subject TSC to the ISFSI.

(continued)

ACTIONS	A note has been added to the ACTIONS, which states that, for this LCO, separate Condition entry is allowed for each TSC LOADING OPERATION. This is acceptable, since the Required Actions for each Condition provide appropriate compensatory measures for each TSC not meeting the LCO. Subsequent TSCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions. <u>A.1</u> If the removable surface contamination of the TSC that has been loaded with spent fuel is not within the LCO limits, action must be initiated to decontaminate the TSC and bring the removable surface contamination to within limits. The Completion Time of prior TRANSPORT OPERATIONS is appropriate, given that the time needed to complete the decontamination is indeterminate and surface contamination does not affect the safe storage of the spent fuel assemblies.
SURVEILLANCE REQUIREMENTS	SR 3.3.2.1 This SR verifies (either directly or indirectly) that the removable surface contamination on the exterior surfaces of the TSC is less than the limits in the LCO. The Surveillance is performed using smear surveys to detect removable surface contamination. The Frequency requires performing the verification prior to initiating TRANSPORT OPERATIONS in order to confirm that the TSC can be moved to the ISFSI without spreading loose contamination.
REFERENCES	1. FSAR Section 9.1. 2. NRC IE Circular 81-07.

Chapter 14
Quality Assurance

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14 QUALITY ASSURANCE

The NAC International (NAC) Quality Assurance (QA) Program is designed and administered to meet all Quality Assurance criteria of 10 CFR 72, Subpart G [1], 10 CFR 50, Appendix B [2], 10 CFR 71, Subpart H [3], and NQA-1 (Basic and Supplemental Requirements) [4]. The Nuclear Regulatory Commission (NRC) has reviewed and approved (Approval No. 0018) NAC's Quality Assurance Program description.

The NAC Quality Assurance Manual (as approved by the company's President) describes the policy NAC follows to comply with the applicable regulatory quality assurance criteria. The policy described in the NAC Quality Assurance Manual is implemented by detailed procedures presented in the Quality Procedures Manual.

Employing a graded methodology, as described in NRC Regulatory Guide 7.10 [5], NAC applies quality controls to items and activities consistent with their safety significance. Table 14-1 identifies the NAC Quality Assurance Manual sections that address the applicable quality criteria.

Table 14-1 Correlation of Regulatory Quality Assurance Criteria to NAC Quality Assurance Program

Regulatory Quality Assurance Criteria[a]	Corresponding NAC QA Manual Section Number
Organization	1.0
Quality Assurance Program	2.0
Design Control	3.0
Procurement Document Control	4.0
Procedures, Instructions, and Drawings	5.0
Document Control	6.0
Control of Purchased Items and Services	7.0
Identification and Control of Material, Parts and Components	8.0
Control of Special Processes	9.0
Inspection	10.0
Test Control	11.0
Control of Measuring and Test Equipment	12.0
Handling, Storage and Shipping	13.0
Inspection, Test and Operating Status	14.0
Control of Nonconforming Items	15.0
Corrective Action	16.0
Records	17.0
Audits	18.0

[a] The criteria are obtained from 10 CFR 50, Appendix B; 10 CFR 71, Subpart H; and 10 CFR 72, Subpart G

14.1 NAC Quality Assurance Program Synopsis

Eighteen applicable Quality Assurance criteria are identified in 10 CFR 72, Subpart G; 10 CFR 50, Appendix B; 10 CFR 71, Subpart H; and ASME NQA-1 (Basic and Supplemental Requirements). Refer to the following sections for NAC's compliance with each of these criteria.

14.1.1 Organization

The President of NAC has the ultimate authority and responsibility over all organizations and their functions within the corporation. However, the President delegates and empowers qualified personnel with the authority and responsibility over selected key areas, as identified in the NAC Organization Chart (see Figure 14.1-1).

The Vice President, Quality, is responsible for definition, development, implementation, and administration of the NAC Quality Assurance Program. The Quality Assurance organization is independent from other organizations within NAC and has complete authority to assure adequate and effective program execution, including problem identification, satisfactory corrective action implementation and the authority to stop work, if necessary. The Vice President, Quality, reports directly to the President of NAC. The Vice President, Quality, has sufficient expertise in the field of quality to direct the quality function and will be capable of qualifying as a lead auditor.

Strategic Business Unit (SBU) Vice Presidents direct operations and use project teams as appropriate for a particular work scope. SBU Vice Presidents are responsible to the President for the proper implementation of the NAC Quality Assurance Program.

14.1.2 Quality Assurance Program

Employing a grading methodology consistent with NRC Regulatory Guide 7.10, the Quality Assurance Program provides control over activities affecting quality from the design to fabrication, operation, and maintenance of nuclear products and services for nuclear applications. The Quality Assurance Program is documented in the Quality Assurance Manual and implemented via Quality Procedures. These documents are approved by the Vice President, Quality, and the applicable Vice President from each SBU performing activities within the scope of the NAC Quality Assurance Manual.

Personnel assigned responsibilities by the Quality Assurance Program may delegate performance of activities associated with that responsibility to other personnel in their group when those individuals are qualified to perform those activities by virtue of their education, experience, and

training. Such delegations need not be in writing. The person assigned responsibility by the Quality Assurance Program retains full accountability for the activities.

14.1.3 Design Control

The established Quality Procedures covering design control ensure that the design activity is planned, controlled, verified, and documented so that applicable regulatory and design basis requirements are correctly translated into specifications, drawings, and procedures with appropriate acceptance criteria for inspection and test delineated.

All software used to perform engineering calculations is verified for computational accuracy and error tracking, and is controlled in accordance with approved Quality Procedures.

Design interface control is established and adequate to ensure that the review, approval, release, distribution, and revision of design documents involving interfaces are performed by appropriately trained, cognizant design personnel using approved procedures.

Design verification is performed by individuals other than those who performed the original design. These verifications may include design reviews, alternate calculations, or qualification tests. Selection of the design verification method is based on regulatory, contractual, or design complexity requirements. When qualification testing is selected, the "worst case" scenario will be used. The verification may be performed by the originator's supervisor, provided the supervisor did not specify a singular design approach, rule out certain design considerations, or establish the design inputs used in the design, or unless the supervisor is the only individual in the organization competent to perform the verification. When verification is provided by the supervisor, the need and basis shall be so documented in advance and evaluated after performance by internal audit.

Design changes are controlled and require the same review and approvals as the original design.

14.1.4 Procurement Document Control

Procurement documents and their authorized changes are generated, reviewed, and approved in accordance with the Quality Procedures. These procedures ensure that all purchased material, components, equipment, and services adhere to design specification, regulatory, and contractual requirements including Quality Assurance Program and documentation requirements.

NAC Quality Assurance personnel review and approve all purchase orders invoking compliance with the Quality Assurance Program for inclusion of quality-related requirements in the procurement documents.

14.1.5 Procedures, Instructions and Drawings

All activities affecting quality are delineated in the Quality Procedures, Specifications, Inspection/Verification Plans, or on appropriate drawings. These documents are developed via approved Quality Procedures and include appropriate quantitative and qualitative acceptance criteria. These documents are reviewed and approved by Quality Assurance personnel prior to use.

14.1.6 Document Control

All documents affecting quality, including revisions, are reviewed and approved by authorized personnel, and are issued and controlled in accordance with Quality Procedures by those responsible persons or groups. Transmittal forms, with provisions for receipt acknowledgment, are used and controlled document distribution logs are maintained.

All required support documentation for prescribed activities is available at the work location prior to initiation of the work effort.

14.1.7 Control of Purchased Items and Services

Items and services affecting quality are procured from qualified suppliers. These suppliers have been evaluated and selected in accordance with the Quality Procedures based on their capability to comply with applicable regulatory and contractual requirements.

Objective evidence attesting to the quality of items and services furnished by NAC suppliers is provided with the delivered item or service, and is based on contract requirements and item or service complexity. This vendor documentation requirement is delineated in the procurement documents.

Source inspection, receipt inspection, vendor audits, and vendor surveillance are performed as required to assure product quality, documentation integrity, and supplier compliance to the procurement, regulatory and contractual requirements.

14.1.8 Identification and Control of Material, Parts and Components

Identification is maintained either on the item or in quality records traceable to the item throughout fabrication and construction to prevent the use of incorrect or defective items.

Identification, in accordance with drawings and inspection plans, is verified by Quality Assurance personnel prior to releasing the item for further processing or delivery.

14.1.9 Control of Special Processes

Special processes, such as welding, heat treating, and nondestructive testing, are performed in accordance with applicable codes, standards, specifications, and contract requirements by qualified personnel. NAC and NAC suppliers' special process procedures and personnel certifications are reviewed and approved by NAC Quality Assurance prior to their use.

14.1.10 Inspection

NAC has an established and documented inspection program that identifies activities affecting quality and verifies their conformance with documented instructions, plans, procedures, and drawings.

Inspections are performed by individuals other than those who performed the activity being inspected. Inspection personnel report directly to the Vice President, Quality.

Process monitoring may also be used in conjunction with identified inspections, if beneficial to achieve required quality.

Mandatory inspection hold points assure verification of critical characteristics. Such hold points are delineated in appropriate process control documents.

14.1.11 Test Control

NAC testing requirements are developed and applied in order to demonstrate satisfactory performance of the tested items to design/contract requirements.

The NAC test program is established to ensure that preoperational or operational tests are performed in accordance with written test procedures. Test procedures developed in accordance with approved Quality Procedures identify test prerequisites, test equipment and instrumentation, and suitable environmental test conditions. Test procedures are reviewed and approved by NAC Quality Assurance personnel.

Test results are documented, evaluated, and accepted by qualified personnel as required by the Quality Assurance inspection instructions prepared for the test, as approved by cognizant quality personnel.

14.1.12 Control of Measuring and Testing Equipment

Control of measuring and testing equipment/instrumentation is established to assure that devices used in activities affecting quality are calibrated and properly adjusted at specified time intervals to maintain their accuracy.

Calibrated equipment is identified and traceable to calibration records, which are maintained. Calibration accuracy is traceable to national standards when such standards exist. The basis of calibration shall always be documented.

Whenever measuring and testing equipment is found to be out of calibration, an evaluation shall be made and documented of the validity of inspection or test results performed and of the acceptability of items inspected or tested since the previous calibration.

14.1.13 Handling, Storage and Shipping

Requirements for handling, storage and shipping are documented in specifications and applicable procedures or instructions. These requirements are designed to prevent damage or deterioration to items and materials.

Information pertaining to shelf life, environment, packaging, temperature, cleaning and preservation are also delineated as required.

Quality Assurance Surveillance/Inspection personnel are responsible for verifying that approved handling, storage and shipping requirements are met.

14.1.14 Inspection, Test and Operating Status

Procedures are established to indicate the means of identifying inspection and test status on the item and/or on records traceable to the item. These procedures assure identification of items that have satisfactorily passed required inspections and/or tests to preclude inadvertent bypassing of the inspection/test.

Inspection, test and operating status indicators may only be applied or modified by Quality Assurance personnel or with formal Quality Assurance concurrence.

14.1.15 Control of Nonconforming Items

NAC has established and implemented procedures that assure appropriate identification, segregation, documentation, notification and disposition of items that do not conform to specified requirements. These measures prevent inadvertent usage of the item and assure appropriate authorization or approval of the item's disposition.

All nonconformances are reviewed and accepted, rejected, repaired or reworked in accordance with documented approved procedures. If necessary, a Review Board is convened, consisting of engineering, licensing, quality, operations and testing personnel, as applicable, to provide disposition of nonconforming conditions.

NAC procurement documents provide for control, review and approval of nonconformances noted on NAC items, including associated dispositions.

14.1.16 Corrective Action

Conditions adverse to quality, such as failures, malfunctions, deficiencies, defective material/ equipment and nonconformances, are promptly identified, documented and corrected.

Significant conditions adverse to quality will have their cause determined and sufficient corrective action taken to preclude recurrence. These conditions are documented and reported to the Vice President, Quality, who assures awareness by the President.

14.1.17 Records

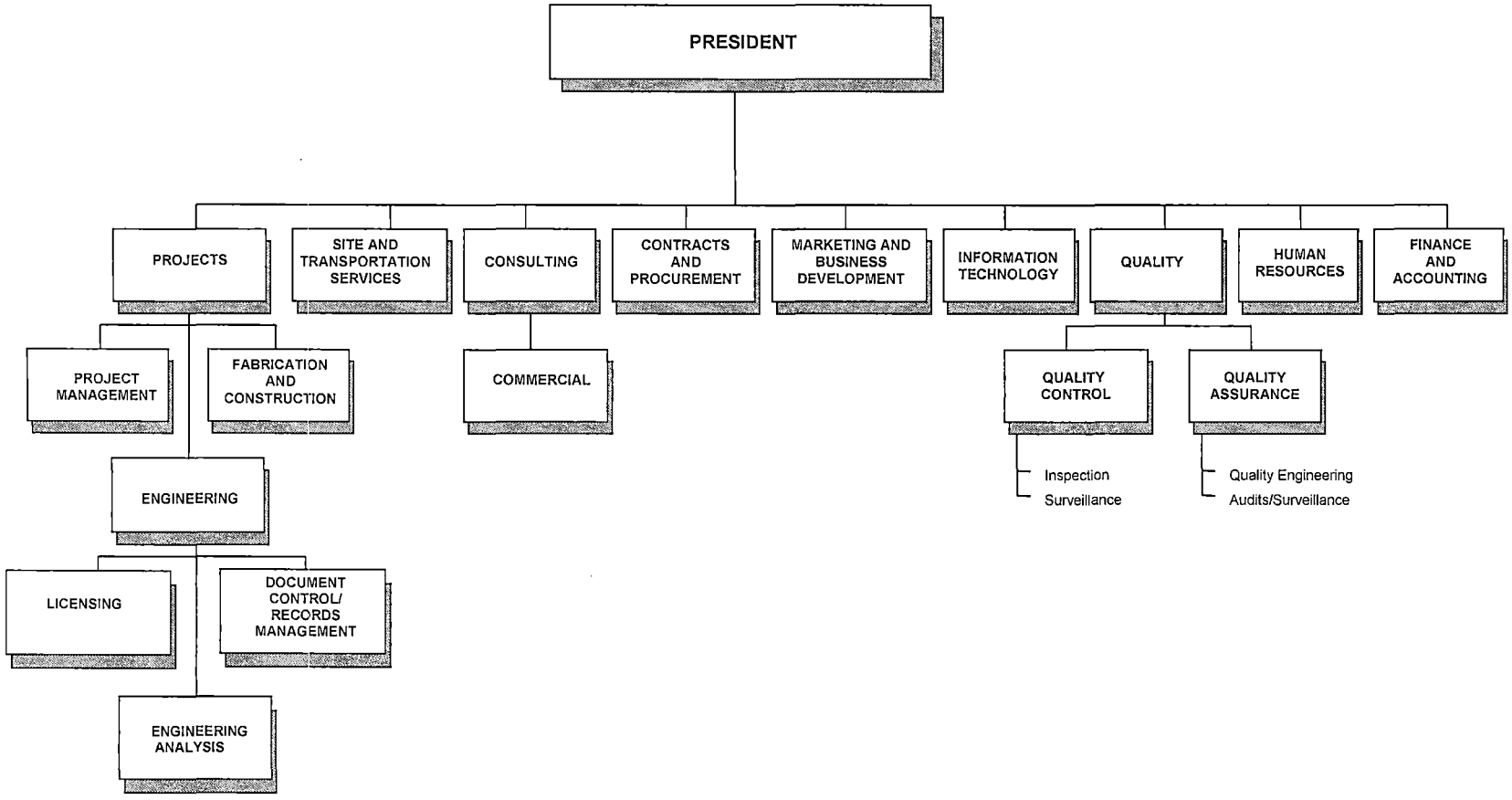
NAC maintains a records system in accordance with approved procedures to ensure that documented objective evidence pertaining to quality-related activities is identifiable, retrievable and retained to meet regulatory and contract requirements, including retention duration, location and responsibility.

Quality records include, but are not limited to, inspection and test reports, audit reports, quality personnel qualifications, design documents, purchase orders, supplier evaluations, fabrication documents, nonconformance reports, drawings, specifications, and so forth. Quality Assurance maintains a complete list of records and provides for record storage and disposition to meet regulatory and contractual requirements.

14.1.18 Audits

Approved Quality Procedures provide for a comprehensive system of planned and periodic audits performed by qualified personnel, independent of activities being audited. These audits are performed in accordance with written procedures and are intended to verify program adequacy and its effective implementation and compliance, both internally and at approved-supplier locations. Internal audits are conducted annually, and approved suppliers are audited on a triennial basis, as a minimum.

Figure 14.1-1 NAC Functional Organization Chart



14.2 References

1. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor-Related Greater than Class C Waste," Subpart G, "Quality Assurance Requirements," US Government, Washington, DC.
2. 10 CFR 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," Code of Federal Regulations, US Government, Washington, DC.
3. 10 CFR 71, Code of Federal Regulations, "Packaging and Transportation of Radioactive Material," Subpart H, "Quality Assurance," US Government, Washington, DC.
4. ASME NQA-1, Part 1, Basic and Supplemental Requirements (as referenced by the ASME Code, including latest accepted addenda), Quality Assurance Requirements for Nuclear Facility Applications.
5. Regulatory Guide 7.10, "Establishing Quality Assurance Programs for Packaging Used in Transport of Radioactive Material," US Nuclear Regulatory Commission, Washington, DC.

Chapter 15
Decommissioning

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15 DECOMMISSIONING

The principal elements of MAGNASTOR® that may require decommissioning are the concrete cask and the TSC. The TSC is designed and fabricated to be suitable for use as part of the waste package for permanent disposal in a deep Mined Geological Disposal System [1] and is not expected to require onsite decommissioning. The concrete cask is not expected to become surface contaminated during use as it does not come in direct contact with radioactive materials. Surface contamination may be removed by standard decontamination techniques, including washing and surface abrasion. The activity concentrations from activation of concrete cask and TSC components are listed in Table 15.2-1, Table 15.2-2 and Table 15.2-3. The analysis conservatively assumes that the neutron flux is constant for 60 years and is based on a source description that bounds both BWR and PWR fuel. The tables only include the radiologically significant isotopes. The isotope contributing the majority of the carbon steel curie activity is ^{55}Fe, which decays following electron capture and is not of radiological concern.

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

Decommissioning of the concrete cask, TSC, and storage pad will be accomplished by the licensee using either licensee personnel or contract personnel working in accordance with a site license and decommissioning plan.

15.1 Decommissioning the Concrete Cask

The concrete 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 concrete cask and the base plate of the concrete cask that supports the TSC. All of these surfaces are made of carbon steel, and it is anticipated that these surfaces could be decontaminated as necessary for decommissioning. 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, concrete, support plates, and reinforcing bar could occur due to neutron flux from the stored fuel. As shown in Table 15.2-1 and Table 15.2-2, only minimal activation of concrete and carbon steel in the concrete cask is expected to occur. Activation data is provided at one day after removal of the TSC. Individual isotopes listed are limited to those exceeding a 1 $\mu Ci/cm^3$ threshold at one year after removal of the TSC.

Decommissioning of the concrete cask will involve the removal of the TSC and the subsequent disassembly of the concrete cask. It is expected that the concrete will be broken up and the steel components segmented to reduce volume. Any contaminated or activated items are expected to qualify for near-surface disposal as Surface Contaminated Objects (SCO) or Low Specific Activity (LSA) material.

15.2 Decommissioning the TSC

The TSC is designed and fabricated to ensure its retrievability for use as a component of the waste package for permanent disposal in accordance with the guidance of ISG-2 [2] and the requirements of 10 CFR 72 [3]. The TSC is fabricated from materials having high long-term corrosion resistance, and it contains no paints or coatings that could adversely affect its permanent disposal. Decommissioning of the TSC will occur only if the fuel contained in the TSC is removed, or if the current requirements for disposal change. Decommissioning will require that the welds at the TSC closure lid and the vent and drain port covers be cut, so that the spent fuel can be removed. Removal of the contents will occur in a spent fuel pool or dry unloading facility, such as a hot cell. Closure welds can be cut either manually, or with automated equipment, using the unloading procedures of Chapter 9, Section 9.3, for wet unloading, or modified as required for dry unloading.

Following removal of its contents, the TSC interior is expected to have significant fixed and removable surface contamination. Additionally, in cases where the TSC has been exposed to accident loading conditions such as a tip-over or drop, fuel particulate materials may have been released into the TSC from damaged fuel rods.

Some effort may be required to remove the fixed and removable surface contamination prior to disposal; however, in practice, it will likely not be absolutely necessary to decontaminate the TSC internals. Since the TSC internal contamination will consist only of by-product materials, any contaminated TSC and internal components are expected to qualify for near-surface disposal as SCO or LSA waste. Any required internal decontamination is facilitated by the smooth surfaces of the TSC and the basket, and by the design that precludes the presence of crud traps. Since the neutron flux rate from the stored fuel is low, as shown in Table 15.2-3, only minimal activation of the TSC is expected to occur. Isotope and total curie concentrations are provided at one day after fuel removal. Only isotopes that meet a 1 $\mu Ci/cm^3$ threshold at one year after fuel removal are listed.

In cases where fuel particulate release is suspected, the interior of the unloaded TSC should be surveyed for fuel particulates, which will require removal prior to final disposition of the empty TSC and lid components. Residual fuel material will be removed, packaged and disposed of in accordance with the appropriate regulations. Similar surveys for, and removal of, fuel particulate materials have routinely been performed on spent fuel racks prior to their removal and off-site shipment.

The unloaded TSC can also qualify as a strong, tight container for other waste. In this case, the TSC can be filled, within weight limits, with other qualified waste, closed, and transported to a

near-surface disposal site. Use of the TSC for this purpose can reduce decommissioning costs by avoiding decontamination, segmenting, and repackaging.

Table 15.2-1 Activity Concentration in the Concrete Cask Reinforcing Bar and Concrete

Isotope	Concentration (Ci/m³)			
	Concrete	Rebar	Lid Concrete	Lid Rebar
^{39}Ar[a]	1.53E-06	--	--	--
^{40}K[b]	3.76E-05	--	3.76E-05	--
^{41}Ca	1.00E-06	--	--	--
^{45}Ca	1.34E-04	--	5.65E-06	--
^{54}Mn	--	7.41E-05	--	--
^{55}Fe	9.01E-05	2.45E-02	3.79E-06	1.02E-03
^{59}Fe	--	6.37E-04	--	--
^{60}Co	6.83E-05	9.39E-04	3.07E-06	4.18E-05
^{63}Ni	--	3.97E-05	--	1.66E-06
^{65}Zn	6.81E-06	1.08E-05	--	--
^{133}Ba	1.41E-06	--	--	--
^{152}Eu	1.70E-04	--	7.06E-06	--
^{154}Eu	1.65E-05	--	--	--
Total	1.34E-03	2.71E-02	9.20E-05	1.14E-03

Table 15.2-2 Activity Concentration in the Concrete Cask Carbon Steel

Isotope	Concentration (Ci/m³)				
	Standoffs	Pedestal	Lid	Outlets	Liner
^{54}Mn	3.91E-03	1.71E-04	2.07E-05	1.36E-05	1.49E-03
^{55}Fe	2.75E-02	3.82E-03	3.05E-03	1.27E-03	2.26E-02
^{59}Fe	1.28E-03	--	--	--	8.37E-04
^{60}Co	1.08E-02	1.39E-03	6.56E-04	3.32E-04	6.03E-03
^{63}Ni	3.87E-06	--	--	--	1.48E-06
Total	4.47E-02	5.67E-03	3.89E-03	1.69E-03	3.17E-02

[a] Argon is a noble gas so this radionuclide will probably have escaped the concrete.

[b] Potassium-40 is a naturally occurring radionuclide. It is present in the concrete due to the inclusion of potassium as a trace constituent of the ordinary concrete; it is not present as a result of activation.

Table 15.2-3 Activity Concentration in the TSC/Basket

Isotope	Concentration (Ci/m³)		
	TSC	Basket	Absorber
^{14}C	2.62E-06	--	--
^{46}Sc	--	--	2.43E-05
^{51}Cr	1.70E-02	--	--
^{54}Mn	2.08E-03	1.35E-01	3.55E-04
^{55}Fe	1.28E-02	6.38E-01	1.64E-03
^{58}Co	5.60E-03	--	--
^{59}Fe	5.98E-04	3.11E-02	--
^{59}Ni	2.11E-05	--	--
^{60}Co	4.12E-02	2.66E-01	2.31E-05
^{63}Ni	2.11E-03	1.34E-04	9.82E-05
^{65}Zn	2.91E-04	--	4.87E-03
^{75}Se	5.32E-05	--	--
^{87}Rb	1.93E-06	--	--
^{110m}Ag	9.53E-06	--	--
^{124}Sb	1.01E-04	--	--
^{134}Cs	8.18E-06	--	--
^{142}Ce	1.18E-05	--	--
^{152}Eu	1.75E-06	--	--
^{154}Eu	1.37E-06	--	--
^{181}W	8.97E-06	--	--
^{185}W	1.48E-04	--	--
Total	9.29E-02	1.11E+00	2.80E-02

15.3 References

1. 10 CFR 61, Code of Federal Regulations, "Licensing Requirements for Land Disposal of Radioactive Waste," US Government, Washington, DC.
2. ISG-2, "Fuel Retrievability," US Nuclear Regulatory Commission, Washington, DC, October 1998.
3. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor-Related Greater Than Class C Waste," US Government, Washington, DC.